# UNIVERSIDAD TÉCNICA DE AMBATO

## FACULTAD DE INGENIERÍA CIVIL Y MECÁNICA

## CARRERA DE INGENIERÍA MECÁNICA

**TRABAJO ESTRUCTURADO DE MANERA INDEPENDIENTE PREVIO A LA OBTENCIÓN DEL TITULO DE INGENIERO MECÁNICO**

**TEMA:**

# “ENSAYOS DESTRUCTIVOS EN CIGÜEÑALES DE MOTORES A GASOLINA RECUPERADOS MEDIANTE EL PROCESO DE METALIZACIÓN CON LA MÁQUINA TAFA MODELO 8830 EN LA EMPRESA RECTIFICADORA PAZMIÑO S.A. PARA GARANTIZAR LA CALIDAD DEL PRODUCTO TERMINADO”

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**AMBATO - ECUADOR**

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# APROBACION DEL DIRECTOR DE TESIS

En calidad de tutor del presente trabajo de investigación sobre el tema: “Ensayos destructivos en cigüeñales de motores a gasolina recuperados mediante el proceso de metalización con la máquina TAFA modelo 8830 en la empresa rectificadora Pazmiño S.A, para garantizar la calidad del producto terminado”, presentado e investigado por el señor egresado José Sebastián Caiza Vega, considero que esta investigación reúne los requisitos y méritos suficientes para ser sometidos a la evaluación del jurado examinador designado por el H. consejo Académico.

Ambato abril 2011

EL TUTOR

………………….

Ing. Alejandro Moretta

# AUTORIA DEL PROYECTO DE INVESTIGACIÓN

Los criterios emitidos en el presente trabajo de investigación bajo el tema "Ensayos destructivos en cigüeñales de motores a gasolina recuperados mediante el proceso de metalización con la máquina TAFA modelo 8830 en la empresa rectificadora Pazmiño S.A, para garantizar la calidad del producto terminado", como también las ideas, conclusiones, recomendaciones y propuestas son de exclusiva responsabilidad de mi persona en calidad de autor de este trabajo de investigación.

Ambato, abril 2011

**EL AUTOR**

……………………

José Sebastián Caiza

# DEDICATORIA

*El presente trabajo se lo dedico en primer lugar a Dios, a los seres que siempre creyeron en mí mis padres José Esteban Caiza Lizano y Sulema del Roció Vega Vaca, mis hermanas Mónica y María José Caiza Vega, mis sobrinos Carla y Jorge, a mi hermano político Oswaldo, que me enseñaron que no hay meta inalcanzable, a creer en mí, en alcanzar lo que yo quiero y no lo que el resto del mundo supone que es lo único que puedo alcanzar, he aquí plasmado lo que puedo alcanzar a llegar. Gracias por ser ese apoyo que siempre estuvo, está y estará, mil gracias por ser ustedes a quienes yo tengo el honor de poder llamar mi familia.*

*José Sebastián*

# AGRADECIMIENTO

A la Universidad Técnica de Ambato, a la Facultad de Ingeniería Civil y Mecánica, a los docentes que durante mi carrera universitaria supieron impartir de manera profesional sus conocimientos, un agradecimiento especial al personal que labora en Rectificadora Pazmiño Quito, por las facilidades y tiempo prestado para la realización de la presente investigación.

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# RESUMEN EJECUTIVO

El presente trabajo de investigación se llevó a cabo en la Rectificadora Pazmiño S.A. la cual se encuentra ubicada en la ciudad de Quito, el mismo que tiene por objeto el poder crear una nueva visión del proceso de metalización de cigüeñales de motores a gasolina con la máquina metalizadora TAFA modelo 8830.

Al llevar la investigación a un segmento específico del trabajo de rectificación de un motor a gasolina, se puso énfasis en la recuperación del cigüeñal mediante el proceso de metalización, el mismo que inicia cuando el cigüeñal es considerado como obsoletos a razón de que uno o más muñones de biela o bancada se encuentran fuera del límite permisible para ser rectificado con lo que se determinó que si bien el proceso de metalizado es nuevo en la empresa, es un buen método de recuperación y disminución del costo en comparación de adquirir un nuevo.

Al obtener estos resultados de valoración del proceso de metalización, se busca crear un manual que le permita a Rectificadora Pazmiño S.A, el poder entregar a sus clientes un trabajo que presente las garantías necesarias, para calificar al proceso como aceptable.

El personal de Rectificadora Pazmiño S.A, tanto el de planta como el administrativo siempre busca vías que le permitan mejorar su servicio, es así como todos están dispuestos a aplicar y respetar una guía con el cual se puede señalar una garantía real para con el cliente.

# INTRODUCCIÓN

## CAPITULO I

La primera fase empieza con el descubrimiento o planteamiento deliberado del problema, que en el presente trabajo de investigación es Ensayos destructivos en cigüeñales de motores a gasolina recuperados mediante el proceso de metalización con la máquina metalizadora TAFA modelo 8830 en la empresa rectificadora Pazmiño S.A, para garantizar la calidad del producto terminado.

El problema se concretó delimitando el objeto de estudio y estableciendo sus fronteras para ello hemos contextualizado en macro, meso y micro. También indicamos los objetivos tanto general como específicos, es decir los resultados que esperamos alcanzar mediante el proceso investigativo.

## CAPITULO II

En el segundo capítulo una vez que se plantea el problema a estudiar, hemos agrupado toda la información existente que ayude a desarrollar la investigación, recopilando algunas ideas o informaciones previas, algunos referentes teóricos y conceptuales. Para la fundamentación filosófica. Indicamos que a partir del nacimiento del problema surgió la hipótesis (proposiciones explicativas, casuales y provisionales), sin saber aún si las observaciones, hechos, datos, la aprobarán o desaprobarán.

De la hipótesis se deriva la variable independiente y dependiente a estudiar, se debe fundamentar en ellas la determinación del campo de investigación, los métodos a emplear y la información a recoger.

## CAPITULO III

La metodología del trabajo constituye la esencia del proyecto, aquí detallamos el ¿Cómo se va a realizar la investigación?, en el capítulo tercero detallamos que el tipo de investigación que se utilizó es la combinada, entre los métodos tenemos el analítico, sintético y dialéctico; las técnicas utilizadas fueron: la observación, bibliografía y encuesta. Para recolectar la información se utilizó probetas de estudio con características propias total del universo, mientras que la bibliográfica de libros relacionados con las variables.

## CAPITULO IV

En el capítulo cuarto se realiza el análisis de los resultados estadísticos destacando tendencias o relaciones fundamentales de acuerdo con los objetivos e hipótesis. La interpretación de los resultados se realizó con basándonos en los resultados arrojados por el estudio de las probetas. La hipótesis de la investigación que es la respuesta tentativa del problema fue verificada y comprobada mediante el análisis de los resultados de las probetas.

## CAPITULO V

El capítulo cinco fue el aporte personal a la investigación realizada sobre la base de los datos y conocimientos recolectados a lo largo del estudio, dando contestación a los objetivos e hipótesis planteada; así llegamos a la conclusión en las que el proceso de metalización de cigüeñales de motores a gasolina con la máquina TAFA 8830 es un proceso bueno y puede ser extendida una garantía sobre este trabajo.

## CAPITULO VI

En el capítulo sexto nos referimos a la propuesta que se realizó sobre la base de las conclusiones obtenidas en las diferentes etapas del proceso investigativo y sobre la experiencia del investigador. En la justificación describimos las razones por las cuales se plantea la propuesta y los beneficios que se espera obtener con su aplicación, en los objetivos indicamos el propósito que esperamos alcanzar con la aplicación de la propuesta.

En este capítulo elaboramos las actividades o acciones que ejecutamos para implementar la propuesta, indicamos los recursos, realizamos el cronograma el que se planificó y elaboró cuidadosamente, a fin de poder supervisar por un lado la naturaleza y secuencia de las actividades, y por otra el tiempo disponible de duración de cada una de estas. La fuente de financiamiento para la propuesta fue es el autofinanciamiento y el aporte de la empresa donde se desarrolla la investigación.

# CAPITULO I

# EL PROBLEMA DE INVESTIGACIÓN

## 1.1 TEMA

Ensayos destructivos en cigüeñales de motores a gasolina recuperados mediante el proceso de metalización con la máquina TAFA modelo 8830 en la empresa rectificadora Pazmiño S.A, para garantizar la calidad del producto terminado.

## 1.2 PLANTEAMIENTO DEL PROBLEMA

### 1.2.1 CONTEXTUALIZACIÓN

En Centroamérica y Latinoamérica, como es bien conocido el poder económico de adquisición de la mayoría de ciudadanos de cada país es muy limitado, razón por lo cual son el lugar del continente donde se genera el problema de vehículos con gran cantidad de años, derivando en sus respectivos problemas, como en la reparación de los motores para alargar su vida útil, lo cual con lleva a buscar las formas más accesibles y económicas para realizar el trabajo sin comprometer la durabilidad y la calidad.

En Latinoamérica cuenta con dos países donde se producen algunas partes de refacción para los motores, estos países son Argentina y Brasil.

El país con mayor desarrollo en partes para vehículos en Latinoamérica es Brasil debido a que cuenta con plantas de ensamblaje de vehículos de las marcas General Motors, Volkswagen, Mercedes, entre las más conocidas, debido a contar con estas plantas de ensamblaje Brasil también se ha tornado en un productor de partes de motor como en nuestro caso investigado es el cigüeñal, para uno o varios modelos de motores, y de sus diversas casas fabricantes[1].

Nuestro país se caracteriza por mantener un gran parque automotor de varios años de antigüedad y variedad ya que no es un país fabricante sino en su mayoría consumista, además que el costo de adquirir automotores o renovarlos no puede ser cubierto por cualquier ciudadano de nuestro país, la marca chevrolet tiene un gran acogida en el país por lo cual  ha creado el hecho propicio para la adopción de mantener vehículos de esta marca en el parque automotor, más que por hobbie por necesidad, los mismos que por ser fabricados en otros países donde se tornan obsoletos dejan de producir elementos de reemplazo para los mismos, o por una negligencia del usuario o fabricante,  tienden a averiarse antes del tiempo que se ha determinado el fabricante para una avería, lo cual conlleva a buscar una solución para solventar estos inconvenientes, dando paso a que los concesionarios de cada marca de vehículo, hacer importadores directos de repuestos.

Con lo cual los vehículos con mayor presencia en el parque automotor cuentan con una gran red de concesionarios, localizando varios polos de comercialización de repuestos nuevos y usados a nivel nacional siendo el mayor de ellos en Guayaquil por contar con el puerto debido a que la mayoría de elementos que se reemplazan deben ser importados en un gran volumen o son en otro caso de gran peso.  La provincia de Pichincha una de las más importantes de nuestro país ya que es nuestra capital y siendo el polo de desarrollo centro norte, ha dado la oportunidad de la creación y crecimiento de diferentes negocios relacionado con los motores de combustión interna a gasolina, es así que a partir de la necesidad de adquirir, fabricar o solucionar, los elementos que integran el motor de combustión interna a gasolina, que  ya cumplieron su vida útil, desgaste por reparaciones anteriores o algunos sufrieron anomalía en su normal funcionamiento, y con la ventaja de contar con una gran cantidad de repuestos inmediatos a su alcance, las empresas rectificadoras de motores tuvieron una gran oportunidad para crearse o en algunos casos crecer, convirtiéndose en un sector competitivo.

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[1] Información proporcionada por Autolandia S.A, Jaime Nicolalde  Departamento de ventas de Repuestos.

En Quito se concentro el crecimiento de toda la provincia debido a que es su capital y donde se concentran la mayor cantidad de ciudadanos, las empresas rectificadoras de motores ante la necesidad de solventar los problemas que presentaban sus clientes por falta de elementos de reemplazo, que no podían ser abastecidos por las concesionarias e importadores de repuestos, para sus vehículos en la mayoría por ser antiguos o en otros casos por ser demasiado nuevos, se vieron ante la encrucijada de solucionar de una u otra forma el inconveniente, con lo cual abrió una puerta para implementar nuevos servicios en cada rectificadora, es así que Rectificadora Pazmiño S.A, y su departamento de adquisición de repuestos se encontraron a su parecer que el mayor problema sobre elementos de reemplazo en los motores de combustión interna a gasolina, debido a ser un elemento muy robusto, rígido y contar con una alta vida útil según fabricantes no se cuenta con un elevado stock y mucho menos en nuestro medio se habían importado, es por esta razón que decidió implementar un servicio para que cigüeñales de motores a gasolina considerados obsoletos puedan ser recuperados mediante un proceso que no comprometa en mayor cantidad las propiedades mecánicas iníciales.

### 1.2.2 ANÁLISIS CRÍTICO

La empresa es mediana pero líder en su sector, posee una infraestructura en planta física y humana capaz de prestar y garantizar sus servicios, por esta razón se ha buscado el implantar controles de calidad propios de la empresa en los servicios de reconstrucción de bielas, cabezotes, blocks y cigüeñales, de los motores de combustión interna. Pero desde hace cinco años a tras la empresa se encontró en una encrucijada en relación a la inexistencia en el mercado de cigüeñales para motores a gasolina dado sea por la antigüedad o por no ser modelos comerciales nuevos, surgiendo imperiosa necesidad de encontrar alguna solución para satisfacer al cliente, siendo así la empresa decide invertir en la compra de la máquina metalizadora TAFA modelo 8830, con lo cual da la solución a la necesidad sus clientes.

La máquina metalizadora TAFA modelo 8830 rellena los codos de biela y bancada de los cigüeñales de motores a gasolina, que son objeto de este estudio, las especificaciones de medidas son proporcionadas por el software PRO-SIS, la ventaja de contar con estas especificaciones es poder determinar el desgaste del cigüeñal de los motores a gasolina y qué cantidad de material necesita ser rociado para recuperar sus medidas originales, a pesar de esto existe un incumplimiento de control de calidad en el proceso de metalización de cigüeñales de motores a gasolina razón por la cual no se puede ofrecer una garantía sobre el producto terminado, debido a que empíricamente se conoce que el cigüeñal perdió o disminuyo ciertas propiedades mecánicas por el proceso de desgaste al cual fue sometido.

La metalización que realizamos, no tiene un soporte técnico y se basa en la política interna de prueba y error, que consiste en la aplicación de cierta técnica o forma de aplicación del material y luego verificación mediante el desbaste en la rectificadora de cigüeñales donde se palpaba algún error en el proceso de metalización aplicado en determinado cigüeñal, con lo cual se determino ciertos paramentaros que influyen en el proceso, y se obtiene aparentemente una calidad aceptable. Siguiendo su rumbo de una empresa seria y de garantizar sus trabajos, decide buscar un proceso de calidad al proceso de metalizado, para implementar parámetros internos de garantía con el fin de seguir en el mercado como una empresa de calidad.

### 1.2.3 PROGNOSIS

En nuestro país como se menciono antes en la contextualización existe un parque automotor, con una larga vida, lo que crea la falta de piezas de remplazo, esto genero que Rectificadora Pazmiño S.A, busque la forma de recuperar una pieza de trabajo del motor como es el cigüeñal, razón por la cual adquiere la máquina metalizadora TAFA modelo 8830, con la cual ofrecen mitigar esta carencia de poder adquirir un cigüeñal nuevo y a la vez el costo del mismo por ser elevado debido a que deben ser importados, al ofrecer este servicio busca el entregar su sello de trabajo que es la calidad real en el trabajo, por lo cual ve la necesidad de investigar y generar una guía de proceso en el metalizado del cigüeñales de motores a gasolina, con el único fin de mantenerse en el mercado como una empresa seria.

Al carecer de un proceso de calidad sobre la metalización de cigüeñales de motores a gasolina incumpliremos con las políticas de calidad internas de Rectificadora Pazmiño S.A. sino también terminara con el prestigio y posicionamiento que goza en el mercado al ser considerada una empresa de visión, dejando el espacio propicio para el surgimiento de este proceso en otra empresa.

### 1.2.4 FORMULACIÓN DEL PROBLEMA

¿La falta de un control del proceso de metalización en los cigüeñales de motores a gasolina con la máquina metalizadora TAFA modelo 8830 en la empresa rectificadora Pazmiño S.A determinara la calidad del producto terminado?

### 1.2.5 PREGUNTAS DIRECTRICES

- ✓ ¿Cuál es la factibilidad de realizar los ensayos destructivos en el cigüeñal de forma completa?
- ✓ ¿Qué normas son las adecuadas para realizar los ensayos destructivos en muestras de metalización?
- ✓ ¿Qué procedimiento es el adecuado para la realización del control de calidad del proceso de metalización?

### 1.2.6 DELIMITACIÓN DEL PROBLEMA

#### 1.2.6.1. De contenido

- Ensayos Destructivos
- Ingeniería de Materiales

#### 1.2.6.2. Delimitación Espacial

- Rectificadora Pazmiño S.A. De las Brevas E10-250 y Av. De las Palmeras, sector El Inca, Quito – Ecuador.
- Laboratorios de la Universidad Politécnica Nacional.

### 1.2.6.3. Delimitación Temporal

- El proyecto planteado se realizará en el período comprendido entre mayo a noviembre de 2010

## 1.3 JUSTIFICACIÓN DEL PROYECTO

El motor de combustión interna a gasolina es la unidad energética y motriz de los medios de transporte, máquinas, equipos e instalaciones estacionarias que trabajan en otras ramas productivas, después de un tiempo de servicio es necesario reparar los motores.

Durante las reparaciones el costo de los materiales y piezas de repuesto representa aproximadamente el 60 % del costo total de la reparación, lo cual justifica los esfuerzos por alargar la vida útil de las piezas mediante su recuperación[2].

Es así que siendo el cigüeñal uno de los elementos constructivos más costosos del motor de combustión interna a gasolina, su recuperación por aportación de material con las propiedades necesarias, a los muñones o apoyos de los cigüeñales de los motores a gasolina, que llegan a las medidas límites permisibles, que son verificadas mediante las especificaciones técnicas proporcionadas por el programa PRO-SIS, ya sea por el rectificado sucesivo, o que sufren averías anormales en algunos de sus apoyos por diferentes causas, y por falta del stock necesario en el mercado, se procede a la recuperación de los mismo a través del proceso de metalización con la máquina metalizadora TAFA modelo 8830.

Considerando que la empresa Rectificadora Pazmiño S.A no solo busca brindar un buen servicio, sino también garantizar el mismo; además busca implementar un control sobre el proceso de metalización en cigüeñales de motores a gasolina con la máquina metalizadora TAFA modelo 8830; para normalizar un sistema de calidad sobre el producto terminado con la aplicación de una guía interna para el proceso de metalizado de cigüeñales, mediante ensayos destructivos previos que estén relacionados con las

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[2] Datos obtenidos del historial de trabajos realizados por Rectificadora Pazmiño S.A Anexo 7

posibles variaciones que la máquina permite efectuar para el proceso de metalización, con el objeto de entregar el mejor proceso para dar una garantía real del producto terminado.

## 1.4 OBJETIVOS

### 1.4.1 Objetivo General

Analizar y evaluar por medio de ensayos destructivos el proceso de metalización en cigüeñales de motores a gasolina con la máquina metalizadora TAFA modelo 8830 para establecer una calidad real del producto terminado.

### 1.4.2 Objetivos Específicos

- Realizar un estudio de cuantificación de los metales presentes en el cigüeñal mediante espectrómetro de chispa

- Ejecutar ensayo de metalografía para cerciorar mediante micro estructura que el cigüeñal a metalizar corresponde o no a un acero de fundición

- Construir probetas con el acero disponible en el mercado el cual posea las características cercanas a las del cigüeñal.

- Establecer el tipo de ensayos destructivo en cigüeñales que me permita dar una calidad real al proceso de metalización con la máquina metalizadora TAFA modelo 8830.

- Aplicar normas internacionales para los ensayos: de fatiga las ASTM E 466 – E 468, en ensayos a tracción la ASTM E8, los ensayos de micro estructura ASTM E0007-03, ASTM E0003-01 y ASTM E 0045-97 y los ensayos de dureza ASTM E 18.

- Analizar los resultados obtenidos en las diferentes prácticas de ensayos destructivos (tracción, flexión, metalográfico) realizados a los prototipos durante el proceso de metalización en cigüeñales de motores a gasolina con la máquina metalizadora TAFA modelo 8830.

- Formalizar una guía de control de calidad y evaluación del proceso de metalización de cigüeñales de motores a gasolina.

# CAPITULO II

# MARCO TEÓRICO

## 2.1 ANTECEDENTES INVESTIGATIVOS

Rectificadora Pazmiño S.A, es una empresa que le gusta innovar y mejorar sus áreas, es así como muchos de sus procesos en sus inicios fueron realizados de manera artesanal, con la demanda creciente del mercado y el paso del tiempo desarrollo estrategias que le permiten asumir la inminente competitividad del mercado.

Siguiendo esta línea de innovación implementa el servicio de recuperación de cigüeñales de motores a gasolina con la máquina metalizadora TAFA modelo 8830, el cual no es un simple y común servicio sino es el dar una alternativa para a largar la vida útil de cigüeñales que por rectificaciones anteriores ya no cuentan con la tolerancia necesaria o por anomalías presentadas en alguna parte del cigüeñal debidas a un incorrecto cuidado por parte de sus propietarios. Es esta premisa se decide considerar el estudio técnico que busque la mejor aplicación de la metalización con el fin de poder entregar un trabajo con características similares al original.

## 2.2 FUNDAMENTACIÓN FILOSÓFICA

La presente investigación se enfocará en el paradigma crítico – propositivo debido a que permite una comprensión y análisis de la realidad la misma que está en constante cambio y además se puede proponer alternativas de solución al problema estudiado. El presente trabajo está basado en el paradigma naturalista, porque permite realizar una investigación cualitativa la misma que tiene como objetivo la descripción de las cualidades del fenómeno en estudio, además es crítica porque permite comparar la información y obtener un criterio particular de cada individuo; tales razones hacen que dicha investigación pueda desenvolverse en diferentes realidades estableciendo un estudio más realista. Cabe recalcar que la investigación cualitativa se ha concebido últimamente como aquella en la que participan los individuos y comunidad para solucionar sus propias necesidades y problemas, bajo la guía de técnicos al respecto, pero con la participación directa de todos los interesados en su desarrollo; por tal motivo se la ha considerado como la más apropiada para este estudio. Con ello se investigará y se buscará la manera de proponer nuevas premisas que ayuden al mejor desenvolvimiento del proceso de metalización en cigüeñales de motores a gasolina.

## 2.3 FUNDAMENTACIÓN LEGAL[3]

El proceso de termorociado que se realiza con la máquina TAFA 8830 se rige bajo las siguientes normas:

- Materiales

El fabricante determina la aplicación de los alambres 75B (alambre Base) y 60T (alambre de recuperación), los cuales están normados bajo para el alambre 75B las siguientes especificaciones:
PWA-36937 (PWA 271-37 Rev D), GE Manual operation number 70-49-38 as an alternate to 70-49-10, Avco M3951B, Rolls Royce OMAT #3/229, SNECMA DMR33-011, Garrett FP5045 and BF Goodrich Service Letter 1623, y el alambre

60T bajo MIL-W-6712C y la Rolls Royce MSRR 9507/103, la garantía que ofrece sobre estos alambres es la de libre de impurezas y cero defectos de fabricación (ver anexo 1-2).

- Proceso.- El proceso es semiautomático ya que la máquina mediante su sistema funde los alambres a $4000^{o}C$ y lo emite, este es direccionado por el operario a través de la pistola sobre los codos del cigüeñal. Por ser un proceso de soldadura se encuentra normado por la AWS (American Welding Society):

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[3] Anexo 3 Respaldo Magnético

AWS C2.1-73 RECOMMENDED SAFE PRACTICES FOR THERMAL SPRAYING (Recomendaciones de Prácticas Seguras Para Termorociado)
AWS TSS-85 THERMAL SPRAYING: PRACTICE THEORY, AND APPLICATION (Teoría, práctica y aplicación del rociado térmico).

## 2.4 FUNDAMENTACIÓN CIENTÍFICA

### 2.4.1 FUNDAMENTACIÓN CIENTÍFICA DE LA VARIABLE INDEPENDIENTE

#### 2.4.1.1 INGENIERÍA DE LOS MATERIALES

Es la ciencia de los materiales que estudia los requerimientos, propiedades y evaluaciones de los diversos materiales utilizados por la ingeniería, por esto se hace necesario conocer de ellos su micro y macro estructura, adicionalmente las fuerzas a las que están sometidos, ya que estas generan diferentes esfuerzos (producidas por fuerzas internas de los materiales que se oponen a la fuerza exterior aplicada) dependiendo de su plano de aplicación con respecto al material.

En ingeniería se necesita saber cómo responden los materiales sólidos a fuerzas externas como la tensión, la dureza, la compresión, la torsión, la flexión o la cizalladucha. Los materiales sólidos responden a dichas fuerzas con una fuerza contraria, cuando se vence esta fuerza excedimos su límite de dureza [1] (En la que el material pierde se tamaño y forma originales cuando se elimina la fuerza externa).

#### 2.4.1.2 RESISTENCIA DE LOS MATERIALES

La resistencia de materiales clásica es una disciplina de la ingeniería mecánica y la ingeniería estructural que estudia los sólidos deformables mediante modelos simplificados. La resistencia de un elemento se define como su capacidad para resistir esfuerzos y fuerzas aplicadas sin romperse, adquirir deformaciones permanentes o deteriorarse de algún modo. [5]

### 2.4.1.3 PROPIEDADES MECÁNICAS DE LOS MATERIALES

Propiedades mecánicas: Son los que determinan el comportamiento de los materiales, que actúan una o más fuerzas. [3,5].

PROPIEDADES

- **Resistencia** Capacidad que tiene un material que soporta golpes sin deformarse.
- **Elasticidad:** Las deformaciones desaparecen cuando se anula el esfuerzo que las provoca
- **Plasticidad:** Permite que el material tenga deformación permanente sin llegar a la rotura
- **Ductilidad:** Propiedad que permite que el material se deforme antes de llegar a la rotura
- **Fragilidad:** Opuesta a la ductilidad, el material se rompe con deformación nula o despreciable
- **Maleabilidad:** Propiedad que permite, por procesos mecánicos, formar láminas delgadas sin fracturas.

ESFUERZOS

- **Tracción** Se denomina tracción al esfuerzo a que está sometido un cuerpo por la aplicación de dos fuerzas que actúan en sentido opuesto, y tienden a estirarlo.
- **Compresión** El esfuerzo de compresión es la resultante de las tensiones o presiones que existe dentro de un sólido deformable o medio continuo, caracterizada porque tiende a una reducción de volumen o un acortamiento en determinada dirección.
- **Flexión** Se denomina flexión al tipo de deformación que presenta un elemento estructural alargado en una dirección perpendicular a su eje longitudinal.
- **Torsión** Es la solicitación que se presenta cuando se aplica un momento sobre el eje longitudinal de un elemento constructivo o prisma mecánico.

### 2.4.1.4 MOTOR

Máquina destinada a producir movimiento a expensas de otra fuente de energía

**Motor de combustión interna** Es un tipo de máquina que obtiene energía mecánica directamente de la energía química producida por una mezcla aire-combustible, que arde dentro de una cámara de combustión

FIGURA No 1 Motor de combustión interna
Fuente: Talleres Rectificadora Pazmiño S.A

**Motor de combustión Externa** Es una máquina que realiza una conversión de energía calorífica en energía mecánica mediante un proceso de combustión que se realiza fuera de la máquina

FIGURA No 2 Motor de combustión Externa
MTOP "Boletín de prensa 29 diciembre 2007"
Fuente: http://www.mtop.gov.ec/noticias.php?pageNum_noticias=0&totalRows_noticias=12&mes=12

**Motor Eléctrico**
Se denomina así al motor capaz de transformar la energía eléctrica que recibe almacenada en una serie de baterías en energía mecánica capaz de mover las ruedas del automóvil.

FIGURA No 3 Motor Eléctrico
Fuente: Máquinas Eléctricas, Juan José Manzano Orrego

### 2.4.1.5 CIGÜEÑAL

Un cigüeñal es un eje acodado, con codos y contrapesos presente en ciertas máquinas que, aplicando el principio del mecanismo de biela - manivela, transforma el movimiento rectilíneo alternativo en rotatorio y viceversa

FIGURA No 4 Cigüeñal
Fuente: Talleres Rectificadora Pazmiño S.A

### 2.4.1.6 HERRAMIENTAS

Objeto o aparato, normalmente artificial, que se emplea para facilitar o posibilitar un trabajo, ampliando las capacidades naturales del cuerpo humano, para el presente trabajo necesitamos las siguientes herramientas:

- **Sierra** Herramienta que consta de una hoja de acero, uno de cuyos bordes presenta dientes afilados que al frotar una superficie dura la divide.

FIGURA No 5 Sierra
Fuente: Talleres Rectificadora Pazmiño S.A

- **Cortafríos** Se llama cortafrío a una herramienta manual de corte que se utiliza principalmente para cortar metal.

FIGURA No 6 Cortafríos
Fuente: Talleres Rectificadora Pazmiño S.A

- **Mascara respiratoria** La **máscara filtro** es el equipo más utilizado en la protección de las vías respiratorias. La **máscara filtro** integral es utilizado para impedir la entrada de productos contaminantes en las vías respiratorias, entendiéndose como tales: polvo, humo, gases, vapores y nieblas. La máscara filtro es un equipo que se utiliza para eliminar los contaminantes del aire inhalado por el usuario. Las características de esta mascara es que utiliza dos pre filtro marca 3M modelo 5N11, para evitar el ingreso de las partículas que se desprende de este proceso, además cuenta con dos filtro marca 3M modelo 3011 de componente filtrante carbón activado para eliminar todo elemento contaminante presente en el aire antes de que sea inhalado por el operario.

FIGURA No 7 Mascara Respiratoria
Fuente: Talleres Rectificadora Pazmiño S.A

- **Overol de protección** Es una vestimenta que provee un recubrimiento total del operario para evitar que los gases producidos por el proceso de metalización se impregnen en su vestimenta de trabajo y piel expuesta, esta vestimenta está constituida de un material resistente a la temperatura, además de impermeable y ligero para que el operario pueda realizar su trabajo sin molestias.

FIGURA No 8 Overol de protección

Fuente: Talleres Rectificadora Pazmiño S.A

- **Rociador** Es un depósito que rocía sobre el cigüeñal el líquido limpiador para retirar impurezas del mismo.

FIGURA No 9 Rociador

Fuente: Talleres Rectificadora Pazmiño S.A

- **Protector de Oídos** Es un equipo de seguridad industrial utilizado para proteger los oídos de sonidos fuertes producidos por el proceso de metalización que pueden ocasionar enfermedades profesionales.

FIGURA No 10 Protector de oídos
Fuente: Talleres Rectificadora Pazmiño S.A

### 2.4.1.7 PROCESO INDUSTRIAL

Un proceso de fabricación, también denominado proceso industrial, manufactura o producción, es el conjunto de operaciones necesarias para modificar las características de las materias primas. Dichas características pueden ser de naturaleza muy variada tales como la forma, la densidad, la resistencia, el tamaño o la estética. Se realizan en el ámbito de la industria.

Para la obtención de un determinado producto serán necesarias multitud de operaciones individuales de modo que, dependiendo de la escala de observación, puede denominarse proceso tanto al conjunto de operaciones desde la extracción de los recursos naturales necesarios hasta la venta del producto como a las realizadas en un puesto de trabajo con una determinada máquina-herramienta.[1]

### 2.4.1.8 TERMOROCIADO

Los rociados térmicos son especializados y, sin embargo tienen una amplia utilización en la fabricación y mantenimiento. La naturaleza de los procesos es verdaderamente sinérgica. Es decir, hay muchos componentes y variables implicadas, que, cuando trabajan juntos y se aplican correctamente, producen un efecto mucho mayor de lo que indica cuando se consideran por separado. Sin embargo cada componente y la variable deben entenderse para permitir la selección adecuada y el funcionamiento de un proceso determinado. [2, 4,10]

### 2.4.1.9 DEFINICIÓN

El rociado térmico es un conjunto de subprocesos en que material de revestimiento en forma de aerosol finamente dividido, metálico o no metálico son depositados en una condición fundida o semi-fundida sobre un sustrato dispuesto. El material de alimentación puede ser en forma de [10, 20]

- Polvo
- Varilla
- Cable

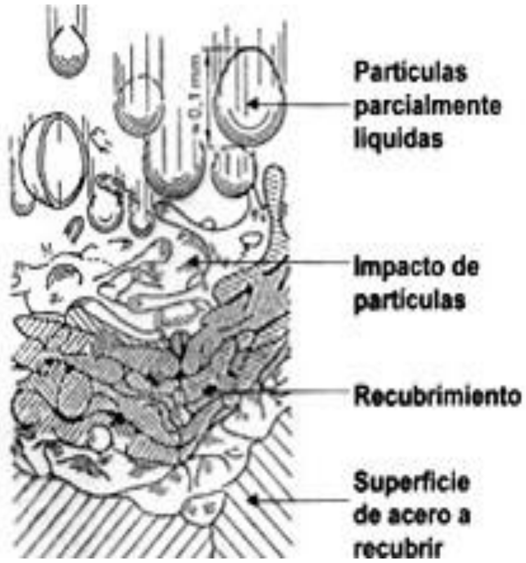


FIGURA No 11 Sección trasversal de una superficie recubierta por Termorociado

Reveron Pojan, Helen María "TERMOROCIADO"

Fuente:http://prof.usb.ve/hreveron/Termo.htm#Proyecci%C3%B3n%20al%20arco%20el%C3%A9ctrico

La pistola de rociado térmico genera el calor necesario mediante el uso de combustibles o un arco eléctrico.

Como los materiales son calentados cambian al estado de plástico o metal fundido y se aceleran por un gas comprimido. Los torrentes confinados de partículas son trasladados al sustrato.

Las partículas golpean la superficie, se acoplan y forman plaquetas delgadas que se ajustan y adhieren a las irregularidades de la superficie preparada y entre ellas, como las partículas rociadas inciden sobre el sustrato se enfrían y se acumulan, partícula por partícula en una estructura laminar, así se forma una capa. [10,20]

### 2.4.1.10 VARIACIONES EN EL PROCESO

Las variaciones básicas en los procesos de rociado térmico acurren en los materiales rociados utilizados, el método de calentamiento, y el método de propulsión de los materiales hacia el sustrato. [10].

Materiales Rociados.- los materiales rociados son usados en formas de polvos, varillas y cables, en la forma de cable en primordialmente usado en Europa. [10]

Muchos metales, óxidos, cerámicos, aleaciones metálicas algunos plásticos naturales y ciertos vasos pueden ser depositados por uno o más de los varios procesos: [10]

### Características

En la figura No. 12 se presenta la sección transversal, de una superficie recubierta con este método. Un aspecto crítico es la porosidad presente en el revestimiento, por lo cual se trata de conseguir el menor porcentaje posible. [10]

Dependiendo de las condiciones también pueden aparecer las partículas no fundidas, que por alguna razón no llegaron a la temperatura de fusión y fueron incorporadas al recubrimiento, esta generalmente interrumpe la continuidad del mismo y disminuye su fuerza cohesiva. [10].

Cuando se rochan metales o aleaciones, parte de ellos se pueden oxidar y aparecen entonces inclusiones de óxidos en el recubrimiento. Esto no siempre es malo, inclusive, un alto porcentaje de óxidos en el recubrimiento puede mejorar la dureza y resistencia del mismo. [10]

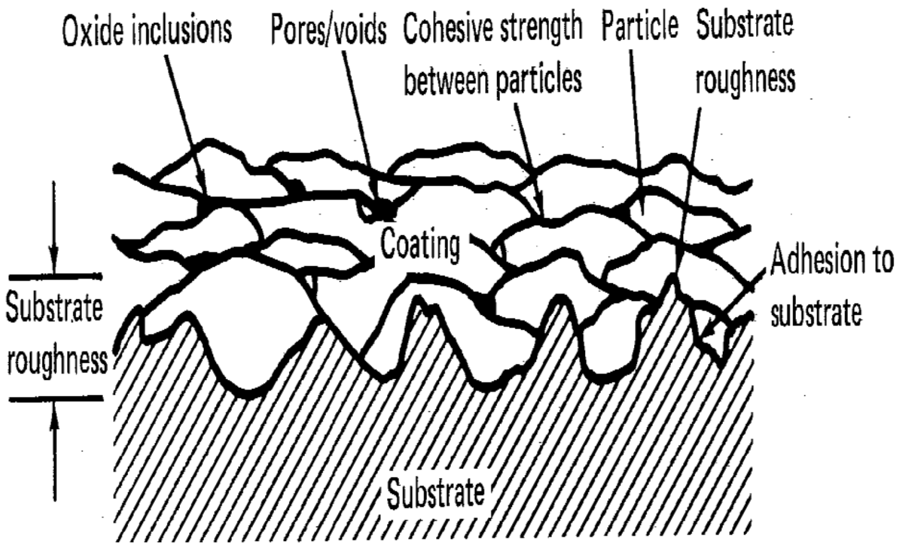
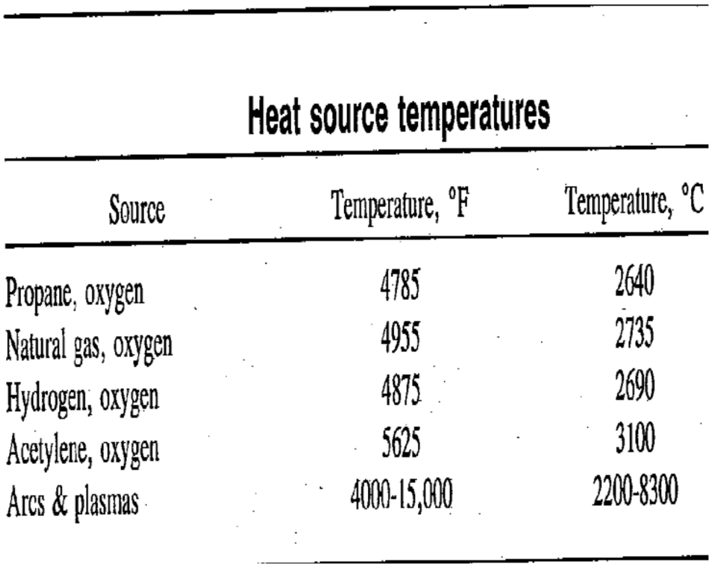


FIGURA No 12 Corte transversal de capa típico para ilustrar la estructura laminar de óxidos e inclusiones
Fuente: Thermal Spraying Practice, Theory, and Application, AWS

### 2.4.1.11 NATURALEZA DE LOS RECUBRIMIENTOS ROCIADOS

El éxito en el uso del revestimiento térmico con spray se basa en el cuidado de la adhesión, a procedimientos específicos del proceso. Una regla básica del rociado térmico es que cualquier desviación de los estándares de una solicitud particular o falta de atención a los detalles producirá el resultado poco confiable. La proporción de densidad de depósito de rociado de capa variará con la velocidad de partícula y la temperatura de la fuente del proceso. [10].

La velocidad de partícula para los distintos procesos, en orden decreciente es: detonación, high-velocity oxygen flame (HVOF), arco por plasma, arco por alambre y rociado por llama. La densidad también depende de la temperatura de la partícula y del tipo de gas de atomización utilizado. Tablas 1 y 2,



**Heat source temperatures**

| Source | Temperature, °F | Temperature, °C |
|---|---|---|
| Propane, oxygen | 4785 | 2640 |
| Natural gas, oxygen | 4955 | 2735 |
| Hydrogen, oxygen | 4875 | 2690 |
| Acetylene, oxygen | 5625 | 3100 |
| Arcs & plasmas | 4000-15,000 | 2200-8300 |

TABLA No1 Temperatura de la Fuente

Fuente: Thermal Spraying Practice, Theory, and Application, AWS

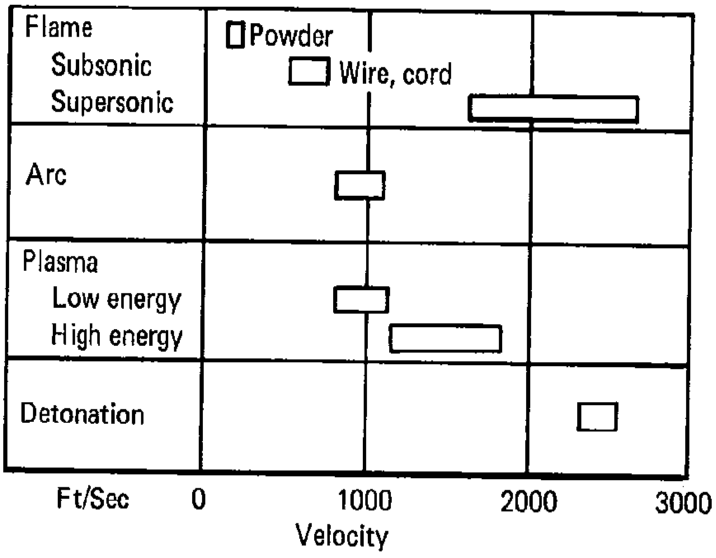


TABLA No 2 Velocidad Promedio de Impacto de las Partículas

Fuente: Thermal Spraying Practice, Theory, and Application, AWS

## 2.4.1.12SOPORTES O SUSTRATOS

Este tipo de recubrimiento puede realizarse virtualmente en casi cualquier tipo de material: metales, cerámicas, vidrios, polímeros, materiales compuestos, etc. la característica esencial de un soporte es que debe presentar cierta rugosidad, de forma tal que el recubrimiento pueda adherirse de forma adecuada. El enlace entre el sustrato y el recubrimiento puede ser mecánico, químico, metalúrgico o una combinación de estos. El método de preparación de la superficie debe seguir los siguientes pasos:

- **Limpiar la superficie.-** ya sea con ultrasonido, utilizando solventes, o cualquier otro método, de forma tal que se asegure que la misma está libre de grasa, óxidos o cualquier otra partícula extraña a la misma. [10]
- **Creación de la rugosidad.-** esto se hace como se dijo anteriormente para aumentar la adherencia de la capa, ya que sirve de anclaje mecánico y aumenta la superficie de contacto. Esto generalmente se hace por Granallado, proceso en el cual se proyectan partículas de un material abrasivo sobre la superficie a recubrir. En metales, a veces se realizan procesos de pasivacion en los que se crea una capa de ácido natural sobre la superficie para mejorar la adherencia. Otros materiales como compuestos y polímeros pueden necesitar preparaciones especiales. [10]

### 2.4.1.13 PROPIEDADES

Las propiedades del recubrimiento, dependen del material de alimentación, del proceso de Termorociado, de los parámetros de aplicación y del pos tratamiento del recubrimiento. [10]

- **Dureza, Densidad y Porosidad:** Los recubrimientos por Termorrociado, suelen utilizarse por su alto grado de dureza relativo a los paint coatings. Su dureza y resistencia a la erosión los hace especialmente valiosos en aplicaciones del alto desgaste. La dureza y densidad de los recubrimientos por Termorrociado son usualmente menores que las del material del cual se hizo el recubrimiento. En general, a mayor velocidad de partícula más duro y denso será el recubrimiento. La porosidad también depende del tipo de proceso de termorociado de los parámetros utilizados y del material utilizado. [4,10]
- **Resistencia a la Corrosión:** Para aplicaciones en muy altas temperaturas y para exposición química, el recubrimiento por Termorrociado debe ser muy resistente a la corrosión. Para estas aplicaciones el recubrimiento ofrece una barrera resistente a la corrosión que protege el substrato. [4.10]

- **Adhesión:** Este tipo de recubrimientos puede tener muy alta adhesión, algunos recubrimientos especiales usados para aplicaciones de alto desgaste aplicados con procesos de alta velocidad de partícula pueden llegar a tener adhesiones que soportan una gran tensión. [10]

### 2.4.1.14 PROCESOS DE TERMOROCIADO

El proceso de termo rociado puede ser categorizado en dos grupos básicos acorde del método de generación de calor. [10]

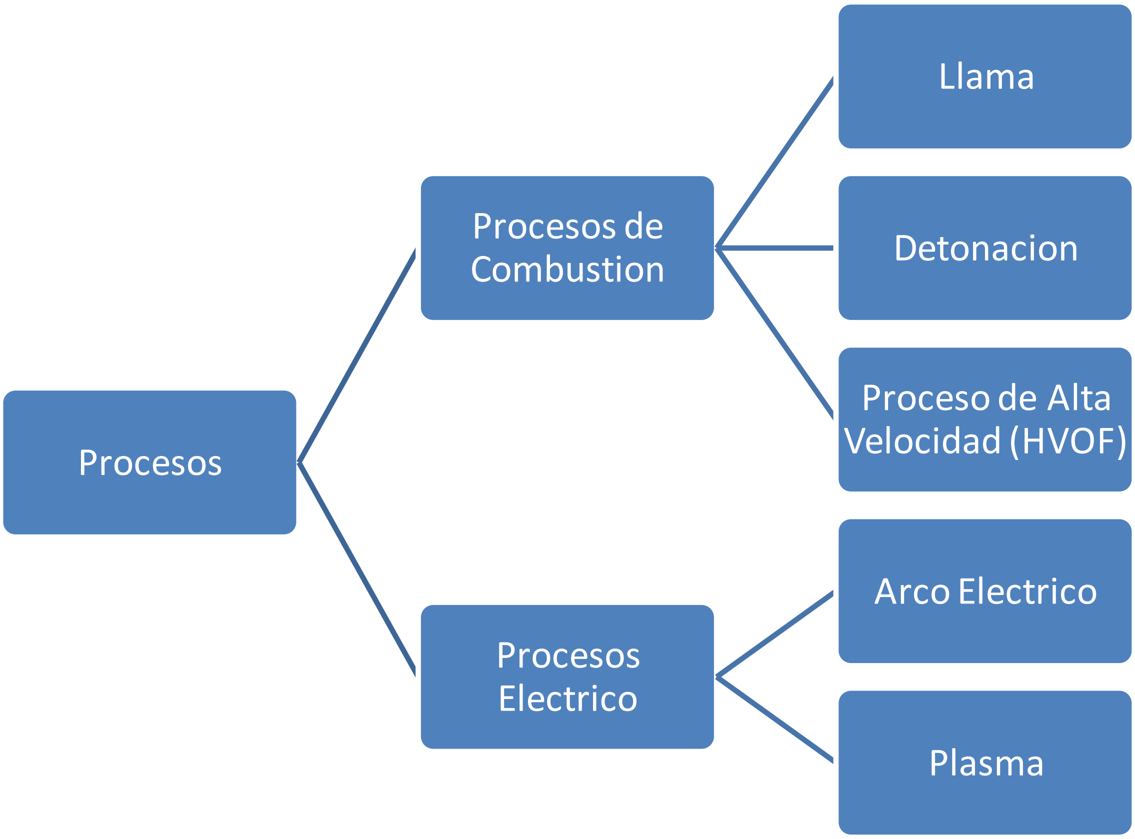


GRAFICO No. 1 Proceso de Termorociado

Fuente: Thermal Spraying Practice, Theory, and Application, AWS

### 2.4.1.15 PROCESOS DE COMBUSTIÓN

**Rociado por llama.-** Es la forma más antigua de Termorociado, puede ser usada con una gran variedad de materiales de alimentación, incluyendo alambres de metal, barras de cerámica, polvos metálicos y no metálicos. [10,20]

El material es alimentado continuamente hacia la pistola donde es fundido en una llama de combustible gaseoso y propulsado hacia el substrato en una corriente de gas atomizado. [10,20]

Algunos gases usados como combustible son: Acetileno y Propano. El aire es generalmente utilizado como gas atomizante. [10,20]

Las llamas de oxiacetilénico son usadas extensivamente para Termorociado con barras debido al grado de control y las altas temperaturas ofrecidas por estos gases. Además esta llama puede ser ajustada para ser oxidante, neutra o reductora. [10,20]

La instalación de un sistema de rociado por llama es relativamente económica y móvil. Para una instalación simple todo lo que se requiere es una antorcha de rociado por llama y una fuente de oxígeno y gas combustible. [20]

Debido a sus bajas velocidades de proyección de partículas comparado con otros procesos de Termorrociado, este tipo de recubrimientos generalmente es de menor calidad, tienen alta porosidad y bajas fueras cohesivas y adhesivas. Una de las aplicaciones más comunes para este tipo de recubrimientos es en protección contra la corrosión. En la siguiente figura se presenta un esquema de un sistema de Termorrociado por llama con alimentación en polvo.

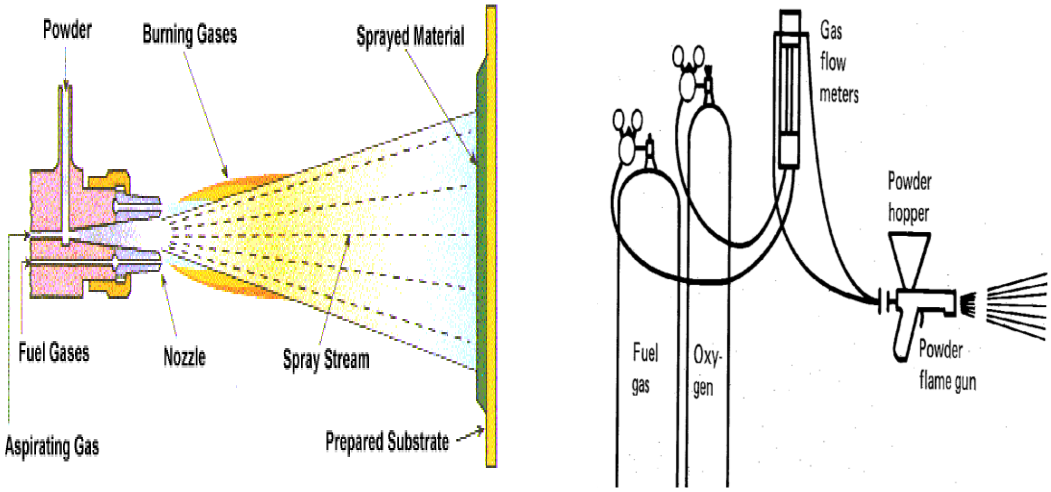


FIGURA No 13 Esquema de un sistema de Termorrociado por llama con alimentación en polvo.
Fuente: Thermal Spraying Practice, Theory, and Application, AWS y
ReveronPojan, Helen Maria "TERMOROCIADO"
http://prof.usb.ve/hreveron/Termo.htm#Proyecci%C3%B3n%20al%20arco%20el%C3%A9ctrico.

**Rociado por Detonación.-** Este proceso es diferente del rociado por llama, en el se usa un proceso de combustión continuo con una serie de explosiones intermitentes que funden y proyectan las partículas hacia la superficie. En la cámara hay una mezcla de oxígeno, acetileno y el material en polvo del cual se hará el recubrimiento, y las detonaciones se hacen varias veces por segundo. El material es depositado a muy altas velocidades para producir recubrimientos muy densos y con altas durezas. El procedimiento se repite hasta obtener el espesor de recubrimiento deseado. El procedimiento alcanza niveles de ruido que exceden los 140 decibeles y por lo tanto debe realizarse en habitaciones a prueba de sonido y de explosiones. Los recubrimientos obtenidos con este método son de excelente calidad, pero con un costo muy alto. Algunas aplicaciones típicas son: recubrimientos de alta resistencia a la abrasión y de altas temperaturas. [10,20]

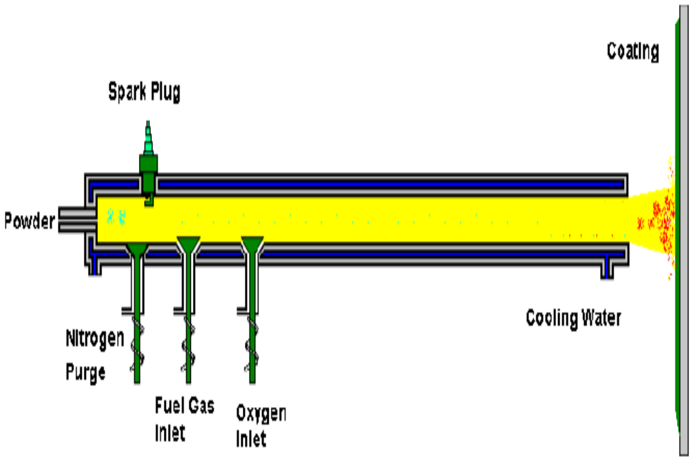


FIGURA No 14 Esquema de un sistema de Termorrociado por Detonación
Fuente :http://prof.usb.ve/hreveron/Termo.htm#Proyecci%C3%B3n%20al%20arco%20el%C3%A9ctrico.

**Rociado por HVOF (High Velocity Oxygen Fuel).-** Es uno de los métodos más nuevos de Termorociado, utiliza oxígeno y un gas como combustible a altas presiones. Algunos gases combustible típicos son propano, propileno e hidrógeno. La mezcla de gases es acelerada a velocidades supersónicas y el material de alimentación en forma de polvo es inyectado dentro de la llama. El proceso minimiza la entrada térmica y maximiza la energía cinética para producir recubrimientos que son realmente densos, con baja porosidad y alta fuerza de enlace. [10,20]

Este proceso está íntimamente relacionado al rociado por llama., pero una diferencia esencial entre ellos es que en el rociado por llama el procesos de combustión se realiza en el aire ( ambiente), mientras que en el HVOF la combustión se realiza en una pequeña cámara. Debido a las altas presiones creadas en la cámara de combustión, los gases salen a velocidades supersónicas, y aceleran las partículas fundidas. Estas, aunque no alcanzan las velocidades de los gases, alcanzan altas velocidades con las que chocan en la superficie obteniendo un recubrimiento de alta calidad. Este tipo de rociado se usa extensivamente para aplicaciones que requieran alta resistencia a la abrasión. [10,20]

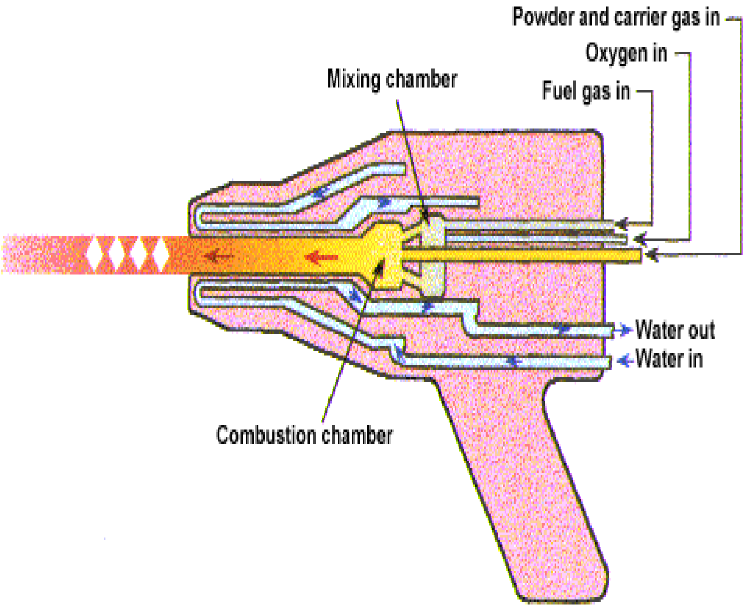


FIGURA No 15 HVOF (High Velocity Oxygen Fuel)
Reveron Pojan, Helen María “TERMOROCIADO”
Fuente :http://prof.usb.ve/hreveron/Termo.htm#Proyecci%C3%B3n%20al%20arco%20el%C3%A9ctrico.

## 2.4.1.16 PROCESOS ELÉCTRICOS

**Proyección al arco eléctrico.-** Es generalmente el método de Termorociado más económico. En este proceso se usa una corriente eléctrica para generar la energía térmica necesaria para fundir los materiales. Este proceso utiliza dos barras de metal como alimentación. Estos dos metales actúan como electrodos que son continuamente consumidos mientras se funden debido al arco eléctrico presente entre ellos. Para que esto suceda, las dos barras deben estar cargadas eléctricamente, una negativa y otra positiva y dispuestas de tal forma que el ángulo entre ellas se reduzca gradualmente. Una diferencia de potencial entre 15 y 50 voltios es aplicada y el calor que se genera funde las puntas de las barras y el gas atomizante proyecta las gotas hacia el substrato. Este gas atomizante es generalmente aire comprimido, pero también se puede usar un gas inerte como Nitrógeno o Argón. La combinación de las altas temperaturas del arco (6000K) y las altas velocidades de las partículas (100 m/seg) producen recubrimientos con mayor fuerza de enlace y menor porosidad que el rociado por llama. El sistema de arco eléctrico utiliza dos alambres metálicos como material de aporte. Los dos alambres están eléctricamente cargados con polaridad inversa e ingresada a la pistola de arco eléctrico a una velocidad coordinada. Cuando los alambres llegan al punto de contacto. Las cargas opuestas crean una energía suficiente para derretir continuamente las puntas de los alambres. Aire comprimido es utilizado para atomizar el material líquido y acelerarlo contra el componente a reconstruir. El tiempo de deposición dependerá de la cantidad de material requerido. Tiene aplicaciones tan variadas como recubrimientos como muñones y en especial de grandes estructuras como puentes, postes de luz y de componentes electrónicos, etc. [10,20]

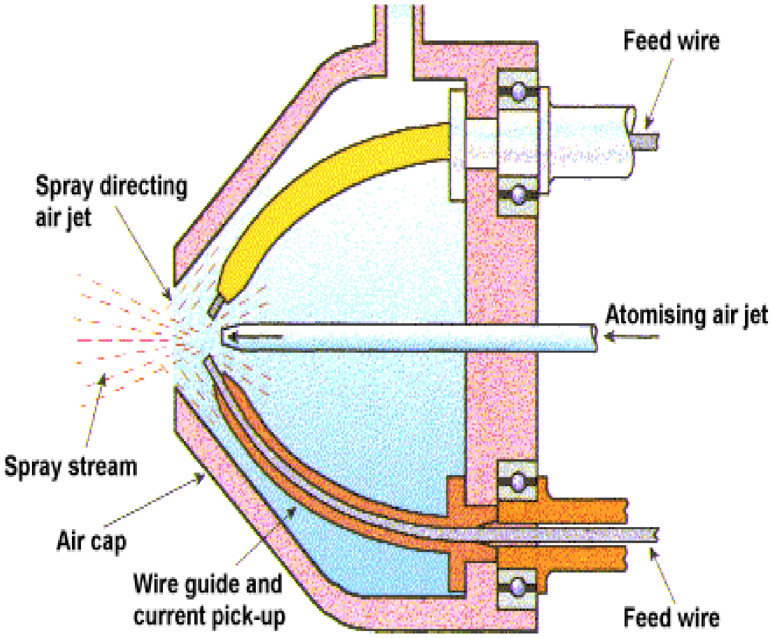


FIGURA No 16 Esquema de un proceso de rociado por arco eléctrico
Reveron Pojan, Helen María "TERMOROCIADO"
Fuente:http://prof.usb.ve/hreveron/Termo.htm#Proyecci%C3%B3n%20al%20arco%20el%C3%A9ctrico.

### 2.1.4.17 COMPONENTES

**Pistola de rociado por arco.-** En una pistola de rociado por arco eléctrico los electrodos de alambre son guiados a través de cables, Los alambres dentro de la pistola son guiados por las puntas de contacto que se denominan contact tips .Hasta ser inyectadas y atomizadas por el aire comprimido el mismo que los dirige por esta zona. Los cables eléctricos aislados se unen a la pistola y la corriente continua es generada por la fuente. [10,20]

Estas pistolas también incluyen el mecanismo para alimentar el cable en una forma controlada, para esto las puntas de contacto son colocadas según el diámetro particular del cable, un botón de ON/OFF se encuentra en la parte superior de la pistola que se encarga de controlar el acceso o para de entrada de aire comprimido, otro botón controla el avance y salida del alambre. [10,20]

**Fuente de energía.-** La fuente de energía provee un voltaje entre 18 y 40 voltios, lo cual permite trabajar con varios metales y aleaciones, una potencia constante es generalmente usada, un pico de voltaje produce un intervalo y aumento del tamaño de la partículas rociadas. El voltaje debe mantenerse en el nivel más bajo y manteniendo una estabilidad en el arco eléctrico, para proporcionar una capa lisa y densa. [10,20]

**Unidad de control del alambre.-** La unidad de control de alambre se coloca sobre la consola de mando que consiste en dos sujetadores donde se colocan los rollos de alambre o carretes, los cuales giran a medida que el material es usado por la pistola, los alambres son conectados hacia la pistola a través del interior de cables flexibles aislados. [10,20]

**Consola de Control.-** La consola de control contiene todos los controles y reguladores necesarios para controlar y monitorear la operación del circuito de energía de la pistola. [10,20]

**Proyección de plasma.-** Este proceso utiliza un arco eléctrico DC para generar un flujo de plasma gaseoso ionizado con muy altas temperaturas que actúa como la fuente de calor para el rociado. El arco se forma entre dos electrodos no consumibles, el cátodo de tungsteno y el ánodo de cobre. [10,20]

La antorcha es alimentada con un flujo continuo de gas inerte el cual es ionizado por el arco DC y es comprimido y acelerado por la antorcha de forma tal que sale a grandes velocidades y altas temperaturas como un *jet* de plasma. El material de alimentación en forma de polvo es alimentado en este plasma donde es calentado y propulsado hacia la superficie a recubrir. [10,20]

Gracias a las altas temperaturas y altas energías térmicas del plasma jet, se pueden rociar materiales con alto punto de fusión tales como cerámicas y metales refractarios. Este proceso usa energías entre 40 y 100 KWatts. [10,20]

Durante este punto de recombinación, las temperaturas llegan a los 16,600 °C, lo cual excede la temperatura superficial del sol, en este momento se inyecta el material de aporte (polvo) en la cámara de gas, el cual es fundido y disparado a alta velocidad mediante la inyección de aire comprimido. [10,20]

Un aspecto importante de mencionar es que a pesar de las altas temperaturas de este proceso, el componente a reconstruir elevara su temperatura solamente de 38 °C a 260 °C (100 °F a 500 °F). Este tipo de recubrimiento se usa ampliamente en partes de equipos como turbinas, en el área de compresores y cámaras de combustión. [10,20]

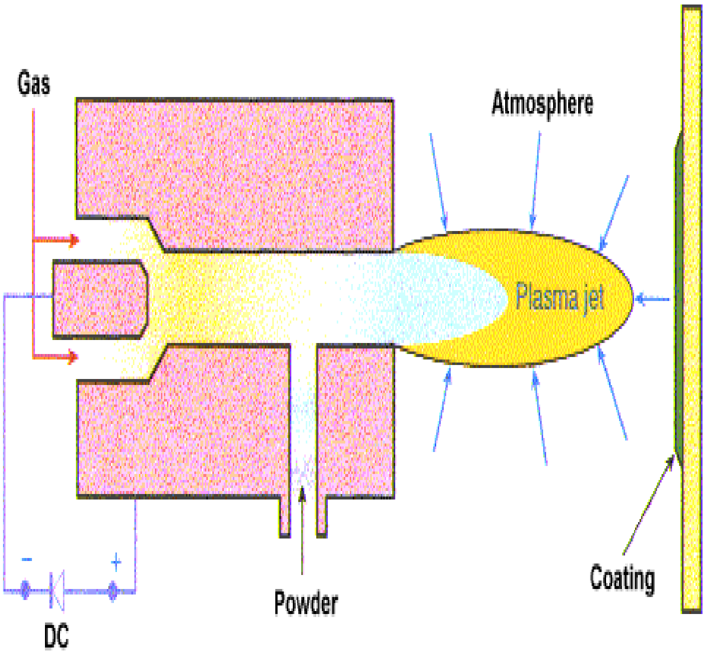


FIGURA No 17 Esquema del sistema de rociado por plasma

Reveron Pojan, Helen María "TERMOROCIADO"

Fuente:http://prof.usb.ve/hreveron/Termo.htm#Proyecci%C3%B3n%20al%20arco%20el%C3%A9ctrico.

### 2.1.4.18 ENSAYOS

Los ensayos en ingeniería se realizan en un determinado material para determinar ciertas características ya sean físicas químicas o de forma para poder conocer la eficiencia de un determinado proceso realizado o aplicado a dicho material. [12, 14,15]

### 2.1.4.19 ENSAYOS DESTRUCTIVOS

Se denomina así a los ensayos que para poder ser realizados y obtener resultados en su mayoría valores se debe destruir una probeta o en el peor de los casos el mismo elemento que se está estudiando hasta poder determinar sus propiedades. Además se complementara el estudio con ensayos destructivos a tracción, compresión, flexión y el de dureza, la metalografía ayudara a este estudio también. [6, 18,19]

### 2.1.4.20 ENSAYO DE TRACCIÓN

El ensayo de tracción de un material consiste en someter a una probeta normalizada a un esfuerzo axial de tracción creciente hasta que se produce la rotura de la probeta. Este ensayo mide la resistencia de un material a una fuerza estática o aplicada lentamente. Las velocidades de deformación en un ensayo de tensión suelen ser muy pequeñas. [7, 9, 16]. En un ensayo de tracción pueden determinarse diversas características de los materiales elásticos:

- Módulo de elasticidad o Módulo de Young, que cuantifica la proporcionalidad anterior. [5]

$$E = \frac{\sigma}{\epsilon} = \frac{F/_S}{\Delta L/_L}$$

Donde:

$E = Modulo\ de\ elasticidad\ o\ de\ Young$
$\sigma = Esfuerzo$
$\epsilon = Deformacion\ Unitaria$
$F = Fuerza\ o\ Carga\ aplicada$
$S = Área$
$\Delta L = Varicion\ de\ Longitud$
$L = Longitud\ Inicial$

- Coeficiente de Poisson, que cuantifica la razón entre el alargamiento longitudinal y el acortamiento de las longitudes transversales a la dirección de la fuerza. [5]

  $$\nu = \frac{\epsilon_t}{\epsilon_{ax}}$$

  Donde:

  $\nu = Esfuerzo$
  $\epsilon_t = Deformacion\ en\ sentido\ transversal$
  $\epsilon_{ax} = Deformacion\ en\ sentido\ de\ aplicacion\ de\ la\ fuerza$

- Límite de proporcionalidad: valor de la tensión por debajo de la cual el alargamiento es proporcional a la carga aplicada. [5]
- Límite de fluencia o límite elástico aparente: valor de la tensión que soporta la probeta en el momento de producirse el fenómeno de la cedencia o fluencia. Este fenómeno tiene lugar en la zona de transición entre las deformaciones elásticas y plásticas y se caracteriza por un rápido incremento de la deformación sin aumento apreciable de la carga aplicada. [5]
- Límite elástico (límite elástico convencional o práctico): valor de la tensión al que se produce un alargamiento prefijado de antemano (0,2%, 0,1%, etc.) en función del extensómetro empleado. [5]
- Carga de rotura o resistencia a tracción: carga máxima resistida por la probeta dividida por la sección inicial de la probeta. [5]
- Alargamiento de rotura: incremento de longitud que ha sufrido la probeta. Se mide entre dos puntos cuya posición está normalizada y se expresa en tanto por ciento. [5]
- Estricción: es la reducción de la sección que se produce en la zona de la rotura. [5]

Normalmente, el límite de proporcionalidad no suele determinarse ya que carece de interés para los cálculos. Tampoco se calcula el Módulo de Young, ya que éste es característico del material; así, todos los aceros tienen el mismo módulo de elasticidad aunque sus resistencias puedan ser muy diferentes.

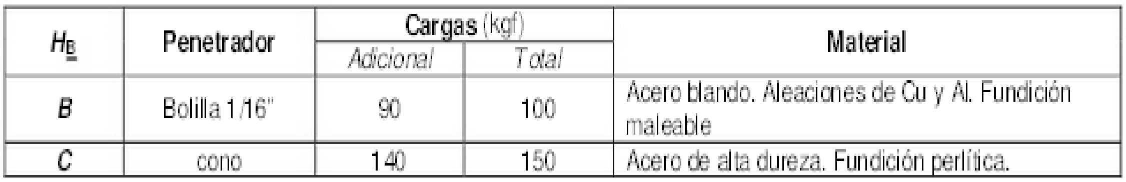
### 2.4.1.21 ENSAYOS DE DUREZA

La dureza de un material es la resistencia que opone a la penetración de un cuerpo más duro. La resistencia se determina introduciendo un cuerpo de forma esférica, cónica o piramidal, por el efecto que produce una fuerza determinada durante cierto tiempo en el cuerpo a ensayar. Como indicador de dureza se emplea la deformación permanente (plástica). En algunos casos, es necesario determinar las características mecánicas de los materiales sin llegar a su destrucción. También podemos determinar la dureza conseguida mediante un tratamiento de dureza.

### DUREZA ROCKWELL

Para los materiales duros se emplea como elemento de penetración un cono de diamante de ángulo120º, y para los semiduros y blandos una bolita de acero de 1/16", deduciéndose la fuerza Rockwell de la profundidad conseguida en la penetración. El cuerpo empleado para la penetración se hace incidir sobre la superficie de la pieza a ensayar con carga previa de 10Kg. La profundidad de penetración alcanzada constituye el valor de partida para la medición de la profundidad de la huella.

Después se aumenta en 140Kg la carga aplicada al cono (150Kg), y en 90Kg la aplicada a la bolita (100Kg), bajándose nuevamente el valor previo. Se mide la profundidad de penetración que queda y en la escala del aparato se lee directamente la correspondiente dureza Rockwell C (H**Rc**) cono o la Rockwell B (H**Rb**) bolita. La siguiente es una tabla simplificada de los materiales más comunes que se miden con Rockwell.



| $H_B$ | Penetrador | Cargas (kgf) | | Material |
|---|---|---|---|---|
| | | *Adicional* | *Total* | |
| *B* | Bolilla 1/16" | 90 | 100 | Acero blando. Aleaciones de Cu y Al. Fundición maleable |
| *C* | cono | 140 | 150 | Acero de alta dureza. Fundición perlítica. |

TABLA No3 Materiales Comúnmente Medidos

Fuente: LUCCHESI, DOMENICO, Ensayos mecánicos de los materiales metálicos, Barcelona, Labor, 1973

## DUREZA BRINELL.

Se comprime una bola de acero templada, de diámetro (D) 2,5; 5 ó 10mm, contra el material a ensayar con una fuerza P. Después de liberar la carga se mide el diámetro (d) de la huella con un dispositivo amplificador óptico. La dureza Brinell es un valor a dimensional resultante de:

$$Hb = \frac{2P}{\pi \times D \times \left(D - \sqrt{D^2 - d^2}\right)}$$

Donde:

*P: carga aplicada en N (kgf)*
*D: diámetro del balín en mm.*
*d: diámetro medio de la huella en mm*

## DUREZA VICKERS

En este caso se emplea como cuerpo de penetración una pirámide cuadrangular de diamante. La huella vista desde arriba es un cuadrado. Este procedimiento es apropiado para aceros nitrurados y cementados en su capa externa, así como para piezas de paredes delgadas de acero o metales no férreos. La dureza Vickers (H**V**) se calcula partiendo de la fuerza en Newton y de la diagonal en mm2 de la huella de la pirámide según la fórmula:

$$HV = 1.8544\,\frac{P}{d^2}$$

Donde:

*P: carga aplicada en N*
*d: Diagonal media de la huella en mm.*
*La diagonal (d) es el valor medio de las diagonales de la huella (d1) y (d2).*

$$d = \frac{d_1 - d_2}{2}$$

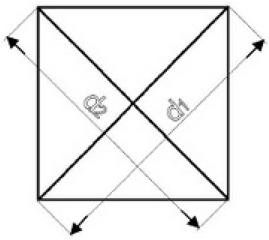


GRAFICO No. 2 Diagonales dejadas por el Penetrador

LUCCHESI, DOMENICO, Ensayos mecánicos de los materiales metálicos, Barcelona, Labor, 1973

### 2.4.1.22 METALOGRAFÍA

La metalografía es la ciencia que estudia las características estructurales o constitutivas de un metal o aleación relacionándolas con las propiedades físicas y mecánicas. Mucha es la información que puede suministrar un examen metalográfico. [6, 13]

### 2.4.1.23 PREPARACIÓN DE LA SUPERFICIE A ANALIZAR

- Para este ensayo es necesaria la preparación de una muestra.
- Cortar la muestra con una cortadora o micro-cortadora metalográfica: es un equipo capaz de cortar con un disco especial de corte por abrasión, mientras suministra un gran caudal de refrigerante, evitando así el sobrecalentamiento de la muestra. De este modo, no se alteran las condiciones microestructurales de la misma.
- La muestra cortada se embute en resina para su mejor tratamiento posterior y almacenado. La embutición se puede realizar mediante resina en frío: normalmente dos componentes, resina en polvo y un catalizador en líquido, o bien en caliente: mediante una embutidora, que, mediante una resistencia interior calienta la resina (monocomponente) hasta que se deshace. La misma máquina tiene la capacidad de enfriar la muestra, por lo que es un proceso recomendado en caso de requerimientos de muchas muestras al cabo del día.[6, 17]

### 2.4.1.24 PULIDO METALOGRÁFICO

Se usa el equipo Debastadora ó Pulidora Metalográfica, se prepara la superficie del material, en su primera fase denominada Desbaste Grueso, donde se desbasta la superficie de la muestra con papel de lija, de manera uniforme y así sucesivamente disminuyendo el tamaño de grano, hasta llegar al papel de menor tamaño de grano. Una vez obtenido el último pulido con el papel de lija de tamaño de grano más pequeño. Al inicio de la segunda fase de pulido denominada Desbaste Fino, en la que se requiere de una superficie plana libre de ralladuras la cual se obtiene mediante una rueda giratoria húmeda cubierta con un paño especial cargado con partículas abrasivas cuidadosamente seleccionadas en su tamaño para ello existen gran posibilidad de abrasivos para efectuar el ultimo pulido; en tanto que muchos harán un trabajo satisfactorio parece haber preferencia por la gama de óxidos de aluminio para pulir materiales ferrosos y de los basados en cobre y óxido de cerio para pulir aluminio, magnesia y sus aleaciones.[6, 14]

La etapa del pulimento es ejecutada en general con paños macizos colocados sobre platos giratorios circulares, sobre los cuales son depositadas pequeñas cantidades de abrasivos, en general diamante industrial en polvo fino o bien en suspensión, con granulometrías como por ejemplo de 10, 6, 3, 1, y 0,25 micras

El pulido se realiza sujetando la muestra a tratar con la mano o bien mediante un cabezal automático para pulir varias muestras a la vez. El cabezal automático ejerce una presión pre-configurada hacia el disco o paño de desbaste o pulido durante un tiempo concreto.

Estos parámetros deben ser configurados según tipo de material (dureza, estado del pulido, etc.) Opcionalmente existen sistemas con dosificador automático de suspensión diamantada. [6,12]

### 2.4.1.25 ATAQUE QUÍMICO

Hay una enormidad de ataques químicos, para diferentes tipos de metales y situaciones. En general, el ataque es hecho por inmersión o fregado con algodón embebido en el líquido escogido por la región a ser observada, durante algunos segundos hasta que la estructura o defecto sea revelada. Uno de los más usados es el NITAL, (ácido nítrico y alcohol), para la gran mayoría de los metales ferrosos. [6]

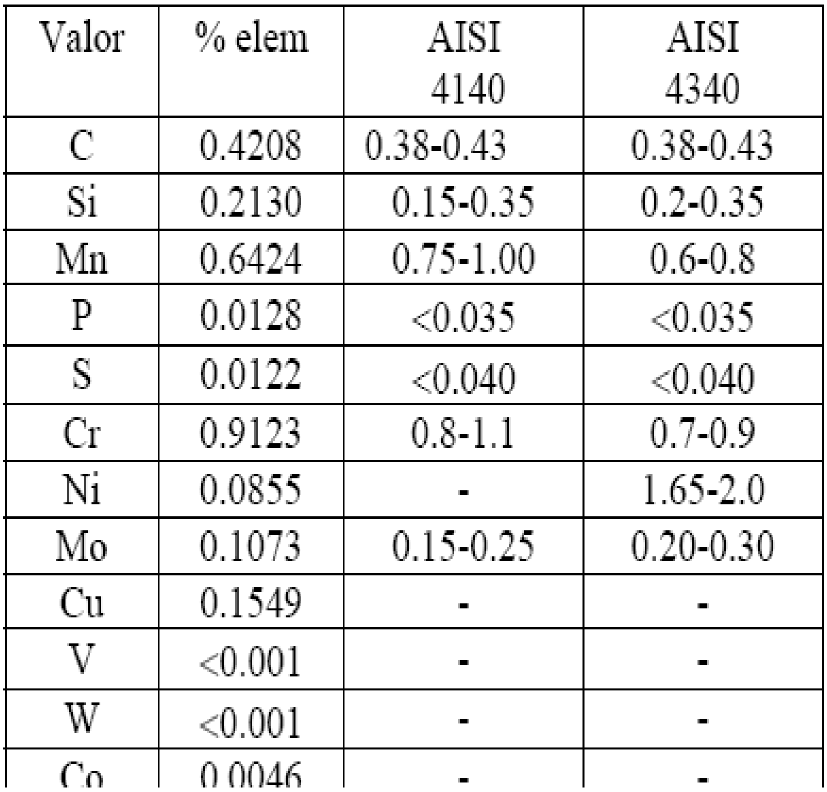
### 2.4.1.26 MICROSCOPIA

Utilización de microscopios estéreos (que favorecen la profundidad de foco y permiten por tanto, visión tridimensional de el área observada) con aumentos que pueden variar de 5x a 64X. El principal instrumento para la realización de un examen metalográfico lo constituye el microscopio metalográfico, con el cual es posible examinar una muestra con aumentos que varían entre *50x* y *2000x*.

El microscopio metalográfico, debido a la opacidad de los metales y aleaciones, opera con la luz reflejada por el metal. Por lo que para poder observar la muestra es necesario preparar una probeta y pulir a espejo la superficie. [6]

### 2.1.4.27MATERIALES PARA LA CONSTRUCCIÓN DE CIGÜEÑALES

Se sabe a partir de la experiencia y de la literatura técnica pertinente, que los aceros más apropiados para la construcción de los elementos de maquinas como un eje cigüeñal son los aceros al carbono de la serie AISI 10xx y los acero aleados de las series AISI 41XX y AISI 43xx con un contenido de carbono no menor a 0,4%. Los aceros más comúnmente utilizados son el AISI 1045, AISI 4140 y AISI 4340, para sustentar estos datos la composición química del acero fue determinada mediante la técnica de espectroscopia de absorción de átomos, en la tabla siguiente se muestran los resultados [21]



| Valor | % elem | AISI 4140 | AISI 4340 |
|---|---|---|---|
| C | 0.4208 | 0.38-0.43 | 0.38-0.43 |
| Si | 0.2130 | 0.15-0.35 | 0.2-0.35 |
| Mn | 0.6424 | 0.75-1.00 | 0.6-0.8 |
| P | 0.0128 | <0.035 | <0.035 |
| S | 0.0122 | <0.040 | <0.040 |
| Cr | 0.9123 | 0.8-1.1 | 0.7-0.9 |
| Ni | 0.0855 | - | 1.65-2.0 |
| Mo | 0.1073 | 0.15-0.25 | 0.20-0.30 |
| Cu | 0.1549 | - | - |
| V | <0.001 | - | - |
| W | <0.001 | - | - |
| Co | 0.0046 | - | - |

TABLA No 4 Composición química de un Cigüeñal vs Aceros
Valdés, Jairo Antonio; Coronado, John Jairo y García, José Isidro. "comparación y estudio de la fractura del cigüeñal de un motor de cuatro cilindros en línea".
Fuente: http://redalyc.uaemex.mx/src/inicio/artpdfred.jsp?icve=84911639025.

De acuerdo a este análisis químico el acero se podría clasificar como un acero AISI 4140, pues la baja cantidad de níquel permite descartar la serie de aceros AISI 43XX, los que presentan una cantidad de níquel superior al 1.65 %. Pero en nuestro país no podemos encontrar este acero en el mercado, pero el AISI 1045 si el cual se puede utilizar para la fabricación de cigüeñales a nivel nacional. [21]

### 2.1.4.28 PROCESO DE METALIZACIÓN

La Metalización o "Thermal Spray" es un proceso que consiste en la aplicación de recubrimientos a un sustrato, para impartirle propiedades distintas o semejantes a las que posee su material base. Los materiales del recubrimiento incluyen metales, aleaciones, carburos, cerámicas, plásticos y estructuras especiales que combinan diversas propiedades. [2, 10]

### 2.4.1.29 METALIZADORA TAFA MODELO 8830

Es un equipo para realizar procesos de Rociado Térmico ó metalización por ARC SPRAY cuenta con una salida ligera, alta de material es unidad resistente diseñada para una operación automática y manual.

FIGURA No 18 Maquina metalizadora TAFA 8830

Fuente: Talleres Rectificadora Pazmiño S.A

| **ESPECIFICACIONES DE METALIZADORA TAFA 8830** | |
|---|---|
| **Voltaje de alimentación** | 230/460, 200(208)/380/415,460/575 a 50 o 60 Hertz tres fases |
| **Presión de Aire** | 40 cfm at 53 psig |
| **Dimensiones** | H-26¼ in, (67cm), W-16¼ in. (41cm), D-30¼ in. (77cm) |
| **Peso** | 346 pounds (157kg). |

TABLA No 5 Especificaciones de Metalizadora TAFA 8830

Fuente: Placa de Posterior Metalizadora TAFA 8830

### 2.4.1.30 TIPOS DE PROCESOS DE METALIZACIÓN

- **Metalización por arco eléctrico** En el proceso de metalización por Arc Spray, un par de alambres metálicos se funden por medio de un arco eléctrico. El material fundido es atomizado por un chorro de aire comprimido e impulsado contra la superficie a ser recubierta.

  Al alcanzar la superficie de la pieza, el material solidifica generando una capa metálica densa que, dependiendo del tipo de material aplicado, puede servir como protección contra la corrosión, resistencia al desgaste, abrasión, conductibilidad térmica o eléctrica, etc.

  Algunas de las mayores ventajas de este proceso es que la capa así formada queda disponible para ser utilizada casi de forma inmediata, ya que no necesita de tiempo de secado o curado; el valor de adherencia de la capa es superior al de otros procesos de metalizado; no hay riesgo de deformación de la pieza tratada, ya que se trata de un proceso en el cual la transferencia de calor a las piezas es prácticamente despreciable; como usa solamente aire comprimido y energía eléctrica, el costo de los aportes es mucho más económico.

  Uno de los campos de aplicación más importante es la aplicación de materiales resistentes a la abrasión y el desgaste en partes de máquinas agrícolas (sinfines, plataformas, codos, etc.).

  Otro es la recuperación dimensional de piezas mecánicas. De forma muy económica, es posible aplicar capas metálicas sobre cualquier componente usado con desgaste o nuevo con errores de mecanizado. [15]
- **Metalización con soplete** Mediante un soplete que tiene dispuesto un depósito sobre el mismo donde se coloca el material de aportación, en forma de polvo, en la corriente gaseosa, la salida de polvo se controla mediante una palanca que se acciona.

  Las partículas de material de aportación funden al llegar a la llama, que proyecta, una vez fundidas, sobre la superficie a metalizar.

  La llama se emplea para precalentar la pieza, para fundir el polvo de aportación y para proyectarlo sobre la superficie. [17]
- **Metalización por electrolisis** Este tipo de metalizado se utiliza en el proceso de cromado de plástico con el cromo hexavalente (Cr (VI)).

Una de las grandes desventajas que presenta este material es su potencial cancerígeno. [17]

### 2.4.1.31 APLICACIÓN DE LA METALIZACIÓN

Tiene gran gama de aplicación pero principalmente es utilizada para la recuperación o regeneración de elementos de maquinaria como ejes o muñones de cigüeñales, los cuales ya sea por reparaciones anteriores ya no cuentan con medida necesaria para ser rectificados nuevamente.

### 2.4.1.32 VENTAJAS Y DESVENTAJA DE LA METALIZACIÓN

- La principal ventaja de la metalización es que permite utilizar los elementos que anteriormente eran considerados ya obsoletos y que la única remediación que existía era la fabricación de uno nuevo.
- Además de que al utilizar este proceso correctamente el producto obtenido tiene las mismas características de uno nuevo pero a una fracción de su costo.
- El uso de este proceso aumenta la disminución de la contaminación por reciclaje de piezas usadas que pueden ser reconstruidas.
- Un control inadecuado de proceso de metalización puede determinar un bajo rendimiento del producto entregado y no cumplir los estándares requeridos en su funcionamiento.

### 2.4.1.33 PASOS PARA METALIZACIÓN EN LA MÁQUINA METALIZADORA TAFA MODELO 8830

- El motor ingresa al área de inspección técnica donde es revisado íntegramente todas sus partes después de una revisión visual se procede a verificación y comparación de medidas con instrumentos específicos para este trabajo.

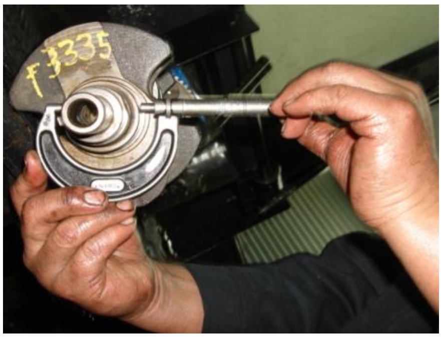
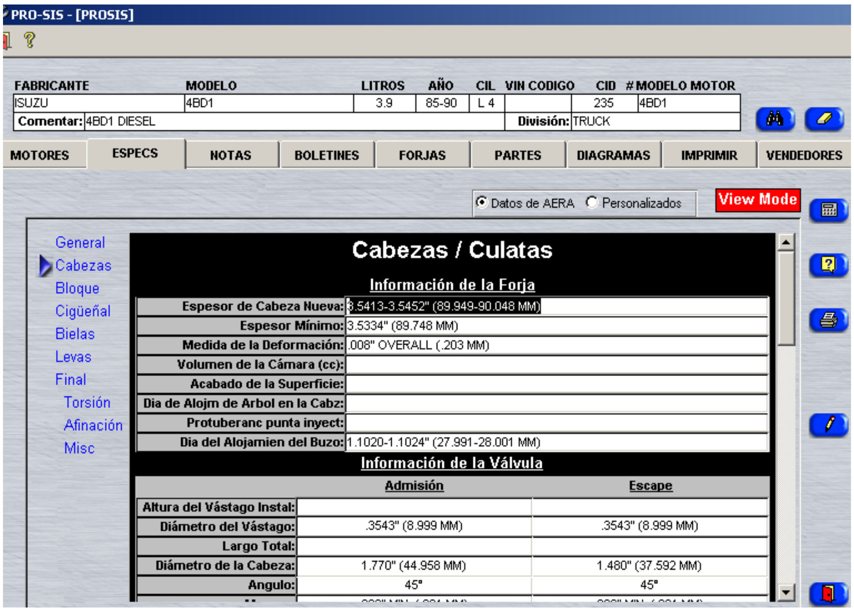


FIGURA  No 19 Toma de medida

Fuente: Talleres Rectificadora Pazmiño S.A

- Las medidas tomadas se comparan con las medidas que proporcionan el programa PRO-SIS que cuenta con base de datos de todos los modelos de motores existentes y es proporcionado por la AERM, para conocer en el estado del motor y así poder determinar el trabajo a realizar.



PRO-SIS - [PROSIS]

| FABRICANTE | MODELO | LITROS | AÑO | CIL | VIN CODIGO | CID | # MODELO MOTOR |
|---|---|---|---|---|---|---|---|
| ISUZU | 4BD1 | 3.9 | 85-90 | L 4 |  | 235 | 4BD1 |

Comentar: 4BD1 DIESEL

División: TRUCK

● Datos de AERA ○ Personalizados

Cabezas / Culatas

Información de la Forja

| | |
|---|---|
| Espesor de Cabeza Nueva: | 3.5413-3.5452" (89.949-90.048 MM) |
| Espesor Mínimo: | 3.5334" (89.748 MM) |
| Medida de la Deformación: | .008" OVERALL (.203 MM) |
| Volumen de la Cámara (cc): | |
| Acabado de la Superficie: | |
| Dia de Alojm de Arbol en la Cabz: | |
| Protuberanc punta inyect: | |
| Dia del Alojamien del Buzo: | 1.1020-1.1024" (27.991-28.001 MM) |

Información de la Válvula

| | Admisión | Escape |
|---|---|---|
| Altura del Vástago Instal: | | |
| Diámetro del Vástago: | .3543" (8.999 MM) | .3543" (8.999 MM) |
| Largo Total: | | |
| Diámetro de la Cabeza: | 1.770" (44.958 MM) | 1.480" (37.592 MM) |
| Angulo: | 45° | 45° |

FIGURA  No 20 Software PRO-SIS

Fuente: Talleres Rectificadora Pazmiño S.A

- Para metalizar el cigüeñal se procede a limpiar la superficie que va hacer metalizada con un agente solvente de gran acción (Thinner).
- Proteger las partes del cigüeñal que no necesitan ser metalizadas con grasa.

- Frota una hoja de sierra sobre la superficie que va hacer metalizada para proporcionar una mejor superficie de adherencia.
- Verificar la presión de aire sea la correcta para el proceso.
- Comprobar que la pistola proporcione un rociado homogéneo del material.
- Encender el torno para que gire el cigüeñal con una velocidad determinada.
- Colocar en posición y distancia correcta la pistola para iniciar el rociado.
- Proceder al rociado comprobando el espesor de la capa de recubrimiento hasta obtener una dimensión más grande que la requerida.
- El cigüeñal metalizado es llevado a la máquina de rectificación de cigüeñales donde se procede a rectificarlo hasta darle la medida requerida.

### 2.4.1.34 ALAMBRE 75B (ALAMBRE BASE)

Es el alambre que se utiliza como adherente entre el material original del cigüeñal y el alambre que va hacer utilizado para la recuperación del mismo.

FIGURA No 21 Alambre 75B (alambre Base)

Fuente: Talleres Rectificadora Pazmiño S.A

### 2.4.1.35 ALAMBRE 60T (ALAMBRE DE RECUPERACIÓN)

Es el alambre que es aplicado después del alambre base y es el encargado de recuperar las medidas que se necesitan del cigüeñal.

FIGURA No 22 Alambre 60T (alambre de recuperación)
Fuente: Talleres Rectificadora Pazmiño S.A

### 2.4.1.36 TORNO

Se denomina al conjunto de máquinas herramienta que permiten mecanizar piezas de forma geométrica de revolución. Estas máquinas-herramienta operan haciendo girar la pieza a mecanizar.

FIGURA No 23 Torno
Fuente: Talleres Rectificadora Pazmiño S.A

### 2.4.1.37 RECTIFICADORA DE CIGÜEÑALES

La rectificadora de cigüeñales es una máquina herramienta, utilizada para conseguir mecanizados de precisión tanto en dimensiones como en acabado superficial de un cigüeñal.

FIGURA No 24 Rectificadora de Cigüeñales BERCO 270
Fuente: Talleres Rectificadora Pazmiño S.A

### 2.4.1.38 PULIDORA DE CIGÜEÑALES

Es una máquina utilizada para dar el acabado final al cigüeñal después de ser rectificado.

FIGURA No 25 Pulidora de Cigüeñales
Fuente: Talleres Rectificadora Pazmiño S.A

### 2.4.1.39 METROLOGÍA

La metrología proviene de los términos griego *μετρον* que significa medida, y *λογος*, cuyo significado es tratado. Por lo tanto podemos decir que metrología es la ciencia y técnica que estudia los sistemas de pesos y medidas, en general estudia su relación con las magnitudes físicas. La metrología tiene dos características muy importantes reflejadas en el instrumento de medida que se use, que son la apreciación y la sensibilidad.

Los físicos y la industria utilizan una gran variedad de instrumentos para llevar a cabo sus mediciones desde objetos sencillos como reglas y cronómetros, hasta potentes microscopios de láser e incluso aceleradores de partículas.[4] Desde el principio de la civilización el hombre, va formando en su mente la idea de medir; comparaba masas de acuerdo a su sensibilidad muscular, media distancias según los distintos esfuerzos al lanzar una piedra, o lo que podía recorrer a pie en un día. Se origina de esta forma la matemática y también una ciencia que hoy es de una importancia vital para cualquier país: LA METROLOGÍA, la cual se basa fundamentalmente en aquella y otras ciencias puras.

### 2.4.1.40 CALIBRACIÓN

Calibración es simplemente un procedimiento de comparación, entre lo que indica un instrumento y lo que "debería indicar", de acuerdo a un patrón de referencia como un valor conocido.[5]

### 2.4.1.41 METROTÉCNIA

La metrotécnia es la tecnología o el conjunto de técnicas que estudian medidas. A diferencia de la metrología, que se centra en la parte teórica y definición de medida, la metrotécnia se ocupa de la realización de la medida propiamente dicha, el uso de los

---

[4] Curso de Capacitación METROLOGÍA dictado en la Empresa Rectificadora Pazmiño S.A

[5] Curso de Capacitación METROLOGÍA dictado en la Empresa Rectificadora Pazmiño S.A

instrumentos de medición, su contracción y conservación, las instrucciones de uso de cada una de ellas, y todo lo que tiene que ver con los trabajos de medición. [6]

### 2.4.1.42 MICRÓMETRO

El micrómetro (del griego *micros*, pequeño, y *metros*, medición), también llamado Tornillo de Palmer, es un instrumento de medición cuyo funcionamiento está basado en el tornillo micrométrico y que sirve para medir las dimensiones de un objeto con alta precisión, del orden de centésimas de milímetros (0,01 mm) y de milésimas de milímetros (0,001mm). Para ello cuenta con 2 puntas que se aproximan entre sí mediante un tornillo de rosca fina, el cual tiene grabado en su contorno una escala. La escala puede incluir un nonio. La máxima longitud de medida del micrómetro de exteriores es de 25 mm, por lo que es necesario disponer de un micrómetro para cada campo de medidas que se quieran tomar (0-25 mm), (25-50 mm), (50-75 mm), etc. Frecuentemente el micrómetro también incluye una manera de limitar la torsión máxima del tornillo, dado que la rosca muy fina hace difícil notar fuerzas capaces de causar deterioro de la precisión del instrumento. [7]

FIGURA No 26 Micrómetro

Fuente: Talleres Rectificadora Pazmiño S.A

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[6] Curso de Capacitación METROLOGÍA dictado en la Empresa Rectificadora Pazmiño S.A

[7] Curso de Capacitación METROLOGÍA dictado en la Empresa Rectificadora Pazmiño S.A

Componentes

El micrómetro usado por un largo período de tiempo, podría experimentar alguna desviación del punto cero; para corregir esto, los micrómetros traen en su estuche un patrón y una llave.

Micrómetro de exteriores:

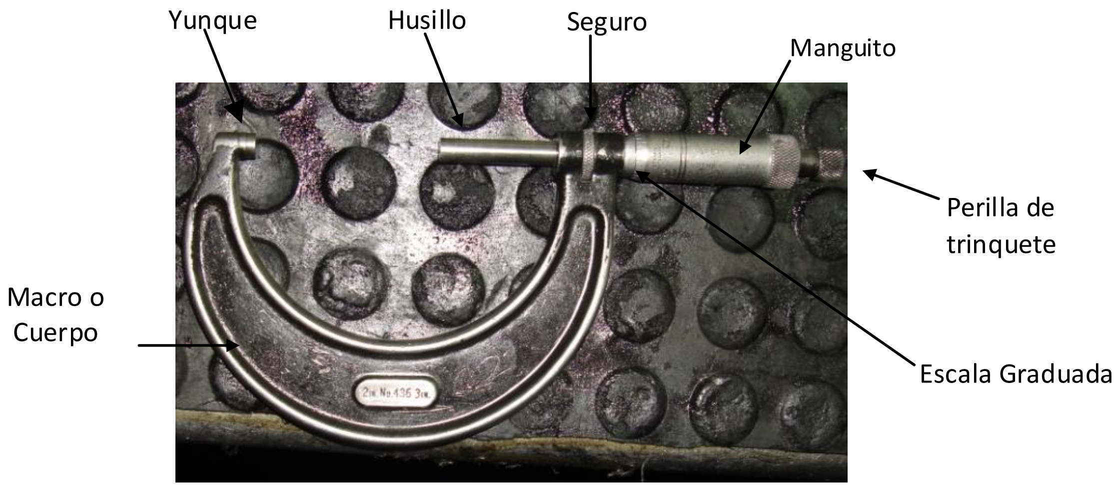

FIGURA No 27 Componentes del Micrómetro

Fuente: Talleres Rectificadora Pazmiño S.A

### 2.4.1.43 MODO DE USO DEL MICRÓMETRO

Precauciones al medir

- Verificar la limpieza del micrómetro
- Utilice el micrómetro adecuadamente

Método correcto para sujetar el micrómetro con las manos

- Algunos cuerpos de los micrómetros están provistos con aisladores de calor, si se usa un cuerpo de éstos, sosténgalo por la parte aislada, y el calor de la mano no afectará al instrumento.
- El trinquete es para asegurar que se aplica una presión de medición apropiada al objeto que se está midiendo mientras se toma la lectura.

- Inmediatamente antes de que el husillo entre en contacto con el objeto, gire el trinquete suavemente, con los dedos. Cuando el husillo haya tocado el objeto de tres a cuatro vueltas ligeras al trinquete a una velocidad uniforme (el husillo puede dar 1.5 o 2 vueltas libres). Hecho esto, se ha aplicado una presión adecuada al objeto que se está midiendo.
- Si acerca la superficie del objeto directamente girando el manguito, el husillo podría aplicar una presión excesiva de medición al objeto y será errónea la medición.
- Cuando la medición esté completa, despegue el husillo de la superficie del objeto girando el trinquete en dirección opuesta. [8]

<u>Asegure el contacto correcto entre el micrómetro y el objeto.</u>

Es esencial poner el micrómetro en contacto correcto con el objeto a medir. Use el micrómetro en ángulo recto (90º) con las superficies a medir.

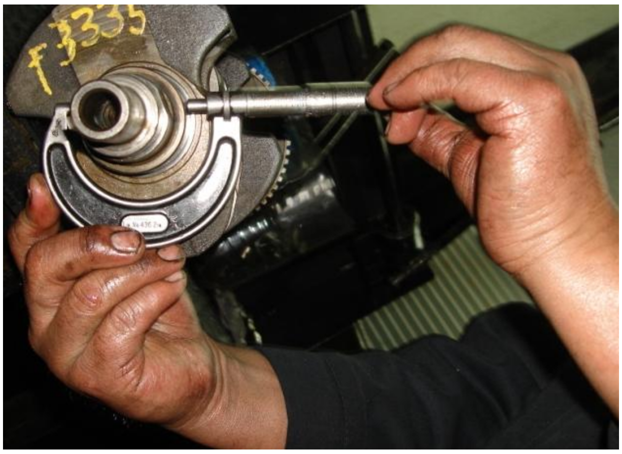

FIGURA No 28 Micrómetro Uso correcto

Fuente: Talleres Rectificadora Pazmiño S.A

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[8] Curso de Capacitación METROLOGÍA dictado en la Empresa Rectificadora Pazmiño S.A

### 2.4.1.44 MÉTODOS DE MEDICIÓN

Cuando se mide un objeto cilíndrico, es una buena práctica tomar la medición dos veces; cuando se mide por segunda vez, gire el objeto 90º. No levante el micrómetro con el objeto sostenido entre el husillo y el yunque. [9]

No gire el manguito hasta el límite de su rotación, no gire el cuerpo mientras sostiene el manguito.

- Verifique que el cero esté alineado

  Cuando el micrómetro se usa constantemente o de una manera inadecuada, el punto cero del micrómetro puede desalinearse.

  Si el instrumento sufre una caída o algún golpe fuerte, el paralelismo y la lisura del husillo y el yunque, algunas veces se desajustan y el movimiento del husillo es anormal.

- Paralelismo de las superficies de medición

  1) El husillo debe moverse libremente.

  2) El paralelismo y la lisura de las superficies de medición en el yunque deben ser correctas.

  3) El punto cero debe estar en posición (si está desalineado siga calibre el micrómetro).

FIGURA No 29 Micrómetro Uso correcto

Fuente: Talleres Rectificadora Pazmiño S.A

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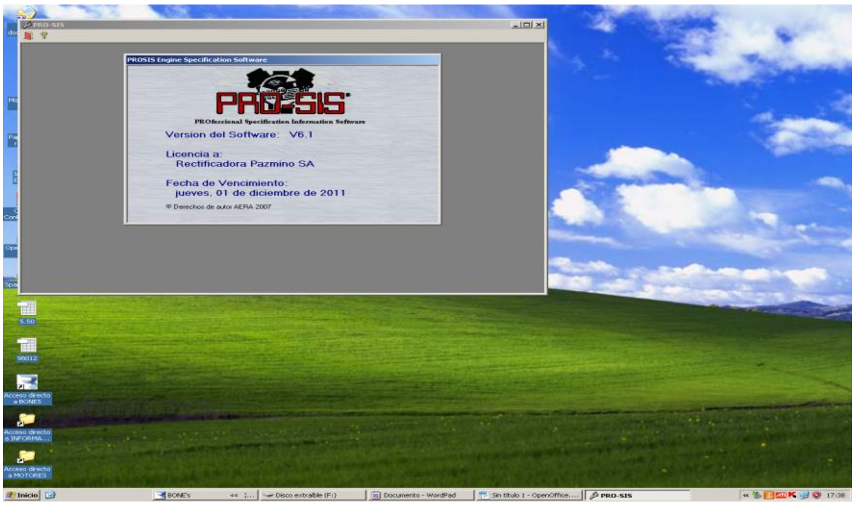
[9] Curso de Capacitación METROLOGÍA dictado en la Empresa Rectificadora Pazmiño S.A

### 2.4.1.45 PRO-SIS

El PRO-SIS (Professional Specification Information Software) significa software profesional de información de especificaciones. Es un programa de computadora proporcionado por la AERA (ENGINE BUILDERS ASSOCIATION), este programa proporciona especificaciones de los fabricantes de motores como medidas, ajustes etc. Los cuales son utilizados por la empresa para realizar sus distintos trabajos como el determinar la medida del cigüeñal todavía puede ser utilizado o ya supero sus límites máximos de desgaste. A continuación se desdobla de forma rápida los pasos a seguir:

## PASOS PARA INGRESAR A PRO-SIS

<u>Paso1. Ingreso al sistema</u>



PROSIS Engine Specification Software

PROfessional Specification Information Software

Version del Software: V6.1

Licencia a:
Rectificadora Pazmino SA

Fecha de Vencimiento:
jueves, 01 de diciembre de 2011

© Derechos de autor AERA 2007

## Paso 2. Escojo la opción de Especificaciones

Version del Software: V6.1

Licencia a: Rectificadora Pazmino SA

Hoy es: jueves, 14 de octubre de 2010

Fecha de Vencimiento: lunes, 01 de noviembre de 2010

Nota:
La información de intercambio de partes contenida en el tab. "Vendedor" es provista por los fabricantes participantes. El grado de exactitud se limita a los datos provistos por estos fabricantes.

License EXPIRES in 18 days! Click Here to Print Renewal Invoice.

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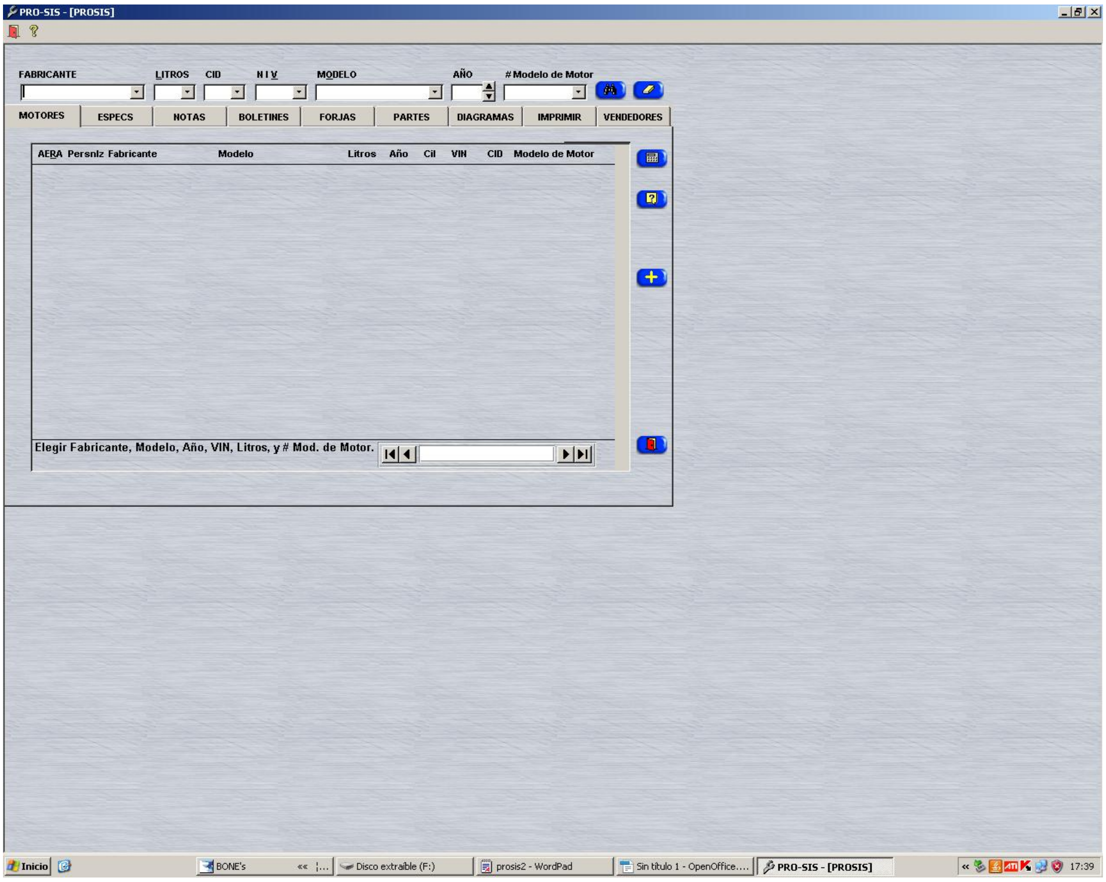
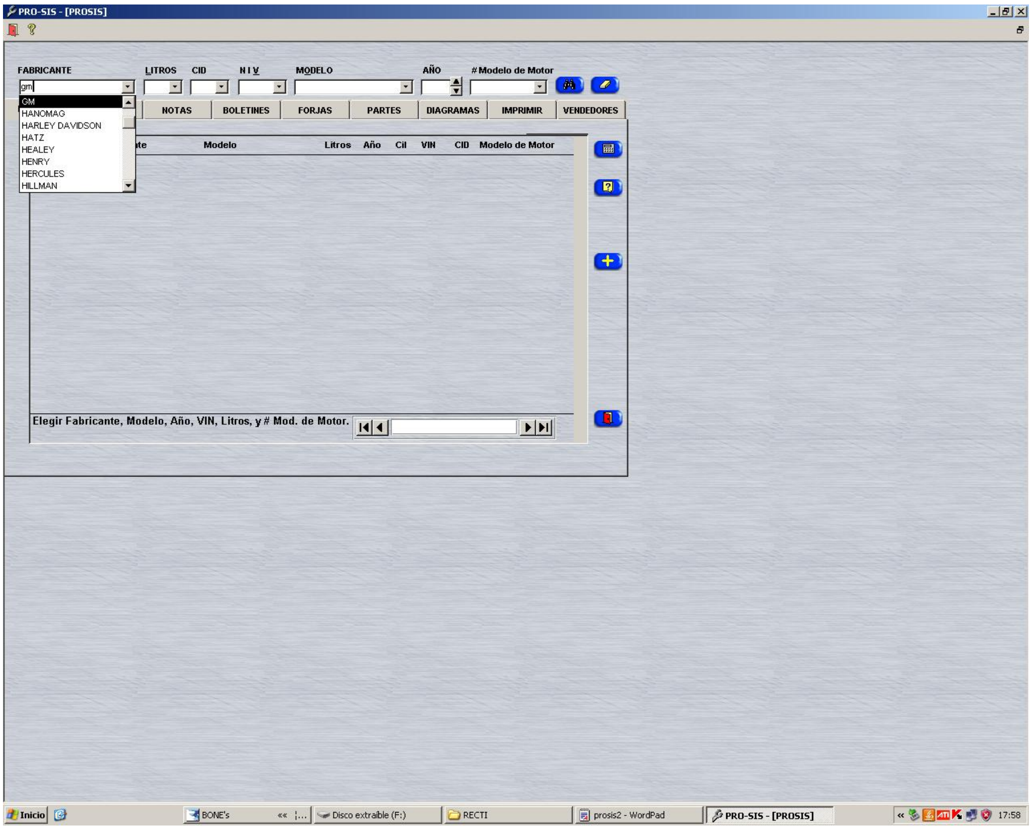
## Paso 3 Ingreso Especificaciones Técnicas a consultar



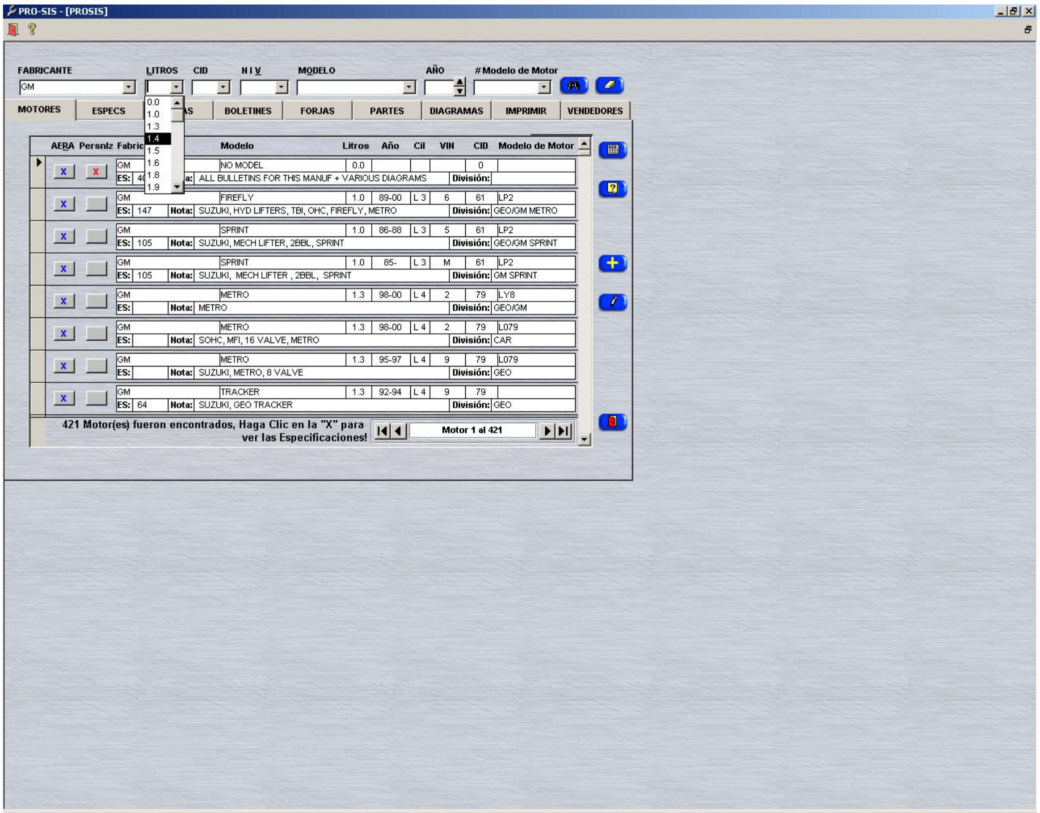
Elegir Fabricante, Modelo, Año, VIN, Litros, y # Mod. de Motor.

## Paso 4 Escojo Especificaciones como: Fabricante, Litros, Modelo, Año entre otros



FABRICANTE: gm

Elegir Fabricante, Modelo, Año, VIN, Litros, y # Mod. de Motor.



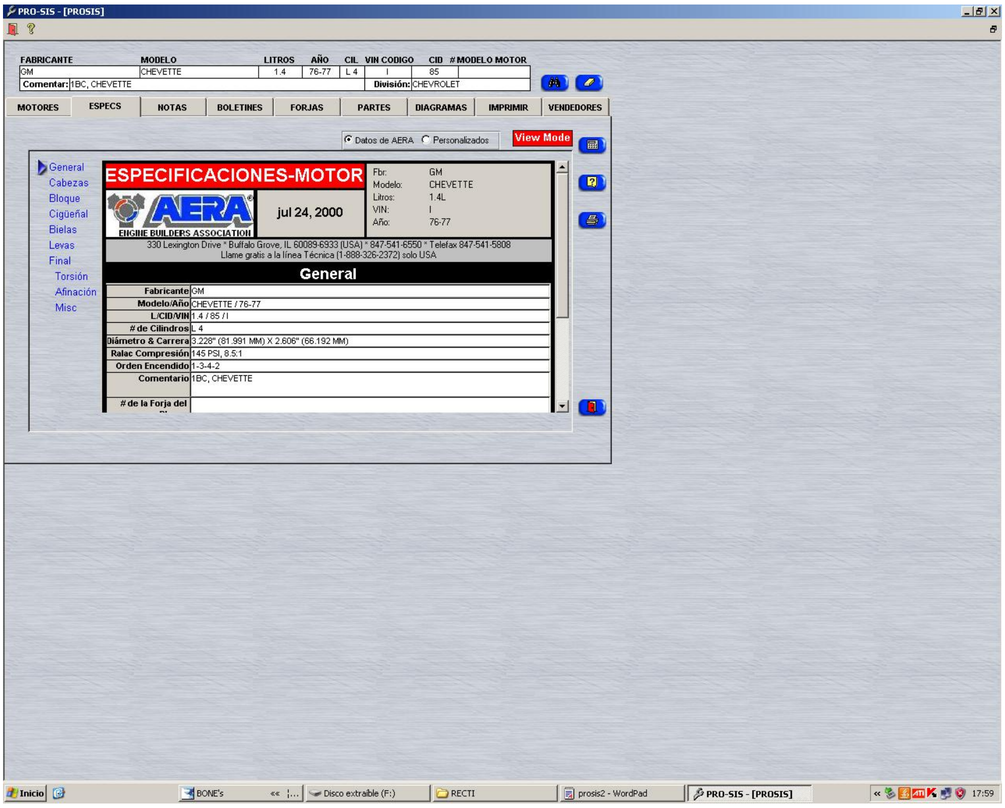
FABRICANTE: GM

| Fabric | Modelo | Litros | Año | Cil | VIN | CID | Modelo de Motor | ES | Nota | División |
|---|---|---|---|---|---|---|---|---|---|---|
| GM | NO MODEL | 0.0 | | | | 0 | | 40 | ALL BULLETINS FOR THIS MANUF + VARIOUS DIAGRAMS | |
| GM | FIREFLY | 1.0 | 89-00 | L 3 | 6 | 61 | LP2 | 147 | SUZUKI, HYD LIFTERS, TBI, OHC, FIREFLY, METRO | GEO/GM METRO |
| GM | SPRINT | 1.0 | 86-88 | L 3 | 5 | 61 | LP2 | 105 | SUZUKI, MECH LIFTER, 2BBL, SPRINT | GEO/GM SPRINT |
| GM | SPRINT | 1.0 | 85- | L 3 | M | 61 | LP2 | 105 | SUZUKI, MECH LIFTER , 2BBL, SPRINT | GM SPRINT |
| GM | METRO | 1.3 | 98-00 | L 4 | 2 | 79 | LY8 | | METRO | GEO/GM |
| GM | METRO | 1.3 | 98-00 | L 4 | 2 | 79 | L079 | | SOHC, MFI, 16 VALVE, METRO | CAR |
| GM | METRO | 1.3 | 95-97 | L 4 | 9 | 79 | L079 | | SUZUKI, METRO, 8 VALVE | GEO |
| GM | TRACKER | 1.3 | 92-94 | L 4 | 9 | 79 | | 64 | SUZUKI, GEO TRACKER | GEO |

421 Motor(es) fueron encontrados, Haga Clic en la "X" para ver las Especificaciones!

Motor 1 al 421

# Paso 5 Aparece Especificaciones técnicas



| FABRICANTE | MODELO | LITROS | AÑO | CIL | VIN CODIGO | CID | # MODELO MOTOR |
|---|---|---|---|---|---|---|---|
| GM | CHEVETTE | 1.4 | 76-77 | L 4 | I | 85 | |

Comentar: 1BC, CHEVETTE
División: CHEVROLET

● Datos de AERA ○ Personalizados

ESPECIFICACIONES-MOTOR

AERA® ENGINE BUILDERS ASSOCIATION

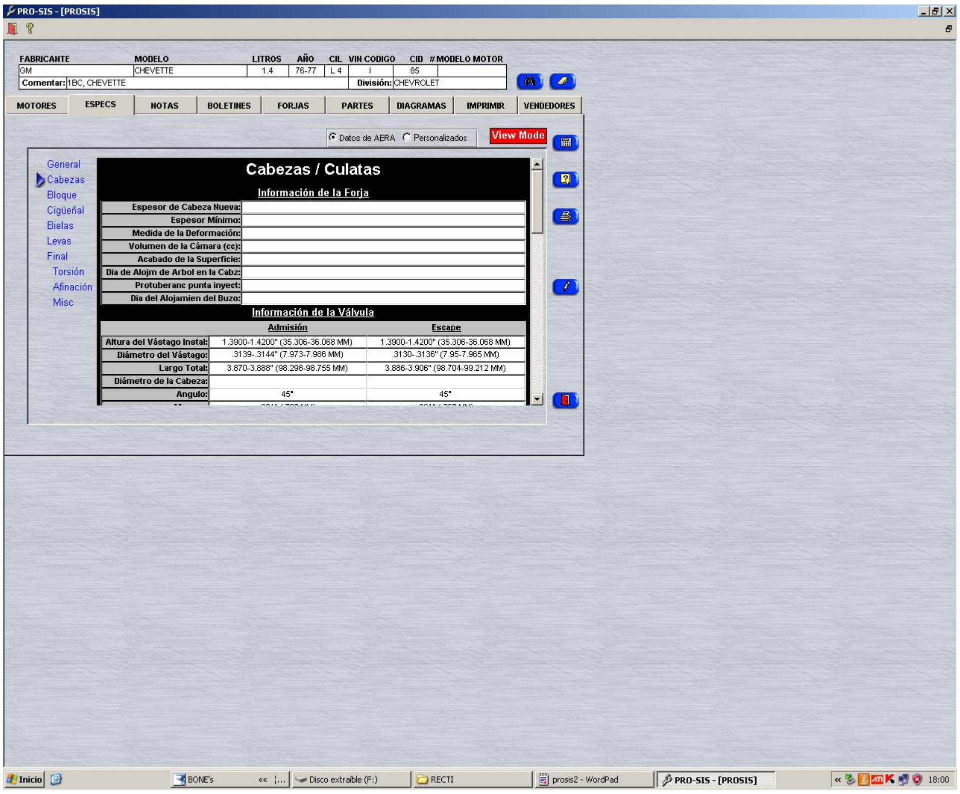
jul 24, 2000

Fbr: GM
Modelo: CHEVETTE
Litros: 1.4L
VIN: I
Año: 76-77

330 Lexington Drive * Buffalo Grove, IL 60089-6933 (USA) * 847-541-6550 * Telefax 847-541-5808
Llame gratis a la línea Técnica (1-888-326-2372) solo USA

General

| | |
|---|---|
| Fabricante | GM |
| Modelo/Año | CHEVETTE / 76-77 |
| L/CID/VIN | 1.4 / 85 / I |
| # de Cilindros | L 4 |
| Diámetro & Carrera | 3.228" (81.991 MM) X 2.606" (66.192 MM) |
| Ralac Compresión | 145 PSI, 8.5:1 |
| Orden Encendido | 1-3-4-2 |
| Comentario | 1BC, CHEVETTE |
| # de la Forja del | |



| FABRICANTE | MODELO | LITROS | AÑO | CIL | VIN CODIGO | CID | # MODELO MOTOR |
|---|---|---|---|---|---|---|---|
| GM | CHEVETTE | 1.4 | 76-77 | L 4 | I | 85 | |

Comentar: 1BC, CHEVETTE
División: CHEVROLET

● Datos de AERA ○ Personalizados

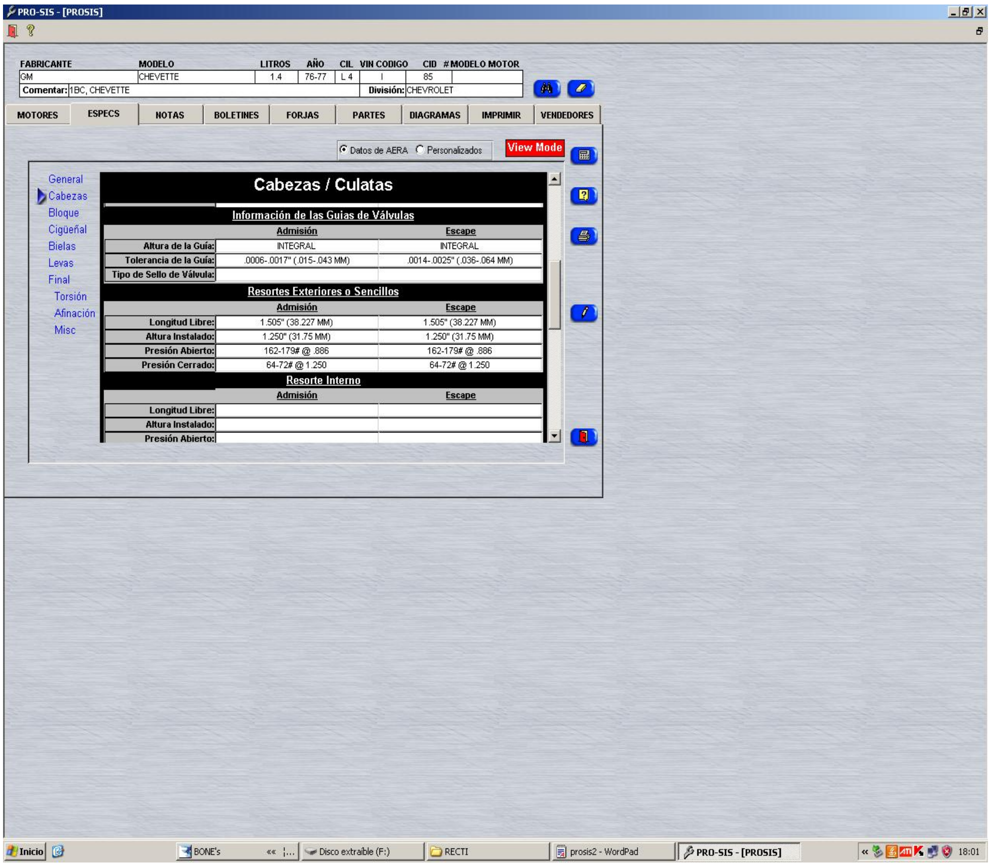
Cabezas / Culatas

Información de la Forja

| | |
|---|---|
| Espesor de Cabeza Nueva: | |
| Espesor Mínimo: | |
| Medida de la Deformación: | |
| Volumen de la Cámara (cc): | |
| Acabado de la Superficie: | |
| Dia de Alojm de Arbol en la Cabz: | |
| Protuberanc punta inyect: | |
| Dia del Alojamien del Buzo: | |

Información de la Válvula

| | Admisión | Escape |
|---|---|---|
| Altura del Vástago Instal: | 1.3900-1.4200" (35.306-36.068 MM) | 1.3900-1.4200" (35.306-36.068 MM) |
| Diámetro del Vástago: | .3139-.3144" (7.973-7.986 MM) | .3130-.3136" (7.95-7.965 MM) |
| Largo Total: | 3.870-3.888" (98.298-98.755 MM) | 3.886-3.906" (98.704-99.212 MM) |
| Diámetro de la Cabeza: | | |
| Angulo: | 45° | 45° |



| FABRICANTE | MODELO | LITROS | AÑO | CIL | VIN CODIGO | CID | # MODELO MOTOR |
|---|---|---|---|---|---|---|---|
| GM | CHEVETTE | 1.4 | 76-77 | L 4 | I | 85 | |

**Comentar:** 1BC, CHEVETTE **División:** CHEVROLET

● Datos de AERA ○ Personalizados

**Cabezas / Culatas**

**Información de las Guias de Válvulas**

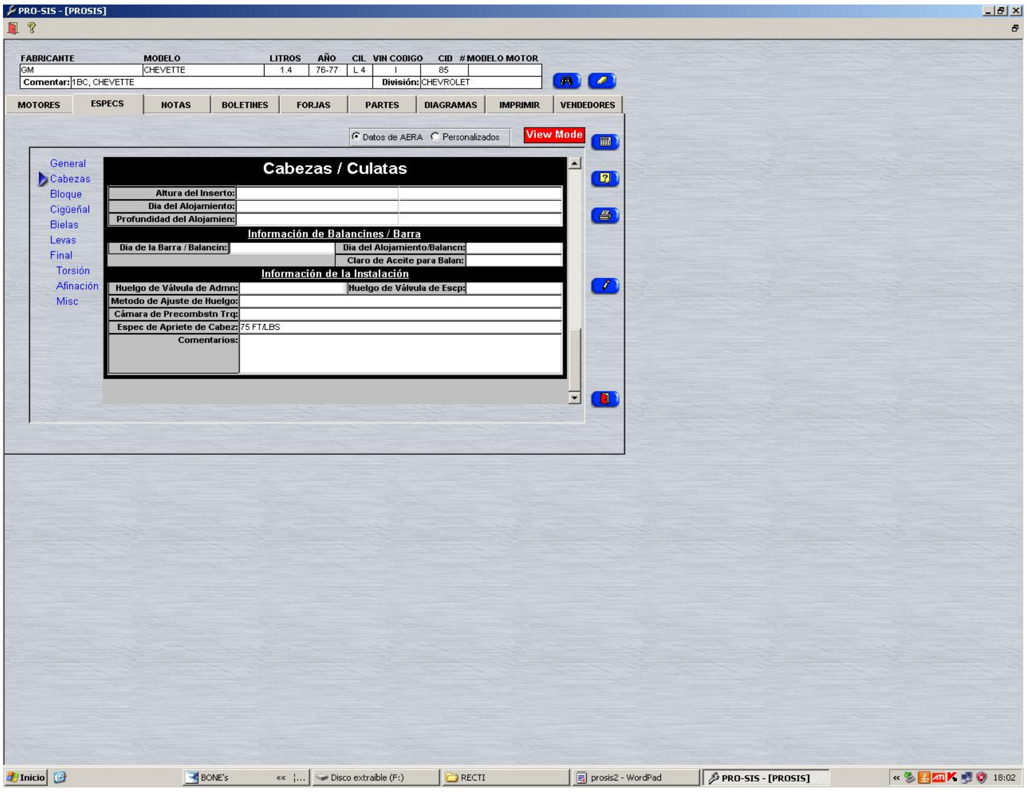
| | Admisión | Escape |
|---|---|---|
| Altura de la Guía: | INTEGRAL | INTEGRAL |
| Tolerancia de la Guía: | .0006-.0017" (.015-.043 MM) | .0014-.0025" (.036-.064 MM) |
| Tipo de Sello de Válvula: | | |

**Resortes Exteriores o Sencillos**

| | Admisión | Escape |
|---|---|---|
| Longitud Libre: | 1.505" (38.227 MM) | 1.505" (38.227 MM) |
| Altura Instalado: | 1.250" (31.75 MM) | 1.250" (31.75 MM) |
| Presión Abierto: | 162-179# @ .886 | 162-179# @ .886 |
| Presión Cerrado: | 64-72# @ 1.250 | 64-72# @ 1.250 |

**Resorte Interno**

| | Admisión | Escape |
|---|---|---|
| Longitud Libre: | | |
| Altura Instalado: | | |
| Presión Abierto: | | |



| FABRICANTE | MODELO | LITROS | AÑO | CIL | VIN CODIGO | CID | # MODELO MOTOR |
|---|---|---|---|---|---|---|---|
| GM | CHEVETTE | 1.4 | 76-77 | L 4 | I | 85 | |

**Comentar:** 1BC, CHEVETTE **División:** CHEVROLET

● Datos de AERA ○ Personalizados

**Cabezas / Culatas**

| | | |
|---|---|---|
| Altura del Inserto: | | |
| Dia del Alojamiento: | | |
| Profundidad del Alojamien: | | |

**Información de Balancines / Barra**

Dia de la Barra / Balancin:

Dia del Alojamiento/Balancn:

Claro de Aceite para Balan:

**Información de la Instalación**

Huelgo de Válvula de Admn:

Huelgo de Válvula de Escp:

Metodo de Ajuste de Huelgo:

Cámara de Precombstn Trq:

Espec de Apriete de Cabez: 75 FT/LBS

Comentarios:

FIGURA No 30 PRO-SIS

Fuente: Talleres Rectificadora Pazmiño S.A

## 2.4.2 FUNDAMENTACIÓN CIENTÍFICA DE LA VARIABLE INDEPENDIENTE.

### 2.4.2.1 ADMINISTRACIÓN

Es la ciencia social, que establece los principios y los procesos por medio de los cuales se alcanza el grado de eficacia y se planifica, organiza, dirige y controla todos los recursos disponibles (físicos, humanos, financieros, etc.) que posee la empresa para lograr sus metas. [1, 12]

### 2.4.2.2 PRODUCCIÓN

Es aquella que formula y desarrolla los métodos más adecuados para la elaboración de los productos al suministrar y coordinar la mano de obra, equipo, instalaciones, materiales y herramientas requeridos. [1]

### 2.4.2.3 CONTROL

Consiste en verificar si todo ocurre de conformidad con las normas adoptadas, con las instrucciones emitidas y con los principios establecidos. [1]

### 2.4.2.4 TIPOS DE CONTROL

Control preliminar, este tipo de control tiene lugar antes de que principien las operaciones e incluye la creación de políticas, procedimientos y reglas diseñadas para asegurar que las actividades planeadas serán ejecutadas con propiedad. En vez de esperar los resultados y compararlos con los objetivos es posible ejercer una influencia controladora limitando las actividades por adelantado. Control concurrente, este tipo de control tiene lugar durante la fase de la acción de ejecutar los planes e incluye la dirección, vigilancia y sincronización de las actividades según ocurran, en otras palabras, pueden ayudar a garantizar que el plan será llevado a cabo en el tiempo específico y bajo las condiciones requeridas.

Control de retroalimentación, este tipo de control se enfoca sobre el uso de la información de los resultados anteriores para corregir posibles desviaciones futuras de estándar aceptable. [1]

### 2.4.2.5 ÁREAS DE DESEMPEÑO DEL CONTROL

Área comercial: Es el área de la empresa que se encarga de vender o comercializar los productos o servicios producidos.

- Control de ventas: Acompaña el volumen diario, semanal, mensual y anula de las ventas de la empresa por cliente, vendedor, región, producto o servicio, con el fin de señalar fallas o distorsiones en relación con las previsiones.
- Áreas de producción: Si la empresa es industrial, el área de producción es aquella donde se fabrican los productos; si la empresa fuera prestadora de servicios, el área de producción es aquella donde se prestan los servicios; los principales controles existentes en el área de producción.
- Control de producción: El objetivo fundamental de este control es programar, coordinar e implantar todas las medidas tendientes a lograr un optima rendimiento en las unidades producidas, e indicar el modo, tiempo y lugar más idóneos para lograr las metas de producción, cumpliendo así con todas las necesidades del departamento de ventas.
- Control de costos: Verificar continuamente los costos de producción, ya sea de materia prima o de mano de obra.
- Control de los tiempos de producción: Por operario o por maquinaria; para eliminar desperdicios de tiempo o esperas innecesarias aplicando los estudios de tiempos y movimientos.
- Control de inventarios: De materias primas, partes y herramientas, productos, tanto subensamblados como terminados, entre otros.
- Control de operaciones Productivos: Fijación de rutas, programas y abastecimientos, entre otros.
- Control de desperdicios: Se refiere la fijación de sus mínimos tolerables y deseables.

- Control de mantenimiento y conservación: Tiempos de máquinas paradas, costos, entre otros.
- Control de calidad: Corregir cualquier desvío de los estándares de calidad de los productos o servicios, en cada sección (control de rechazos, inspecciones, entre otros). [1]

### 2.4.2.6 CALIDAD

Conjunto de propiedades y características de un producto, proceso o servicio que le confieren su aptitud para satisfacer las necesidades establecidas o implícitas. [1]

### 2.4.2.7 TIPOS DE CALIDAD

Calidad externa, que corresponde a la satisfacción de los clientes. El logro de la calidad externa requiere proporcionar productos o servicios que satisfagan las expectativas del cliente para establecer lealtad con el cliente y de ese modo mejorar la participación en el mercado. Los beneficiarios de la calidad externa son los clientes y los socios externos de una compañía. [1]

Por lo tanto, este tipo de procedimientos requiere escuchar a los clientes y también debe permitir que se consideren las necesidades implícitas que los clientes no expresan.

- Calidad interna, que corresponde al mejoramiento de la operación interna de una compañía. El propósito de la calidad interna es implementar los medios para permitir la mejor descripción posible de la organización y detectar y limitar los funcionamientos incorrectos. Los beneficiarios de la calidad interna son la administración y los empleados de la compañía.
- La calidad interna pasa generalmente por una etapa participativa en la que se identifican y formalizan los procesos internos.
- Calidad en el producto Para obtener productos y servicios de calidad, debemos asegurar su calidad desde el momento de su diseño. Un producto o servicio de calidad es el que satisface las necesidades del cliente. [1]

Para evaluar la calidad de un producto se puede contar con estos indicadores:

- La calidad a la Tensión,
- La calidad de Dureza
- La calidad a la Flexión

#### 2.4.2.8 OBJETIVO DE LA CALIDAD

Es proporcionarle al cliente una oferta apropiada con procesos controlados y al mismo tiempo garantizar que esta mejora no se traduzca en costos adicionales. Es posible mejorar un gran número de problemas a un bajo costo. Sin embargo, cuanta más cerca se está de la perfección, más se elevan los costos. [1]

#### 2.4.2.9 ASEGURAMIENTO O GARANTÍA DE CALIDAD:

Todas aquellas acciones planificadas y sistemáticas que proporcionan una confianza adecuada en que un producto o servicio cumpla determinados requisitos de calidad. [1]

#### 2.4.2.10 CONTROL DE CALIDAD

Es el proceso de regulación a través del cual se puede medir la calidad real, compararla con las normas o las especificaciones y actuar sobre la diferencia. [1,13]

#### 2.4.2.11 FUNCIÓN DEL CONTROL DE CALIDAD

Es primordialmente una organización de servicio, para conocer las especificaciones establecidas por la ingeniería del producto y proporcionar asistencia al departamento de fabricación, para que la producción alcance estas especificaciones. Como tal, la función consiste en la colección y análisis de grandes cantidades de datos que después se presentan a diferentes departamentos para iniciar una acción correctiva adecuada. [1,13]

### 2.4.2.12 IMPORTANCIA DEL CONTROL DE CALIDAD

La calidad de un producto se puede ver desde dos enfoques tradicionales que son: Perceptiva: Satisfacción de las necesidades del cliente, Funcional: Cumplir con las especificaciones requeridas.

La mayoría de los tratadistas manejan más esta última, ya que es más objetiva y fácil de determinar; esto permite a las empresas implantar un sistema de calidad, que no es otra cosa que una estructura organizativa de responsabilidades en los procesos. Para implantar un sistema se tiene que establecer la misión empresarial, visión y valores de la empresa, así como sus políticas de calidad de la misma. [1,13]

### 2.4.2.13 MANUAL DE CALIDAD

Especifica la política de calidad de la empresa y la organización necesaria para conseguir los objetivos de aseguramiento de la calidad de una forma similar en toda la empresa. En él se describen la política de calidad de la empresa, la estructura organizacional, la misión de todo elemento involucrado en el logro de la Calidad, etc. El fin del mismo se puede resumir en varios puntos: [1]

- Única referencia oficial.
- Unifica comportamientos decisionales y operativos.
- Clasifica la estructura de responsabilidades.
- Independiza el resultado de las actividades de la habilidad.
- Es un instrumento para la Formación y la Planificación de la Calidad.
- Es la base de referencia para auditar el Sistema de Calidad.

## 2.5 HIPÓTESIS

Al poseer una guía de apoyo en el proceso de metalizado de cigüeñales de motores a gasolina con la máquina metalizadora TAFA modelo 8830 en la Rectificadora Pazmiño S.A, se determinará la calidad real del producto terminado.

## 2.6 SEÑALAMIENTO DE LAS VARIABLES DE LA HIPÓTESIS

| | |
|---|---|
| **Variable independiente:** | Proceso de metalización de cigüeñales de motores a gasolina |
| **Variable dependiente:** | Calidad del producto. |
| **Término de Relación:** | Para determinar |

# CAPITULO III

# METODOLOGÍA

## 3.1 ENFOQUE

En la presente investigación a pesar de ser netamente de campo, predominará lo cuantitativo, por que se utilizan valores numéricos que permitirán realizar las mediaciones y representaciones gráficas de nuestro estudio, con el fin de poder valorar el trabajo a realizar dentro de la institución en el proceso de recuperación de cigüeñales de motores a gasolina con la máquina metalizadora TAFA 8830 que es donde ocurre el problema; así los datos son recogidos de fuentes primarias acorde a los objetivos de la investigación con la finalidad de tener un conocimiento más profundo acerca de la realidad tomando en cuenta que el trabajo depende directamente del daño y lo que el dueño desea.

## 3.2 MODALIDAD BÁSICA DE LA INVESTIGACIÓN

Por la razón de contar con un fundamento científico en el desarrollo del trabajo investigativo sobre el procedimiento de la ejecución, aplicación y del análisis de proceso de metalizado de cigüeñales con la máquina metalizadora TAFA 88 30, es notorio que estará involucrada la modalidad de investigación documental bibliográfica. Estando relaciona por lo tanto toda la bibliografía que corresponda a materiales, ensayos destructivos y técnica de soldadura.

Obviamente que con la finalidad de desarrollar el análisis de identificación del termorociado con la máquina metalizadora TAFA 88 30, y como esta entrega el producto se debe identificar si a un existen fisuras, aparición de líneas visibles de discontinuidad de acuerdo a la eficiencia del termorociado dado según la distancia del disparo, y como esta debe ser desarrollada en el lugar de trabajo se aplicara la modalidad de campo.

## 3.3 TIPO DE INVESTIGACIÓN

Debido a lo expuesto en la modalidad del trabajo de investigación que es en el lugar de trabajo y las diferentes realidades que el mismo puede llegar a tener nos debemos relacionar las variables con el único fin de poder cumplir con los objetivos de la investigación determinamos que el tipo investigación es crítica propositiva. De este modo, a través de este tipo de investigación se busca determinar la relación que existe entre las causas y efectos del problema en el proceso de recuperación de cigüeñales de motores a gasolina con la máquina metalizadora TAFA 8830 que es donde ocurre el problema; además se puede decir que existe una combinación de métodos debido a que el estudio del fenómeno se efectúa desde lo general a lo especifico y viceversa con el objetivo de detectar los factores que determinan ciertos comportamientos.

Teniendo como soporte la investigación bibliográfica que en el presente trabajo se emplea principalmente para fundamentar el marco teórico y brindarle un mayor soporte a lo investigado con diferentes enfoques, conceptualizaciones, ideas de varios autores y documentos de la empresa, con el objetivo de abordar la temática desde todo punto de vista bibliográfico y mantener un soporte más técnico, fundamentar mi trabajo práctico, siempre respetando normas tanto de la técnica como de seguridad.

## 3.4 POBLACIÓN Y MUESTRA

La Rectificadora Pazmiño, es una empresa seria que brinda su servicio a todo tipo de vehículo lo cual genera un tamaño infinito de población a razón del tipo, marca, año y procedencia de los mismos, para constituir mi universo de estudio debí considerar que el cigüeñal a ser estudiado debía ser destruido, razón por la cual la empresa me facilito un cigüeñal de motor a gasolina el cual cumplía los requisitos para el proceso de metalización. Pasando este a ser el universo y a la vez el tamaño de mí muestra. Siendo el total del universo el que tiene la misma capacidad de ser muestra para realizar mi trabajo de investigación.

## 3.5 OPERACIONALIZACIÓN DE VARIABLES

**VARIABLE INDEPENDIENTE:** Proceso de metalización de cigüeñales de motores a gasolina

| CONCEPTUALIZACIÓN | CATEGORÍAS | INDICADORES | ÍTEMS | **INSTRUMENTO** |
|---|---|---|---|---|
| Es la recuperación de sus medidas o tolerancias mediante la aplicación de un recubrimiento de material similar o parecido al original, con el fin de devolverle utilidad. | Tracción<br>Flexión<br>Dureza<br>Metalográfico | La máquina de prueba universal<br>Prensa<br>Durómetro<br>Microscopio | Comparación de Valores de referencia con los obtenidos | Guía del proceso de metalización |

TABLA No. 6

**VARIABLE DEPENDIENTE:** Calidad del producto.

| CONCEPTUALIZACIÓN | CATEGORÍAS | INDICADORES | ÍTEMS | **INSTRUMENTO** |
|---|---|---|---|---|
| Todas aquellas acciones planificadas y sistemáticas que proporcionan una confianza adecuada en que un producto o servicio cumpla determinados requisitos de calidad. | Normas internas de control de Calidad | Revisión al ingreso del cigüeñal<br>Comprobación del trabajo realizado | Comparación de tolerancias y ajustes | Programa PROSIS |

TABLA No. 7

## 3.6 PLAN DE RECOLECCIÓN DE INFORMACIÓN

El plan de recolección de la información es el siguiente:

- Se determinará los sujetos de investigación, en este caso el cigüeñal de motor a gasolina.
- Se elaborará una ficha de control independiente con el fin de poder compararla con la hoja de trabajo existente, tomado en cuenta la operacionalización de las variables de la Hipótesis, las cuales se demostraran al realizar los trabajos de ensayos.

## 3.7 PLAN DE PROCESAMIENTO DE LA INFORMACIÓN

Para entregar una información óptima para la investigación se siguió:

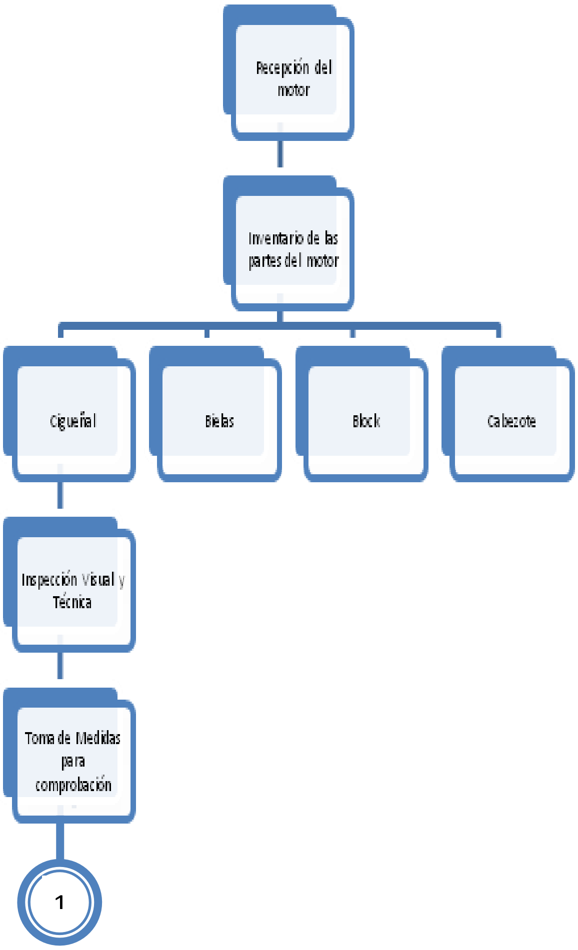
- Se compara y limpia la información recabada
- Se divide codifica la información
- Se confronta proceso ensayo
- Se representa gráficamente los resultados
- Elabora una síntesis general de los resultados.
- Desarrollaremos las conclusiones y recomendaciones generales
- Elaborará una propuesta de solución al problema investigado

# CAPITULO IV

# ANÁLISIS E INTERPRETACIÓN DE RESULTADOS

## 4.1 PROCESO DE DE ANÁLISIS DE RESULTADOS

En el campo cotidiano de desarrollo de trabajo en la empresa RECTIFICADORA PAZMIÑO S.A se ha evaluado como el mejor método de determinación para la aplicación del proceso de termorociado el siguiente basado este diagrama.



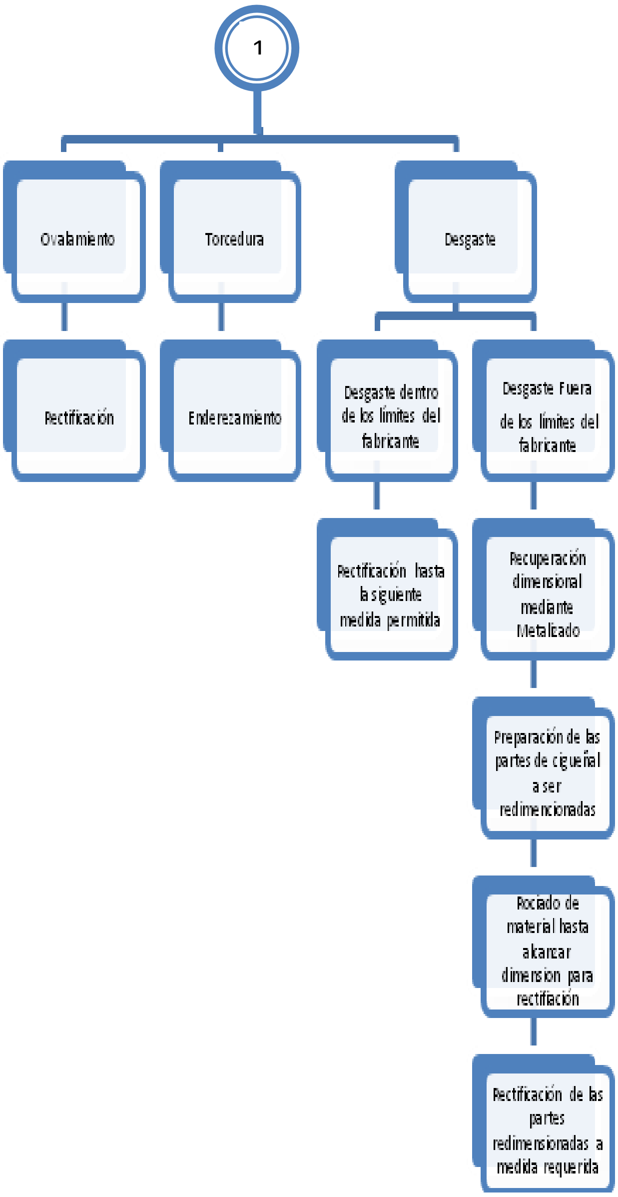
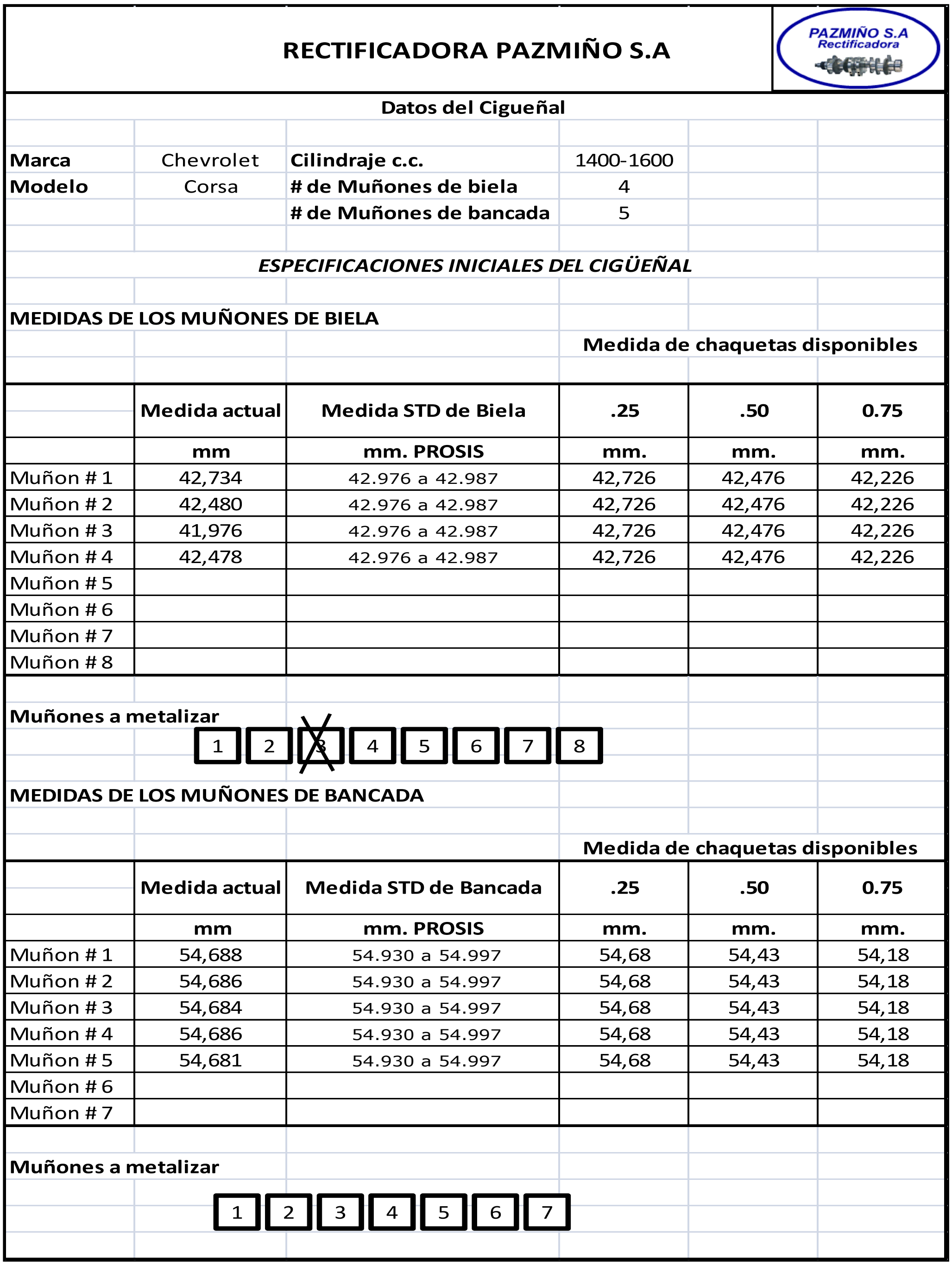


GRÁFICO No. 3 Descripción del Proceso de Metalización

## 4.2 ANÁLISIS DE RESULTADOS

Con el propósito de tener un mejor manejo y control del proceso de metalizado que se lleva a cabo en la empresa RECTIFICADORA PAZMIÑO S.A. se propuso la siguiente hoja de control como anexo en el momento que se determina la utilización del proceso de metalizado. Es necesario indicar que todos los trabajos de metalización se realizan bajo las siguientes medidas primero en una cámara de metalización, a temperatura, presión y flujo de aire en condiciones ambientales normales, las cuales son recomendaciones de la empresa **SAGER ECUADOR S.A.,** que es el distribuidor autorizado en Ecuador de TAFA.



**RECTIFICADORA PAZMIÑO S.A**

**Datos del Cigueñal**

| | | | |
|---|---|---|---|
| **Marca** | Chevrolet | **Cilindraje c.c.** | 1400-1600 |
| **Modelo** | Corsa | **# de Muñones de biela** | 4 |
| | | **# de Muñones de bancada** | 5 |

***ESPECIFICACIONES INICIALES DEL CIGÜEÑAL***

**MEDIDAS DE LOS MUÑONES DE BIELA**

**Medida de chaquetas disponibles**

| | **Medida actual** | **Medida STD de Biela** | **.25** | **.50** | **0.75** |
|---|---|---|---|---|---|
| | **mm** | **mm. PROSIS** | **mm.** | **mm.** | **mm.** |
| Muñon # 1 | 42,734 | 42.976 a 42.987 | 42,726 | 42,476 | 42,226 |
| Muñon # 2 | 42,480 | 42.976 a 42.987 | 42,726 | 42,476 | 42,226 |
| Muñon # 3 | 41,976 | 42.976 a 42.987 | 42,726 | 42,476 | 42,226 |
| Muñon # 4 | 42,478 | 42.976 a 42.987 | 42,726 | 42,476 | 42,226 |
| Muñon # 5 | | | | | |
| Muñon # 6 | | | | | |
| Muñon # 7 | | | | | |
| Muñon # 8 | | | | | |

**Muñones a metalizar**

1 2 ~~3~~ 4 5 6 7 8

**MEDIDAS DE LOS MUÑONES DE BANCADA**

**Medida de chaquetas disponibles**

| | **Medida actual** | **Medida STD de Bancada** | **.25** | **.50** | **0.75** |
|---|---|---|---|---|---|
| | **mm** | **mm. PROSIS** | **mm.** | **mm.** | **mm.** |
| Muñon # 1 | 54,688 | 54.930 a 54.997 | 54,68 | 54,43 | 54,18 |
| Muñon # 2 | 54,686 | 54.930 a 54.997 | 54,68 | 54,43 | 54,18 |
| Muñon # 3 | 54,684 | 54.930 a 54.997 | 54,68 | 54,43 | 54,18 |
| Muñon # 4 | 54,686 | 54.930 a 54.997 | 54,68 | 54,43 | 54,18 |
| Muñon # 5 | 54,681 | 54.930 a 54.997 | 54,68 | 54,43 | 54,18 |
| Muñon # 6 | | | | | |
| Muñon # 7 | | | | | |

**Muñones a metalizar**

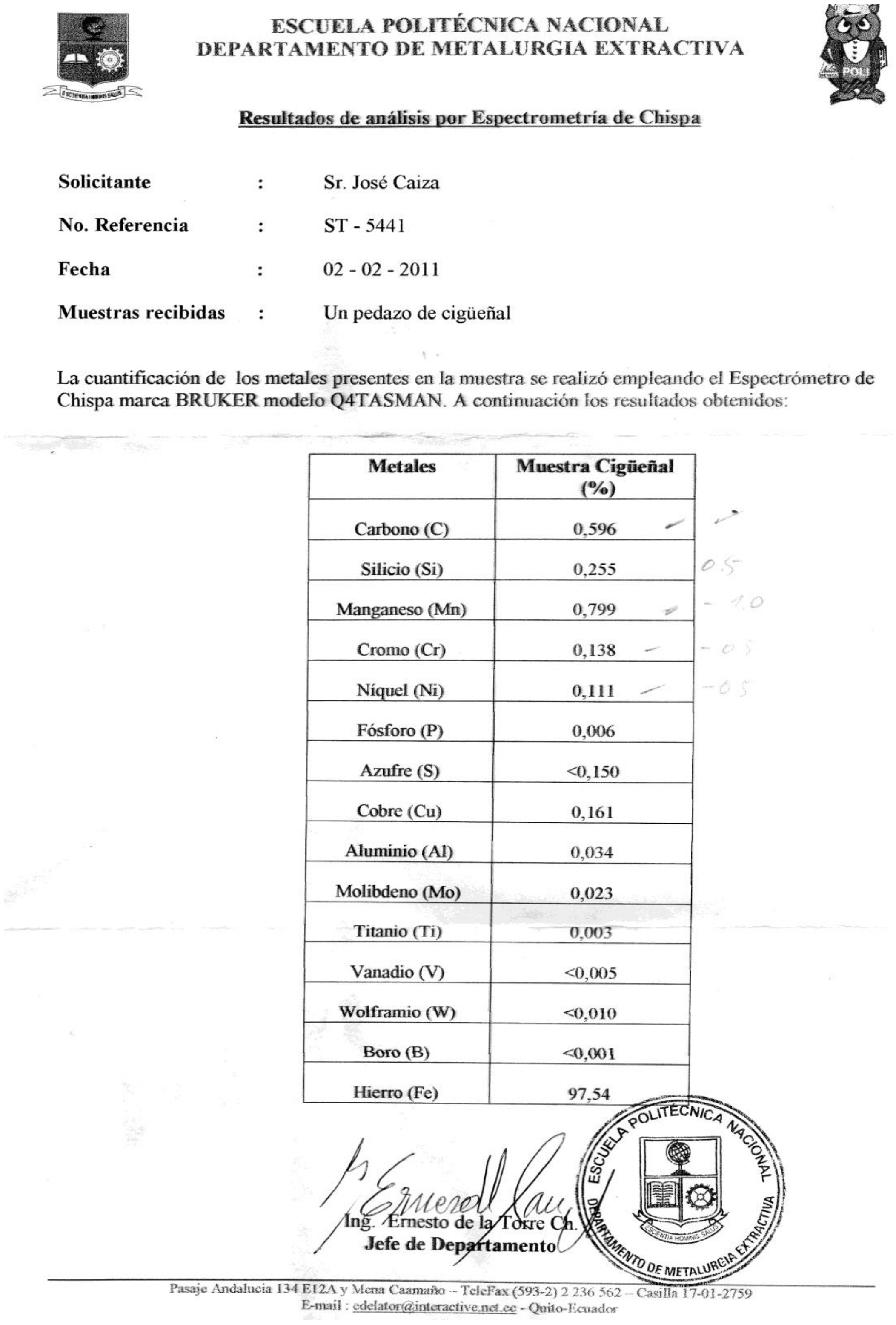
1 2 3 4 5 6 7

FIGURA No. 31 Hoja de Trabajo

Fuente: Talleres Rectificadora Pazmiño S.A

Como los ensayos destructivos en un cigüeñal metalizado no pueden ser realizados directamente sobre un cigüeñal se procedió a realizar los siguientes estudios para poder realizar los ensayos sobre probetas bajo estándares normalizados las pruebas se realizaron de la siguiente manera para obtener resultados que permitan desarrollar el presente trabajo.

### 4.2.1 CUANTIFICACIÓN DE METALES EN MUESTRA DE CIGÜEÑAL



**ESCUELA POLITÉCNICA NACIONAL**
**DEPARTAMENTO DE METALURGIA EXTRACTIVA**

**Resultados de análisis por Espectrometría de Chispa**

**Solicitante** : Sr. José Caiza
**No. Referencia** : ST - 5441
**Fecha** : 02 - 02 - 2011
**Muestras recibidas** : Un pedazo de cigüeñal

La cuantificación de los metales presentes en la muestra se realizó empleando el Espectrómetro de Chispa marca BRUKER modelo Q4TASMAN. A continuación los resultados obtenidos:

| Metales | Muestra Cigüeñal (%) | |
|---|---|---|
| Carbono (C) | 0,596 | |
| Silicio (Si) | 0,255 | 0.5 |
| Manganeso (Mn) | 0,799 | - 1.0 |
| Cromo (Cr) | 0,138 | - 0.5 |
| Níquel (Ni) | 0,111 | - 0.5 |
| Fósforo (P) | 0,006 | |
| Azufre (S) | <0,150 | |
| Cobre (Cu) | 0,161 | |
| Aluminio (Al) | 0,034 | |
| Molibdeno (Mo) | 0,023 | |
| Titanio (Ti) | 0,003 | |
| Vanadio (V) | <0,005 | |
| Wolframio (W) | <0,010 | |
| Boro (B) | <0,001 | |
| Hierro (Fe) | 97,54 | |

Ing. Ernesto de la Torre Ch.
**Jefe de Departamento**

Pasaje Andalucia 134 E12A y Mena Caamaño -- TeleFax (593-2) 2 236 562 -- Casilla 17-01-2759
E-mail : edelator@interactive.net.ec - Quito-Ecuador

Con los resultados obtenidos del ensayo de cuantificación de metales mediante el espectrómetro de chispa se evaluó las tablas de composición química de los aceros y el resultado arrojado es el siguiente.

| **Designación AISI** | **C** | | | **Mn** | | | **P (max)** | **S (max)** |
|---|---|---|---|---|---|---|---|---|
| **NO RESULFURIZADOS**<br>**MÁXIMO DE MANGANESO: 1,00 %** | | | | | | | | |
| 1005 | 0,06 | | max | 0,35 | | max | 0,040 | 0,050 |
| 1006 | 0,08 | | max | 0,25 | - | 0,40 | 0,040 | 0,050 |
| 1008 | 0,10 | | max | 0,30 | - | 0,50 | 0,040 | 0,050 |
| 1010 | 0,08 | - | 0,13 | 0,30 | - | 0,60 | 0,040 | 0,050 |
| 1012 | 0,10 | - | 0,15 | 0,30 | - | 0,60 | 0,040 | 0,050 |
| 1015 | 0,13 | - | 0,18 | 0,30 | - | 0,60 | 0,040 | 0,050 |
| 1016 | 0,13 | - | 0,18 | 0,60 | - | 0,90 | 0,040 | 0,050 |
| 1017 | 0,15 | - | 0,20 | 0,30 | - | 0,60 | 0,040 | 0,050 |
| 1018 | 0,15 | - | 0,20 | 0,60 | - | 0,90 | 0,040 | 0,050 |
| 1019 | 0,15 | - | 0,20 | 0,70 | - | 1,00 | 0,040 | 0,050 |
| 1020 | 0,18 | - | 0,23 | 0,30 | - | 0,60 | 0,040 | 0,050 |
| 1021 | 0,18 | - | 0,23 | 0,60 | - | 0,90 | 0,040 | 0,050 |
| 1022 | 0,18 | - | 0,23 | 0,70 | - | 1,00 | 0,040 | 0,050 |
| 1023 | 0,20 | - | 0,25 | 0,30 | - | 0,60 | 0,040 | 0,050 |
| 1025 | 0,22 | - | 0,28 | 0,30 | - | 0,60 | 0,040 | 0,050 |
| 1026 | 0,22 | - | 0,28 | 0,60 | - | 0,90 | 0,040 | 0,050 |
| 1029 | 0,25 | - | 0,31 | 0,60 | - | 0,90 | 0,040 | 0,050 |
| 1030 | 0,28 | - | 0,34 | 0,60 | - | 0,90 | 0,040 | 0,050 |
| 1035 | 0,32 | - | 0,38 | 0,60 | - | 0,90 | 0,040 | 0,050 |
| 1037 | 0,32 | - | 0,38 | 0,70 | - | 1,00 | 0,040 | 0,050 |
| 1038 | 0,35 | - | 0,42 | 0,60 | - | 0,90 | 0,040 | 0,050 |
| 1039 | 0,37 | - | 0,44 | 0,70 | - | 1,00 | 0,040 | 0,050 |
| 1040 | 0,37 | - | 0,44 | 0,60 | - | 0,90 | 0,040 | 0,050 |
| 1042 | 0,40 | - | 0,47 | 0,60 | - | 0,90 | 0,040 | 0,050 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 1043 | 0,40 | - | 0,47 | 0,70 | - | 1,00 | 0,040 | 0,050 |
| 1044 | 0,43 | - | 0,50 | 0,30 | - | 0,60 | 0,040 | 0,050 |
| 1045 | 0,43 | - | 0,50 | 0,60 | - | 0,90 | 0,040 | 0,050 |
| 1046 | 0,43 | - | 0,50 | 0,70 | - | 1,00 | 0,040 | 0,050 |
| 1049 | 0,46 | - | 0,53 | 0,60 | - | 0,90 | 0,040 | 0,050 |
| 1050 | 0,48 | - | 0,55 | 0,60 | - | 0,90 | 0,040 | 0,050 |
| 1053 | 0,48 | - | 0,55 | 0,70 | - | 1,00 | 0,040 | 0,050 |
| 1055 | 0,50 | - | 0,60 | 0,60 | - | 0,90 | 0,040 | 0,050 |
| 1059 | 0,55 | - | 0,65 | 0,50 | - | 0,80 | 0,040 | 0,050 |
| 1060 | 0,55 | - | 0,65 | 0,60 | - | 0,90 | 0,040 | 0,050 |
| 1064 | 0,60 | - | 0,70 | 0,50 | - | 0,80 | 0,040 | 0,050 |
| 1065 | 0,60 | - | 0,70 | 0,60 | - | 0,90 | 0,040 | 0,050 |
| 1069 | 0,65 | - | 0,75 | 0,40 | - | 0,70 | 0,040 | 0,050 |
| 1070 | 0,65 | - | 0,75 | 0,60 | - | 0,90 | 0,040 | 0,050 |
| 1078 | 0,72 | - | 0,85 | 0,30 | - | 0,60 | 0,040 | 0,050 |
| 1080 | 0,75 | - | 0,88 | 0,60 | - | 0,90 | 0,040 | 0,050 |
| 1084 | 0,80 | - | 0,93 | 0,60 | - | 0,90 | 0,040 | 0,050 |
| 1086 | 0,80 | - | 0,93 | 0,30 | - | 0,50 | 0,040 | 0,050 |
| 1090 | 0,85 | - | 0,98 | 0,60 | - | 0,90 | 0,040 | 0,050 |
| 1095 | 0,90 | - | 1,03 | 0,30 | - | 0,50 | 0,040 | 0,050 |

TABLA No. 8 Designación AISI

FUENTE http://www2.ing.puc.cl/~icm2312/apuntes/materiales/tabla2-2.html

Los componentes químicos del mayor grado de importancia que se asemejan a los resultados obtenidos del ensayo de cuantificación de metales realizado en los laboratorios de extracción de minerales de la universidad politécnica nacional son con el acero AISI 1055, cabe recalcar que el valor del azufre para el tipo de trabajo al cual está sometido este eje de acero sabiendo que los efectos del mismo sobre el acero repercuten directamente sobre su maquinabilidad son de cierta forma depreciables.

Con la obtención de este dato podemos buscar un eje de este tipo de acero para realizar los siguientes ensayos, el acero fue buscado a nivel nacional, como resultado este es un acero de carbono medio q no se distribuye en nuestro país, debido al mercado de disponibilidad de aceros en nuestro país se precedió a buscar un acero cuya composición se asemeja más al de los resultados obtenidos.

Con lo cual determinamos que el acero más aproximado a nuestros requerimientos obtenidos mediante el ensayo de cuantificación de metales es el siguiente 709 ó AISI 4140

IBCA
IVAN BOHMAN C.A.

## 709=AISI 4140
## Acero bonificado para maquinaria

**GENERALIDADES:** 709 es un acero aleado para constrcción de maquinaria,que posee una alta resistente especialmenete en medidas pequeñas y medianas. Como norma, el 709 es suministrado templado y revenido (temple tenaz bonificado), por lo que no se requeriría un tratamineto térmico posterior, a no ser que así lo exija la aplicación y en ese caso, se templaría un aceite para obtener propiedades mecánicas más elevadas.

709 es apropiado para templarse por flama e inducción y susceptible de nitrurar.

**ANÁLISIS TÍPICO %**

| | C | Si | Mn | P | S | Cr | Mo |
|---|---|---|---|---|---|---|---|
| 709 | 0.42 | 0.25 | 0.75 | -- | -- | 1.05 | 0.20 |
| AISI 4140 | 0.38-0.43 | 0.15-0.35 | 0.75-1.00 | <0.035 | <0.040 | 0.80-1.10 | 0.15-0.25 |

**EQUIVALENCIAS**

| | |
|---|---|
| **AISI/SAE** | 4140 |
| **DIN** | 42CrMo4 |
| **W.Nr** | 1.7225 |
| **JIS** | SCM4 |
| **AFNOR** | 42CD4 |

**PROPIEDADES MECÁNICAS EN CONDICIÓN DE SUMINISTRO**

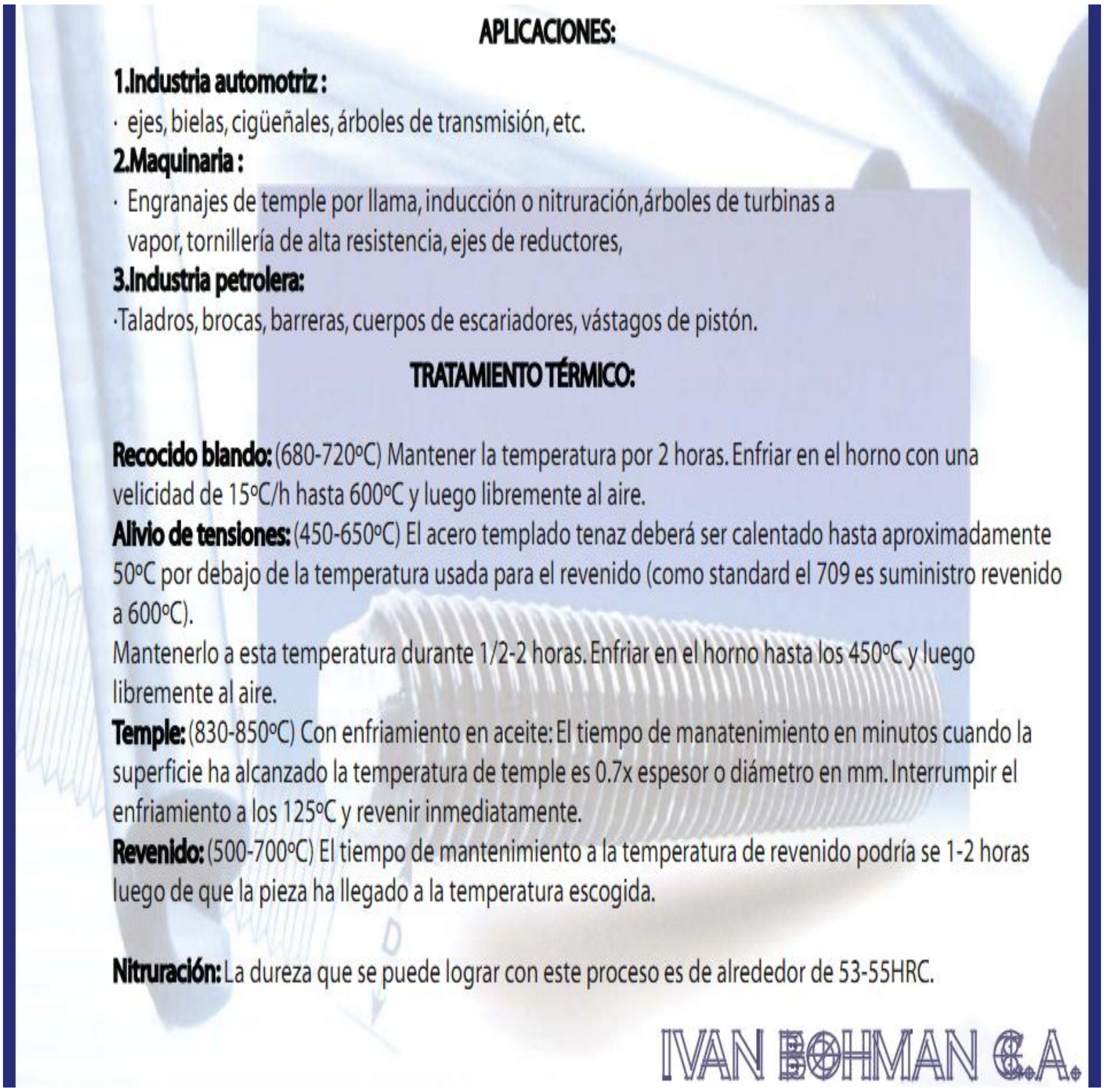
| Resistencia a la Tracción | 90-110kg/mm² |
|---|---|
| Esfuerzo de cedencia | 70kg/mm² |
| Resistencia al impacto,kU | aprox.25 J |
| Elongación, A5 | min12% |
| Reducción de área,Z | min 50% |
| Dureza | 275-320HB |

De acuerdo a DIN 17200 resp. SEW 550. Tolerancia
DIN 1013 resp. DIN 7527 / 6

**Nota:** Esta propiedades mecánicas se garantizan hasta Ø110 mm. Favor consultarmos.

TABLA No.9 Propiedades Fisicoquímicas y Mecánicas del Acero 709

FUENTE http://www.ivanbohman.com.ec/index.html



**APLICACIONES:**

**1.Industria automotriz :**

- ejes, bielas, cigüeñales, árboles de transmisión, etc.

**2.Maquinaria :**

- Engranajes de temple por llama, inducción o nitruración,árboles de turbinas a vapor, tornillería de alta resistencia, ejes de reductores,

**3.Industria petrolera:**

·Taladros, brocas, barreras, cuerpos de escariadores, vástagos de pistón.

**TRATAMIENTO TÉRMICO:**

**Recocido blando:** (680-720ºC) Mantener la temperatura por 2 horas. Enfriar en el horno con una velicidad de 15ºC/h hasta 600ºC y luego libremente al aire.

**Alivio de tensiones:** (450-650ºC) El acero templado tenaz deberá ser calentado hasta aproximadamente 50ºC por debajo de la temperatura usada para el revenido (como standard el 709 es suministro revenido a 600ºC).

Mantenerlo a esta temperatura durante 1/2-2 horas. Enfriar en el horno hasta los 450ºC y luego libremente al aire.

**Temple:** (830-850ºC) Con enfriamiento en aceite: El tiempo de manatenimiento en minutos cuando la superficie ha alcanzado la temperatura de temple es 0.7x espesor o diámetro en mm. Interrumpir el enfriamiento a los 125ºC y revenir inmediatamente.

**Revenido:** (500-700ºC) El tiempo de mantenimiento a la temperatura de revenido podría se 1-2 horas luego de que la pieza ha llegado a la temperatura escogida.

**Nitruración:** La dureza que se puede lograr con este proceso es de alrededor de 53-55HRC.

IVAN BOHMAN C.A.

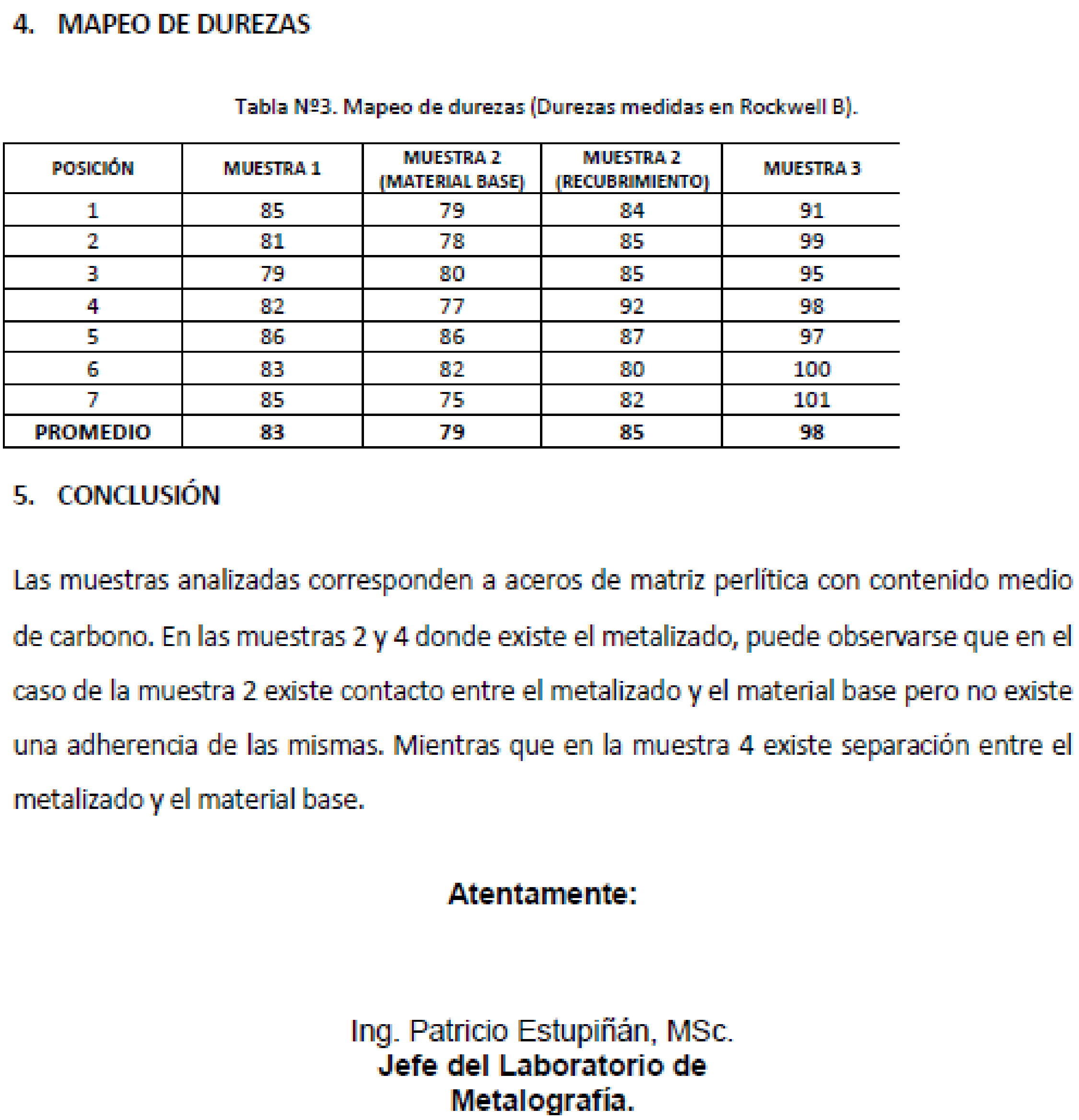
TABLA No.10 Aplicaciones del Acero 709

FUENTE http://www.ivanbohman.com.ec/index.html

Cabe recalcar que el mercado respecto a los aceros en el ecuador es muy reducido por esta razón se selecciono este acero debido que es el más cercano a los resultados obtenidos y que se encuentra en el mercado.

Con la obtención del cual es la composición química de un cigüeñal y la obtención del acero que tenemos disponibilidad en el mercado procedemos a realizar los ensayos siguientes para permitir desarrollando y recolectando todos los datos necesarios para seguir realizando el presente estudio.

## 4.2.2 ENSAYO DE DUREZA



### 4. MAPEO DE DUREZAS

Tabla Nº3. Mapeo de durezas (Durezas medidas en Rockwell B).

| POSICIÓN | MUESTRA 1 | MUESTRA 2 (MATERIAL BASE) | MUESTRA 2 (RECUBRIMIENTO) | MUESTRA 3 |
|---|---|---|---|---|
| 1 | 85 | 79 | 84 | 91 |
| 2 | 81 | 78 | 85 | 99 |
| 3 | 79 | 80 | 85 | 95 |
| 4 | 82 | 77 | 92 | 98 |
| 5 | 86 | 86 | 87 | 97 |
| 6 | 83 | 82 | 80 | 100 |
| 7 | 85 | 75 | 82 | 101 |
| **PROMEDIO** | **83** | **79** | **85** | **98** |

### 5. CONCLUSIÓN

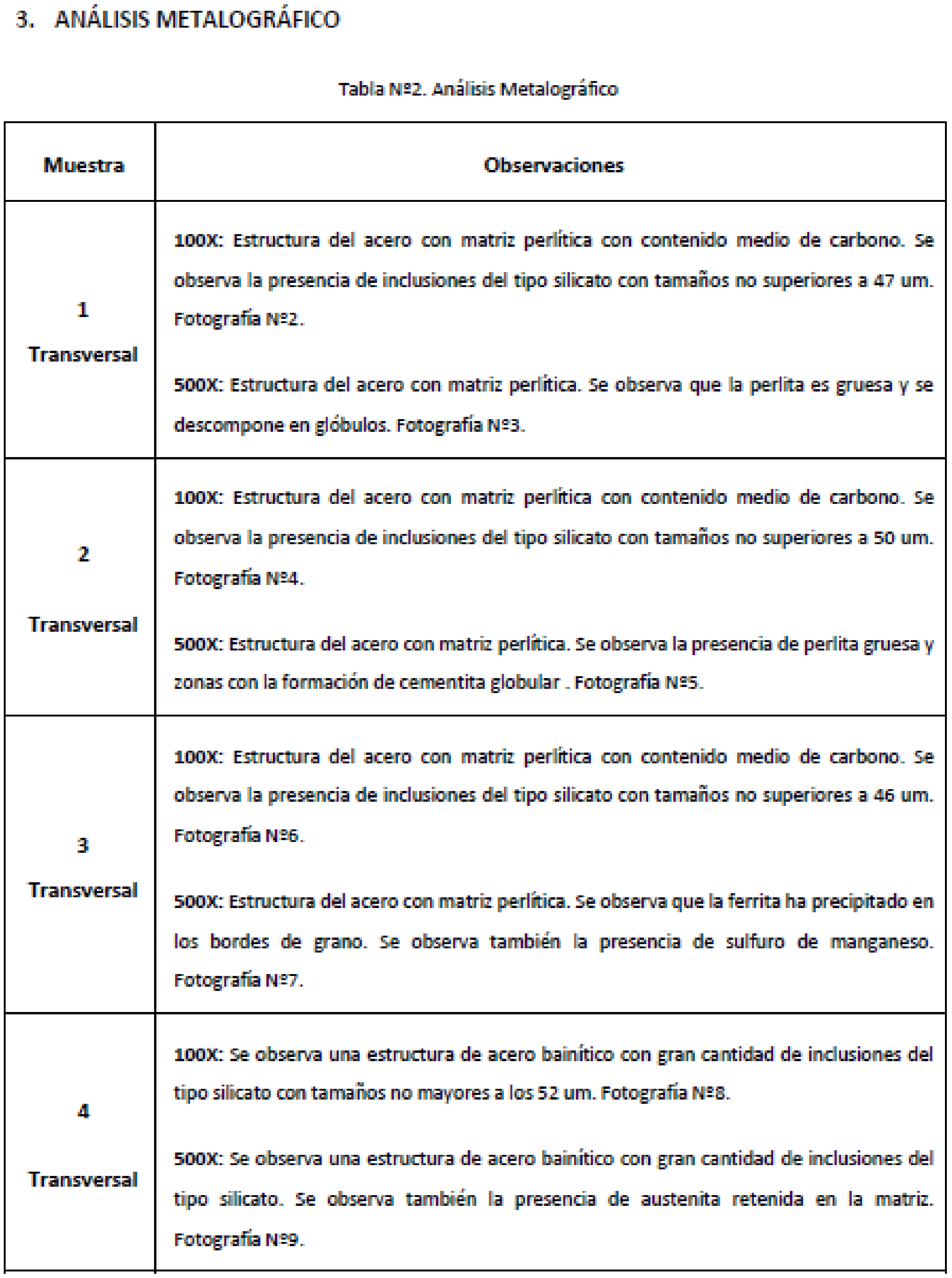
Las muestras analizadas corresponden a aceros de matriz perlítica con contenido medio de carbono. En las muestras 2 y 4 donde existe el metalizado, puede observarse que en el caso de la muestra 2 existe contacto entre el metalizado y el material base pero no existe una adherencia de las mismas. Mientras que en la muestra 4 existe separación entre el metalizado y el material base.

**Atentamente:**

Ing. Patricio Estupiñán, MSc.
**Jefe del Laboratorio de**
**Metalografía.**

La dureza nominal del acero AISI 4140 según tablas es de 275-320 HB, como respalda el informe el resultado de los ensayos de dureza nos arroja un valor de 79 HR – 15N mediante tabla de Shigley (ANEXO 5) de norma ASTM E 140 – 07 (ANEXO 6) realizamos la transformación a unidades HB con lo cual obtenemos un valor de 344 HB lo cual indica que es un acero que esta sobre la dureza nominal de un acero AISI 4140, el valor de la dureza de acero AISI 4140 con el metalizado es de 85 HR – 15N mediante tabla 1 de norma ASTM E 140 – 07 realizamos la transformación a unidades HB con lo cual obtenemos un valor de (464) HB este valor según la norma ASTM E 140 – 07 es un valor fuera de rango para la dureza expresada en la escala Brinell. Con esta comparación tenemos que la dureza del metalizado es un 134 % más duro que el material original.

### 4.2.3 METALOGRAFÍA



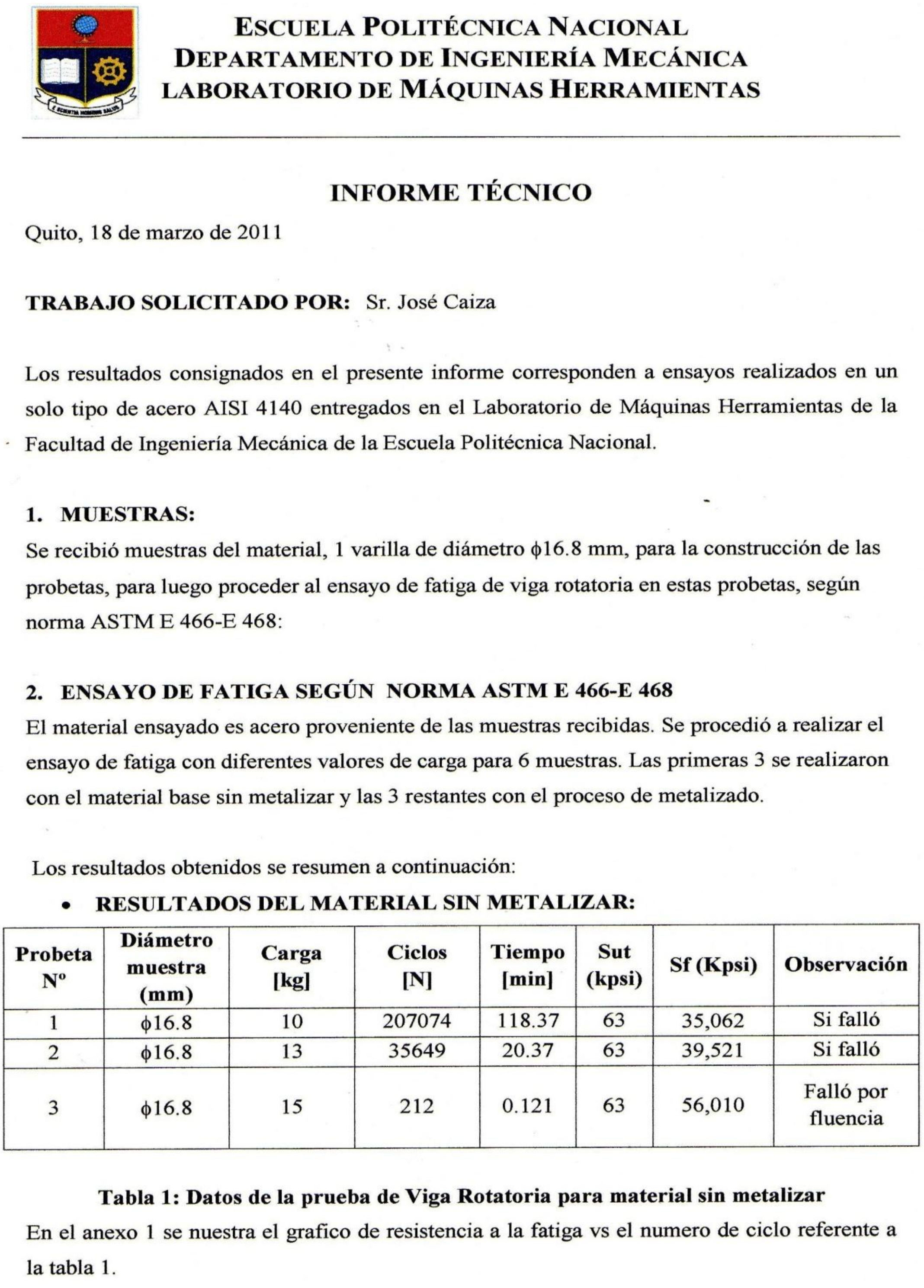
#### 3. ANÁLISIS METALOGRÁFICO

Tabla Nº2. Análisis Metalográfico

| Muestra | Observaciones |
|---|---|
| **1**<br>**Transversal** | **100X:** Estructura del acero con matriz perlítica con contenido medio de carbono. Se observa la presencia de inclusiones del tipo silicato con tamaños no superiores a 47 um. Fotografía Nº2.<br>**500X:** Estructura del acero con matriz perlítica. Se observa que la perlita es gruesa y se descompone en glóbulos. Fotografía Nº3. |
| **2**<br>**Transversal** | **100X:** Estructura del acero con matriz perlítica con contenido medio de carbono. Se observa la presencia de inclusiones del tipo silicato con tamaños no superiores a 50 um. Fotografía Nº4.<br>**500X:** Estructura del acero con matriz perlítica. Se observa la presencia de perlita gruesa y zonas con la formación de cementita globular . Fotografía Nº5. |
| **3**<br>**Transversal** | **100X:** Estructura del acero con matriz perlítica con contenido medio de carbono. Se observa la presencia de inclusiones del tipo silicato con tamaños no superiores a 46 um. Fotografía Nº6.<br>**500X:** Estructura del acero con matriz perlítica. Se observa que la ferrita ha precipitado en los bordes de grano. Se observa también la presencia de sulfuro de manganeso. Fotografía Nº7. |
| **4**<br>**Transversal** | **100X:** Se observa una estructura de acero bainítico con gran cantidad de inclusiones del tipo silicato con tamaños no mayores a los 52 um. Fotografía Nº8.<br>**500X:** Se observa una estructura de acero bainítico con gran cantidad de inclusiones del tipo silicato. Se observa también la presencia de austenita retenida en la matriz. Fotografía Nº9. |

Con los análisis de micro estructura se puedo verificar que la estructura efectivamente corresponde a un acero con matriz perlítica con contenido medio de carbono como lo también se lo demuestra con la cuantificación de metales con el espectrómetro, como se puede observar en las observaciones del informe el cigüeñal y las probetas del acero gozan de las mismas característica de estructura y contenido de carbono.

### 4.2.4 ENSAYOS A FATIGA



**ESCUELA POLITÉCNICA NACIONAL**
**DEPARTAMENTO DE INGENIERÍA MECÁNICA**
**LABORATORIO DE MÁQUINAS HERRAMIENTAS**

## INFORME TÉCNICO

Quito, 18 de marzo de 2011

**TRABAJO SOLICITADO POR:** Sr. José Caiza

Los resultados consignados en el presente informe corresponden a ensayos realizados en un solo tipo de acero AISI 4140 entregados en el Laboratorio de Máquinas Herramientas de la Facultad de Ingeniería Mecánica de la Escuela Politécnica Nacional.

**1. MUESTRAS:**

Se recibió muestras del material, 1 varilla de diámetro ϕ16.8 mm, para la construcción de las probetas, para luego proceder al ensayo de fatiga de viga rotatoria en estas probetas, según norma ASTM E 466-E 468:

**2. ENSAYO DE FATIGA SEGÚN NORMA ASTM E 466-E 468**

El material ensayado es acero proveniente de las muestras recibidas. Se procedió a realizar el ensayo de fatiga con diferentes valores de carga para 6 muestras. Las primeras 3 se realizaron con el material base sin metalizar y las 3 restantes con el proceso de metalizado.

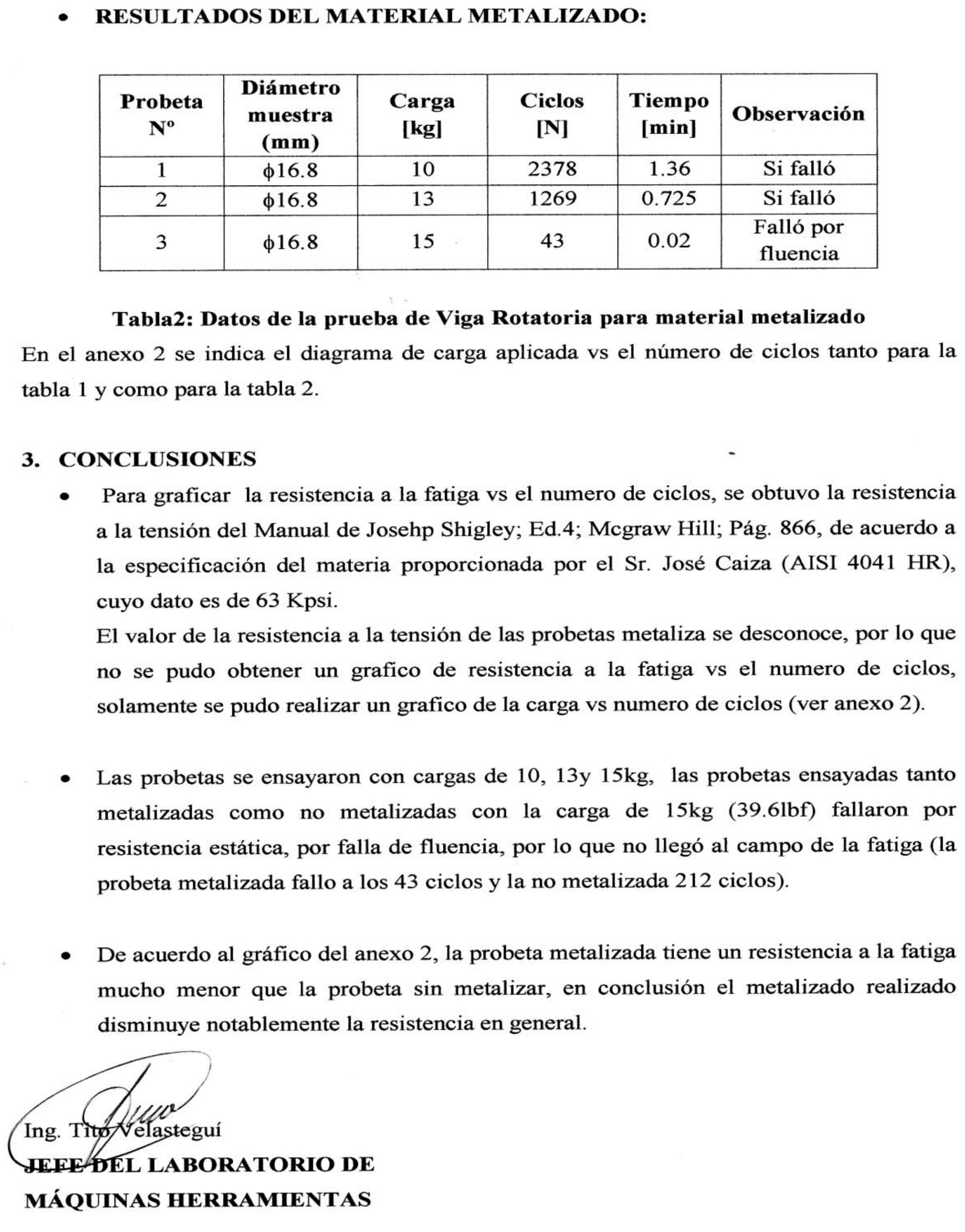
Los resultados obtenidos se resumen a continuación:

- **RESULTADOS DEL MATERIAL SIN METALIZAR:**

| Probeta Nº | Diámetro muestra (mm) | Carga [kg] | Ciclos [N] | Tiempo [min] | Sut (kpsi) | Sf (Kpsi) | Observación |
|---|---|---|---|---|---|---|---|
| 1 | ϕ16.8 | 10 | 207074 | 118.37 | 63 | 35,062 | Si falló |
| 2 | ϕ16.8 | 13 | 35649 | 20.37 | 63 | 39,521 | Si falló |
| 3 | ϕ16.8 | 15 | 212 | 0.121 | 63 | 56,010 | Falló por fluencia |

**Tabla 1: Datos de la prueba de Viga Rotatoria para material sin metalizar**

En el anexo 1 se nuestra el grafico de resistencia a la fatiga vs el numero de ciclo referente a la tabla 1.



- **RESULTADOS DEL MATERIAL METALIZADO:**

| Probeta Nº | Diámetro muestra (mm) | Carga [kg] | Ciclos [N] | Tiempo [min] | Observación |
|---|---|---|---|---|---|
| 1 | ϕ16.8 | 10 | 2378 | 1.36 | Si falló |
| 2 | ϕ16.8 | 13 | 1269 | 0.725 | Si falló |
| 3 | ϕ16.8 | 15 | 43 | 0.02 | Falló por fluencia |

**Tabla2: Datos de la prueba de Viga Rotatoria para material metalizado**

En el anexo 2 se indica el diagrama de carga aplicada vs el número de ciclos tanto para la tabla 1 y como para la tabla 2.

## 3. CONCLUSIONES

- Para graficar la resistencia a la fatiga vs el numero de ciclos, se obtuvo la resistencia a la tensión del Manual de Josehp Shigley; Ed.4; Mcgraw Hill; Pág. 866, de acuerdo a la especificación del materia proporcionada por el Sr. José Caiza (AISI 4041 HR), cuyo dato es de 63 Kpsi.
  El valor de la resistencia a la tensión de las probetas metaliza se desconoce, por lo que no se pudo obtener un grafico de resistencia a la fatiga vs el numero de ciclos, solamente se pudo realizar un grafico de la carga vs numero de ciclos (ver anexo 2).

- Las probetas se ensayaron con cargas de 10, 13y 15kg, las probetas ensayadas tanto metalizadas como no metalizadas con la carga de 15kg (39.6lbf) fallaron por resistencia estática, por falla de fluencia, por lo que no llegó al campo de la fatiga (la probeta metalizada fallo a los 43 ciclos y la no metalizada 212 ciclos).

- De acuerdo al gráfico del anexo 2, la probeta metalizada tiene un resistencia a la fatiga mucho menor que la probeta sin metalizar, en conclusión el metalizado realizado disminuye notablemente la resistencia en general.

Ing. Tito Velasteguí
**JEFE DEL LABORATORIO DE**
**MÁQUINAS HERRAMIENTAS**

La interpretación de los resultados es muy factible de asimilar ya que como se ha indicado el cigüeñal está sometido a esfuerzos de tracción y compresión demuestra que si nuestro sistema de redimensionamiento va hacer utilizado en aplicaciones diferentes a las de un cigüeñal debe considerarse muy bien el tipo de fuerzas y esfuerzos a aplicar sobre la parte metalizada.

### 4.2.5 ENSAYO A TRACCIÓN

Como se enuncio anteriormente los ensayos destructivos no pudieron ser realizados en el propio cigüeñal debido a su geometría y que en el país no se cuenta con la tecnología necesaria para lo mismo, la razón fundamental porque se determino su composición para poder elegir un acero al cual mediante ensayos estandarizados poder determinar la influencia del proceso de metalizado sobre una probeta de material base o sin metalizar, por lo cual se presenta a continuación el informe técnico y curvas de esfuerzo vs. % de deformación.

**ESCUELA POLITÉCNICA NACIONAL**
**DEPARTAMENTO DE INGENIERÍA MECÁNICA**
**LABORATORIO DE ANÁLISIS**
**DE ESFUERZOS Y VIBRACIONES**

LAEV

**INFORME TÉCNICO**

LAEV – FEB.33

Quito, 23 de febrero de 2011

**TRABAJO SOLICITADO POR:**

Sr. José Caiza

**ORDEN DE TRABAJO Nº 001730**

Los resultados contenidos en el presente informe corresponden a ensayos realizados en probetas de acero pertenecientes al Sr. José Caiza y entregadas en el Laboratorio de Análisis de Esfuerzos y Vibraciones de la Escuela Politécnica Nacional.

**RESULTADOS**

1. **MUESTRA:** Dos (2) probetas de sección circular para ensayo de tracción bajo la norma ASTM E8.
2. **ENSAYO DE TRACCIÓN BAJO LA NORMA ASTM E8**

| Probeta | Diámetro (mm) | Área (mm) | Carga a la Rotura |  | Esfuerzo de fluencia |  | Resistencia a la tracción |  | % Elongación en 50mm |
|---|---|---|---|---|---|---|---|---|---|
|  |  |  | (lbf) | (N) | (ksi) | (MPa) | (ksi) | (MPa) |  |
| T1 | 12,59 | 124,5 | 31.900 | 141.898 | 150,5 | 1038 | 165,2 | 1140 | 19,2 |
| T2 | 12,60 | 124,7 | 25.800 | 114.764 | 128,0 | 883 | 133,4 | 920 | 18,0 |

*** Se anexan curvas esfuerzo vs. % de deformación.**

Ing. Orlando Cobos
**JEFE (E) DEL LABORATORIO DE**
**ANÁLISIS DE ESFUERZOS Y VIBRACIONES**

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Página 1 de 2

**Anexo**

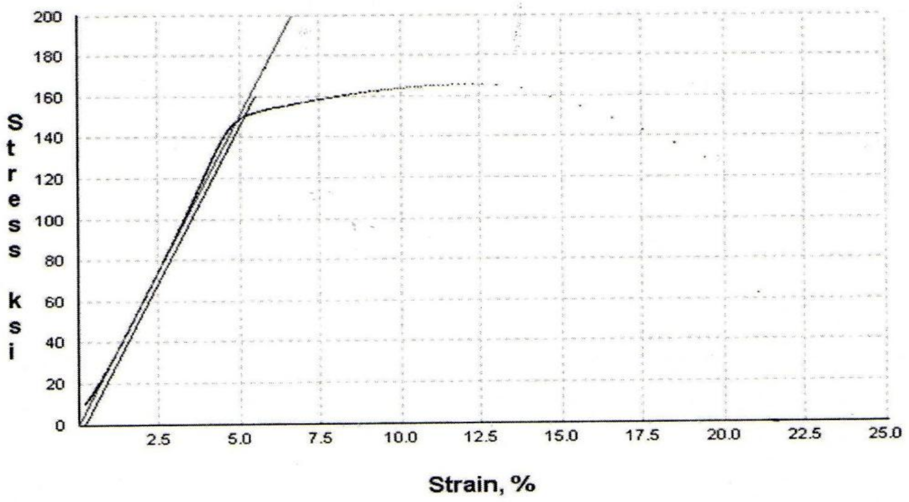

**Figura 1.** Esfuerzo vs. % deformación para la probeta T1.

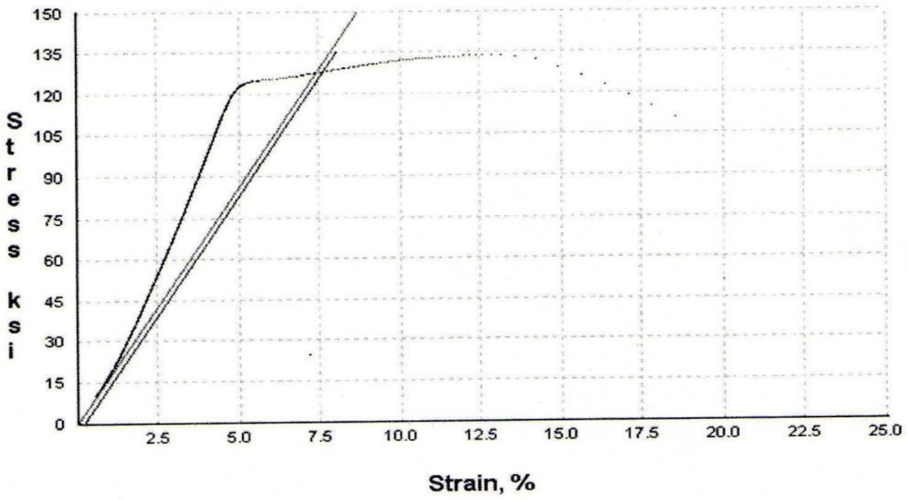

**Figura 2.** Esfuerzo vs. % deformación para la probeta T2.

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Orden Nº: 001730

Página 2 de 2 O.C

La interpretación de este ensayo realizado es que el acero metalizado AISI 4140 con respecto al acero AISI 4140 sin metalizar a variado en las siguientes propiedades, en el acero AISI 4140 sin metalizar los resultados fueron la carga de la rotura de 31900 lbf, el esfuerzo a la fluencia es de 165,2 KPsi y la resistencia a la tracción es de 165,2 KPsi, en el acero AISI 4140 metalizado los resultados fueron carga la rotura 25800 lbf, el esfuerzo de fluencia 128,0 KPsi, y la resistencia a la tracción es de 133,4 KPsi, como se puede ver claramente las propiedades mecánicas del acero metalizado AISI 4140 son menores en un porcentaje de entre el 15% en el esfuerzo de fluencia y el 20% en la carga de la rotura y la resistencia a la tracción, debido a que el material tendió a incrementar su fragilidad, como se indica en los diagramas deformación vs esfuerzo pero el material se vuelve más resistente al desgaste. A continuación vamos a determinar el modulo de Young a partir de los datos obtenidos de los ensayos. Primero del acero sin metalizar sabemos que el modulo de Young o modulo de elasticidad se puede determinar mediante:

$$E = \frac{\sigma}{\varepsilon}$$

Donde:

$E = Modulo\ de\ elasticidad\ o\ de\ Young$

$\sigma = Esfuerzo$

$\epsilon = Deformacion\ Unitaria$

De donde mediante grafico conocemos los datos de $\sigma$ y $\varepsilon$. Entonces $\varepsilon$ como debe ser adimensional entonces

$$\varepsilon = \frac{19.2\ mm \times 0.5}{100} = 0.096mm = \frac{0.096mm}{19.2mm} = 0.005$$

$$\sigma = 1038\ MPa$$

Reemplazando los valores tenemos

$$E = \frac{1038\ MPa}{0.005} = 207600MPa = 207{,}6\ GPa$$

En la tabla E-23 del libro Diseño en Ingeniería Mecánica de Joseph E. Shigley, encontramos el valor nominal del modulo de Young que es igual a $E = 200\ GPa$ comparado con el obtenido se verifica q estamos trabajando con material base el acero AISI 4140. Segundo de acero metalizado también sabemos que el modulo de Young o modulo de elasticidad se puede determinar mediante:

$$E = \frac{\sigma}{\varepsilon}$$

De donde mediante grafico conocemos los datos de $\sigma$ y $\varepsilon$. Entonces $\varepsilon$ como debe ser a dimensional entonces

$$\varepsilon = \frac{18.0\ mm \times 0.5}{100} = 0.09mm = \frac{0.09mm}{18mm} = 0.005$$

$$\sigma = 883\ MPa$$

Reemplazando los valores tenemos

$$E = \frac{883\ MPa}{0.005} = 176600MPa = 176{,}6\ GPa$$

Esta medida indica que otras propiedades también cambiaron en relación al acero sin metalizar, la primera es el límite de elasticidad nos indica que la probeta metalizada resistirá un 15% menos de esfuerzo sin tener una deformación permanente, además que su rigidez disminuirá en la misma proporción con respecto a la rigidez del acero sin metalizar.

Ahora cabe recalcar que el acero se recupero dimensionalmente de un diámetro de 11.59 mm y que según tabla numero 7 sabemos que la reducción del área que puede sufrir este tipo de acero es como mínimo el 50% de su área inicial, vamos a calcular los valores de esfuerzos que podría resistir este material teniendo en cuenta que el esfuerzo depende proporcionalmente al área de aplicación.

Si de los ensayos anteriores tenemos que la resistencia máxima a la tracción es de 133.4 Kpsi, con un área de 0.1932 in$^2$, aplicamos la fórmula para encontrar las fuerzas aplicadas:

$$P = \sigma \times A$$

Donde:

$P = Carga\ Aplicada$

$\sigma = Esfuerzo$

$A = Área$

Obtenemos la siguiente Tabla

| **Probeta Desbastada Metalizada** | | |
|---|---|---|
| **Fuerza kgf ksi** | **Área in** | **Esfuerzo Kpsi** |
| 25,77 | 0,19 | 133,40 |
| 24,73 | 0,19 | 128,00 |
| 23,18 | 0,19 | 120,00 |
| 21,97 | 0,19 | 113,73 |
| 20,68 | 0,19 | 107,03 |
| 19,38 | 0,19 | 100,33 |
| 18,09 | 0,19 | 93,63 |
| 16,80 | 0,19 | 86,93 |
| 15,50 | 0,19 | 80,23 |
| 14,21 | 0,19 | 73,53 |
| 12,91 | 0,19 | 66,83 |
| 11,62 | 0,19 | 60,13 |
| 10,32 | 0,19 | 53,43 |
| 0,00 | 0,19 | 0,00 |

TABLA No.11 Determinación de carga a partir de esfuerzo y área Para Probeta Metalizada

De donde utilizaremos las fuerzas encontradas para determinar los esfuerzos que se producen en la probeta desbastada sin metalizar. Aplicaremos la Formula

$$\sigma = \frac{P}{A}$$

Donde:

$\sigma = Esfuerzo$

$P = Carga\ Aplicada$

$A = Área$

Con lo que obtenemos la siguiente tabla

| **Probeta Desbastada sin Metalizar** | | |
|---|---|---|
| **Fuerza kgf ksi** | **Área in** | **Esfuerzo Kpsi** |
| 25,77 | 0,16 | 157,01 |
| 24,73 | 0,16 | 150,66 |
| 23,18 | 0,16 | 141,24 |
| 21,97 | 0,16 | 133,87 |
| 20,68 | 0,16 | 125,98 |
| 19,38 | 0,16 | 118,09 |
| 18,09 | 0,16 | 110,21 |
| 16,80 | 0,16 | 102,32 |
| 15,50 | 0,16 | 94,44 |
| 14,21 | 0,16 | 86,55 |
| 12,91 | 0,16 | 78,66 |
| 11,62 | 0,16 | 70,78 |
| 10,32 | 0,16 | 62,89 |
| 0,00 | 0,16 | 0,00 |

TABLA No.12 Determinación de carga a partir de esfuerzo y área Probeta sin Metalizar

Los valores indicados en rojo en las dos tablas me permiten comprobar mediante la comparación de esfuerzo, que la probeta sin metalizar considerada ya inútil sometiéndola a la recuperación dimensional mediante el proceso de metalización no solo cumplió con la redimensionamiento de la misma sino como indican los valores también se recupero la fuerza de carga a la rotura de 21.97 Kgf ó 21970 lbf a un valor de 25.8 Kgf ó 25800 lbf lo cual representa una recuperación del 14%, con lo cual la calidad del metalizado es buena.

## 4.3 VERIFICACIÓN DE LA HIPÓTESIS

Con los resultados obtenidos de cada ensayos llevado a cabo y su posterior análisis desarrollados desde la página 70 hasta la página 87 se concluye, el proceso de metalización, que se lleva a cabo en la empresa Rectificadora Pazmiño S.A con la máquina metalizadora TAFA 8830, entrega una buena calidad real sobre el producto terminado.

# CAPITULO V

# CONCLUSIONES Y RECOMENDACIONES

## 5.1 CONCLUSIONES

- Debido a la complejidad geométrica y robustez del cigüeñal, se planteo la utilización de un espectrómetro para cuantificar los metales presentes en el cigüeñal dispuesto para el presente estudio (págs. 72-76).

- La cuantificación de metales necesita un respaldo adicional para una verificación con exactitud del material base que conforma el cigüeñal, por esta razón se aplico el estudio metalográfico para que con el estudio de la micro estructural, se verifico totalmente que este cigüeñal fue fabricado a partir de un acero (págs.78,79 )

- Después de la aplicación de estudios anteriores como el espectrómetro y la metalografía, al no poder obtener una probeta de las dimensiones requeridas de un cigüeñal para poder realizar los respectivos ensayos, y teniendo en cuenta el la disponibilidad de aceros en el mercado, se procedió a una comparación entre resultados de los estudios para determinar un acero idóneo que refleje la mayor semejanza con el material del cigüeñal es así que se seleccione el acero AISI 4140 (págs. 72-76).

- Al aplicar los ensayos destructivos como el ensayo a tracción, el de fatiga y de dureza se obtuvieron datos suficientes para una buena determinación de la calidad real del producto (págs. 70-87).

- Mediante la aplicación de ensayos destructivos y los resultados arrojados por los mismos se pudo conocer la variación real en propiedades mecánicas en relación a un material sin desgate a un recuperado mediante proceso de metalización (págs. 81-87).

- Con la realización de todos los ensayos en los laboratorios de la Escuela Politécnica Nacional, y sus respectivos respaldos se cuenta con resultados confiables además de que se tiene la plena seguridad de que se aplicaron normas internacionales para la realización de los mismos. Para fatiga las ASTM E 466 – E 468, en ensayos a tracción la ASTM E8, los ensayos de micro estructura ASTM E0007-03, ASTM E0003-01 y ASTM E 0045-97 y los ensayos de dureza ASTM E 18.

- Para dar un valor a toda la investigación se debe buscar una forma real de plasmarlo y utilizarlo en beneficio directo para la empresa y sus clientes. (págs. 109-124).

## 5.2 RECOMENDACIONES

- Tener presente las dimensiones y la robustez del cigüeñal que generan un gran problema al momento de su manipulación, estudio y análisis.

- Ser consciente de la realidad nacional de disponibilidad de materiales en este caso específico de aceros, para considerar un acero disponible en el país y que se asemeje lo mayor posible a las propiedades físico químicas del al acero del cigüeñal estudiado.

- Al evaluar con ensayos destructivos siempre se debe buscar muestras que permitan trabajar en su totalidad para ser manipulados hasta su destrucción. Razón por la cual debe ser correctamente calificada la cantidad de especímenes disponibles para realizar los ensayos y estudios.

- Los ensayos a tracción, el de fatiga y de dureza quedan comprobados como los más idóneos para la realización de la presente investigación. Dejando la premisa de que donde se pueda aplicar ensayos destructivos, realizarlos para una determinación muy viable de los resultados.

- Con resultados reales y evaluados se puede en la empresa valorar un tiempo real de garantía en el producto.

- Utilizar laboratorios que tengan un respaldo no solo de antigüedad sino de calidad debido a que los resultados obtenidos de los mismos son de vital importancia para la correcta realización del presente estudio.

- Buscar la forma más práctica y con un costo moderado para la sociabilización de los resultados con el propósito de crear una garantía real en el proceso de metalización con la máquina metalizadora TAFA 8830 en la empresa Rectificadora Pazmiño S.A.

# CAPITULO VI

# LA PROPUESTA

## 6.1 DATOS INFORMATIVOS

### 6.1.1 TÍTULO

Implementación de una guía del proceso de metalizado en la empresa Rectificadora Pazmiño S.A. de cigüeñales de motores a gasolina recuperados mediante el proceso de metalización con la máquina metalizadora TAFA modelo 8830 para garantizar la calidad del producto terminado.

### 6.1.2 INSTITUCIÓN EJECUTORA

- Rectificadora Pazmiño S.A
- Área de metalización

### 6.1.3 BENEFICIARIOS

Con la aplicación de esta propuesta los beneficiarios directos son:

- La empresa Rectificadora Pazmiño S.A.
- Los clientes

### 6.1.4 UBICACIÓN

La empresa de reconstrucción de motores Rectificadora Pazmiño S.A. se encuentra ubicada en la provincia de Pichincha, en la ciudad Quito, En el sector norte conocido como el Inca, calles las brevas E 10 – 250 y avenida De las palmeras.

### 6.1.5 TIEMPO ESTIMADO PARA LA EJECUCIÓN

El tiempo que se estima para la elaboración y ejecución de la propuesta está comprendido en un periodo de seis meses, teniendo como:

- Inicio: septiembre 2010
- Fin: Marzo 2011

### 6.1.6 EQUIPO TÉCNICO RESPONSABLE.

Las personas que integran el equipo técnico responsable de llevar a cabo la propuesta en la institución son:

- Operario de la máquina metalizadora TAFA 8830
- Operario de la Rectificadora de cigüeñales BERCO 232B
- Operario del Torno Ikeagi
- Laboratoristas de la Universidad Politécnica Nacional del Ecuador
- Pasante Investigador.

### 6.1.7 COSTO

Para el desarrollo e implementación de la propuesta se utilizarán varios recursos los mismos que se detallan con sus respectivos costos en la siguiente tabla:

| Materiales | VALOR $ |
|---|---|
| Cortes de Cigüeñal | 20 |
| Transportes | 40 |
| Impresiones | 50 |
| Compra de eje de acero AISI 4140 de 3/4“ | 40 |
| Compra de eje de acero AISI 4140 de 5/8“ | 28 |
| Ensayo de cuantificación de metales por Espectrómetro | 120 |
| Ensayos de Tracción | 80 |
| Ensayos de Fatiga | 1000 |
| Ensayos Metalográfico | 680 |
| Ensayos de Dureza | 320 |
| Subtotal: | 2378 |
| Total Bruto: | 2378 |
| Rubro del 15% de Imprevistos | 356.7 |
| **TOTAL :** | 2734.7 |

TABLA No. 13 Costo de la Propuesta

## 6.2 ANTECEDENTES DE LA PROPUESTA

Las empresas reconstructoras de motores y los usuarios de las mismas siempre han buscado la alternativa de ahorrar o aprovechar al máximo cada componente del vehículo es así que frente a una gran encrucijada que llegan en algún momento las empresas reconstructoras de motores la cual es tener que pedir la compra de algún componente nuevo del motor, en este caso puntual del cigüeñal del motor por diversas circunstancias recae en un fuerte egreso de dinero para el propietario del vehículo, pero no siendo ese el único inconveniente, sino también el de la disponibilidad inmediata en los concesionarios, o de ser algún motor del cual por su antigüedad, por su país de fabricación o por el año de fabricación no exista todavía o se haya descontinuado la fabricación de mencionada parte, surge una gran necesidad que tuvo que ser cubierta por estas empresas. Es así que caracterizándose la empresa Rectificadora Pazmiño S.A siempre por ser una empresa innovadora decide implementar el proceso de recuperación de cigüeñales mediante rociado térmico, para mitigar la necesidad de los propietarios de vehículos con este inconveniente, el proceso se vino aplicando desde el año 2008, sin ningún tipo de estudio del resultado obtenido, razón por la cual este proceso no se garantiza en la empresa, es un proceso de recuperación dimensional rápido, eficaz y económico.

La empresa Rectificadora Pazmiño siempre se ha caracterizado por la seriedad y calidad en todos sus trabajos realizados razón por la cual goza con una gran acogida en el mercado por su seriedad y rapidez, es por esta misma razón que la empresa decide realizar el presente estudio para determinar la calidad del proceso de metalizado y con los resultados reales arrojados poder considerar el tiempo de garantía del trabajo realizado.

Con la finalidad de estandarizar los procesos y pasos que intervienen en proceso de termorociado se visiona la necesidad de esta propuesta con lo cual se creara una guía que al ser implementada metodológicamente en cada utilización del proceso de termorociado podamos asegurar un resultado continuo y homogéneo además de saber cuáles van hacer los resultados reales obtenidos al aplicar el proceso de termorociado utilizando la guía. De acuerdo a la propuesta planteada, se ha verificado que no existen soluciones exactamente iguales en los trabajos de tesis existentes en la biblioteca de Ingeniería Civil y Mecánica.

## 6.3 JUSTIFICACIÓN

Las empresas reconstructoras de motores en su mercado de demanda se encuentra muy saturada y es por esta razón que cada empresa tiene o busca su forma para mantener un número de clientes fijos o de demanda estable con sus respectivas elevaciones en algunos meses y depresiones en otros, esta razón es por la cual cada empresa ofrece un

servicio adicional a sus trabajos en un principio fue el servicio puerta a puerta sin recargos, el cual en su mayoría se implemento y luego el resto de empresas también lo implementaron.
De esta manera la empresa Rectificadora Pazmiño S.A. también se ve con el mismo problema del mercado demanda saturado, por esta razón la empresa se propuso como meta la rapidez y calidad en su trabajo lo cual le ha permitido establecer una gran cantidad de clientes frecuentes al punto de lograr trabajar con la mayoría de concesionarios de vehículos de la provincia de pichincha.

Por esta razón y sustentados en su principio decide evaluar su trabajo de metalización para poder conocer la calidad de este proceso, con lo cual se decide crear una guía para estandarizar los procesos y pasos que intervienen en el proceso de termorociado para que el resultado sea siempre igual al del estudio para conocer sus propiedades y garantizar los resultados siempre que se siga la guía elaborada.

Cabe recalcar que la guía se realizo en base al optimo desempeño de la maquinaria personal e insumos de la empresa Rectificadora Pazmiño S.A. La guía detalla los pasos para un proceso de termorociado en un cigüeñal motor a gasolina, la calidad se evaluó sobre probetas elaboradas para realizar ensayos destructivos, ya que la geometría del cigüeñal no permitió evaluarlo sobre sí mismo.

## 6.4 OBJETIVOS

### 6.4.1 OBJETIVO GENERAL

Elaborar una guía del proceso de metalizado en la empresa Rectificadora Pazmiño S.A. de cigüeñales de motores a gasolina recuperados mediante el proceso de metalización con la máquina metalizadora TAFA modelo 8830 para garantizar la calidad del producto terminado.

### 6.4.2 OBJETIVO ESPECÍFICO

- Establecer los procedimientos necesarios para realizar el proceso de rociado térmico o metalización en la empresa rectificadora Pazmiño S.A.

- Elaborar ensayos destructivos en probetas equivalentes a un cigüeñal de motores a gasolina
- Diseñar y aplicar la guía de proceso de metalizado en el área de recuperación de cigüeñales de la empresa rectificadora Pazmiño S.A.

## 6.5 ANÁLISIS DE FACTIBILIDAD

La presenta propuesta es perfectamente factible de realizarla debido a que cumple con todos los aspectos y recursos necesarios para su desarrollo y ejecución, el mismo que se determinan a continuación:

### 6.5.1 POLÍTICA

La empresa Rectificadora Pazmiño S.A. se caracteriza por tener una política de control interno muy exigente sobre todos sus procesos y trabajos que se realizan dentro de la empresa, con su seriedad como carta de presentación ante todo trabajo, ofrecer garantía sobre trabajo realizado, con esta primicia la empresa ha buscado la manera de poder brindar este tipo de valor agregado a su trabajo puntualmente en el proceso de termo rociado. Al ser termorociado ser un proceso nuevo desarrollado dentro de la empresa rectificadora Pazmiño S.A. busca poder brindar una garantía sobre este trabajo realizado para poder cumplir con las políticas internas de la empresa.

### 6.5.2 TECNOLÓGICO

El ambiente de trabajo en que se desenvuelve el termorociado dentro de la empresa, necesita de tecnología la cual se detalla a continuación. Micrómetros de exteriores, es la herramienta utilizada para poder medir y comparar la medida tomada con la medida proporcionada por el programa PROSIS, con lo cual se puede determinar el desgaste de cada muñón de cigüeñal ya sea de bancada o biela y proceder a evaluar si el cigüeñal ya se encuentra fuera del límite del cual se pueden encontrar repuestos o no. Metalizadora TAFA 8830, es la máquina que realiza en si el proceso de termo rociado mediante la utilización de una corriente de aire y el uso de electricidad para fundir los alambres que van ingresando, se van fundiendo y posteriormente son expulsados a través de la pistola de rociado hacia la superficie del codo del cigüeñal que va a ser recuperado hasta la medida necesitada para poder ser rectificado. Rectificadora de cigüeñales, Es la máquina donde se rectifica los muñones de biela, primero se balancea el cigüeñal, luego se procede a tomar la medida de ingreso y se desbasta mediante una piedra hasta la medida necesitada o requerida para los repuestos que se disponen en el mercado, el proceso se repite según sea necesario. Pulidora de Cigüeñales, es una maquina completaría a la rectificadora de cigüeñales que como su nombre lo indica sirve para pulir o dar el acabado superficial necesario `para que el cigüeñal pueda ser utilizado.

### 6.5.3 ORGANIZACIONAL

Para desarrollar e implementar la propuesta de solución anteriormente descrita es imprescindible cumplir con actividades que conforman el proceso administrativo como planificar, organizar dirigir y controlar las mismas que son importantes para la adecuada realización de la idea y el cumplimiento de los objetivos.

### 6.5.4 RECURSOS HUMANOS

Es el recurso considerado como el más importante porque son aquellas personas que intervienen directamente para que la propuesta se desarrolle; cabe decir que está constituido por personas idóneas, preparadas y capaces para poder implementar de la mejor manera.

### 6.5.5 RECURSO ECONÓMICO FINANCIERO

Para llevar a cabo la propuesta planteada se hace necesario contar con el factor económico para solventar los costos que ella implica, de esta manera los fondos para este fin serán proporcionados a través de departamento financiero los fondos serán destinados exclusivamente solo para el estudio del proceso de termo rociado. Se facilita su obtención debía que esta propuesta ayudara favorablemente para la obtención de la calidad del termorociado.

### 6.5.6 RECURSO LEGAL

En el plano legal la propuesta está basada en: La utilización y aplicación de las norma internacionales

- AWS C2.1-73 RECOMMENDED SAFE PRACTICES FOR THERMAL SPRAYING (Recomendaciones de Prácticas Seguras Para Termorociado)
- AWS TSS-85 THERMAL SPRAYING: PRACTICE THEORY, AND APPLICATION (Teoría, práctica y aplicación del rociado térmico).

## 6.6 FUNDAMENTACIÓN CIENTÍFICA

### 6.6.1 ESPECTRÓMETRO DE CHISPA O ARCO

Se usa para el análisis de elementos metálicos en muestras sólidas. Para materiales no conductores, se usa polvo de grafito para hacer conductora la muestra. En los métodos de espectroscopia de arco tradicionales se usa una muestra sólida que es destruida durante el análisis. Un arco eléctrico o chispa se pasan por la muestra, calentándola a alta temperatura para excitar los átomos. Los átomos de analito excitado emiten luz en varias longitudes de onda que pueden ser detectadas mediante métodos espectroscópicos comunes. Ya que las condiciones que producen la emisión por arco no son controladas cuantitativamente, el análisis de los elementos es cualitativo. Hoy día, las fuentes de chispa con descargas controladas bajo una atmósfera de argón permiten que este método pueda ser considerado eminentemente cuantitativo, y su uso está muy extendido en los laboratorios de control de producción de fundiciones y acerías.

FIGURA No. 32 Espectrómetro

Fuente: JOSÉ CAIZA

### 6.6.2 ENSAYO DE DUREZA

El último ensayo rutinario es el de Dureza Superficial, que es la resistencia de un material a ser marcado por otro. Se prefiere el uso de materiales duros cuando éstos deben resistir el roce con otros elementos. Es el caso de las herramientas de construcción (palas, carretillas, pisos, tolvas):

- El ensayo es realizado con indentadores en forma de esferas, pirámides o conos.
- Estos elementos se cargan contra el material y se procede a medir el tamaño de la huella que dejan. Es un ensayo fácil y no destructivo; puede realizarse en cualquier sitio, ya que existen durímetros fácilmente transportables.
- Una de las ventajas del ensayo de dureza es que los valores entregados pueden usarse para hacer una estimación de la resistencia a la tracción.
- La dureza superficial puede aumentarse añadiendo al material una capa de carbono, en un tratamiento térmico denominado cementación.
- La clasificación y los métodos varían con cada material, dando origen a los números de dureza:
    - **HBN** (Hardness Brinell Number)
    - **HRA**, **HRB**, **HRC**, ... (Hardness Rockwell series A, B, C, ...)
    - HVN (Hardness Vickers Number).

### 6.6.3 ENSAYO A TRACCIÓN

**Meta**

Este método de prueba cubre la prueba de tensión de materiales metálicos en cualquier forma a temperatura ambiente, específicamente, los métodos de determinación de la resistencia de cedencia, elongación, resistencia a la tensión y reducción de área.

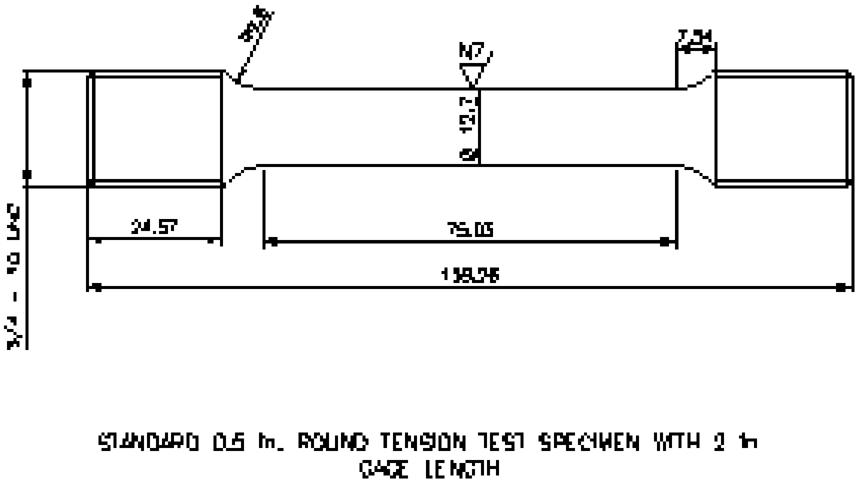

FIGURA No. 33 Norma ASTM E 8 – 01

Fuente: Norma ASTM E 8 – 01

## Uso y significancia

- La prueba de tensión brinda información de la resistencia y la ductilidad de materiales bajo esfuerzos de tensión uniaxiales. Esta información puede ser de gran ayuda para comparar materiales, desarrollo de aleaciones, control de calidad y diseño bajo ciertas circunstancias.
- Los resultados de las pruebas de tensión de especímenes maquinados a dimensiones estandarizadas de porciones seleccionadas de una parte o materiales puede no representar totalmente la resistencia y ductilidad de todo el producto entero.
- Los métodos de prueba son considerados satisfactorios para aceptar pruebas de equipos comerciales. Los métodos de prueba han sido empleados extensivamente para este propósito.

## Aparatos

- Máquinas de tensión: Máquinas empleadas para las pruebas de tensión deben conformarse dentro de los requerimientos de prácticas E4. Las fuerzas empleadas en determinar la resistencia de tensión y la resistencia de cedencia deben estar dentro de la aplicación de un rango de fuerzas verificadas de la máquina de tensión

FIGURA No. 34Maquina Universal de Pruebas
Fuente: JOSÉ CAIZA

FIGURA No. 35 Probetas Después del Ensayos a Tracción (SIN METALIZAR)
Fuente: JOSÉ CAIZA

FIGURA No. 36 Probetas Después del Ensayos a Tracción (SIN METALIZAR)
Fuente: JOSÉ CAIZA

FIGURA No. 37 Probetas Después del Ensayos a Tracción (METALIZADA)
Fuente: JOSÉ CAIZA

### 6.6.4 ENSAYO DE FATIGA

**Introducción**

En presencia de cargas fluctuantes, en el vértice de discontinuidades geométricas más o menos agudas se produce un fenómeno de deformación elasto-plástica cíclica a partir del cual se produce la iniciación de la fisura por fatiga. La condición superficial y la naturaleza del medio cumplen un rol importante sobre la resistencia a la fatiga, esto es sobre el número de ciclos necesarios para que aparezca la fisura. Desde un punto de vista ingenieril, cuando la fisura adquiere una longitud de aproximadamente 0.25 mm se acepta habitualmente que se ha completado la etapa de iniciación.

A partir de ahí se considera que se está en la etapa de extensión o de crecimiento estable que eventualmente culmina en la rotura monótona de la sección remanente. La proporción de la vida total que corresponde a la etapa de iniciación aumenta hacia la región de alto ciclo, entendiéndose habitualmente por tal a aquella en la cual la iniciación se produce en no menos de aproximadamente 10 ciclos de 4. La naturaleza esencialmente multiparamétrica del fenómeno de fatiga, en el que la influencia de los distintos parámetros no puede en general considerarse de manera aislada, constituye la razón de la gran dispersión que generalmente acompaña a los resultados experimentales relacionados con este fenómeno.

En general, puede decirse que las predicciones sobre vida a la fatiga efectuada en base a datos generales publicados y la teoría existente, son tan imprecisas como lo son los pronósticos de mediano plazo en meteorología o economía. Sin embargo, a diferencia de lo que ocurre en estas disciplinas, la realización de ensayos específicos de fatiga aplicados a situaciones particulares, permite incrementar la capacidad de predicción hasta el límite habitual en las ciencias mecánicas.

El ensayo a la fatiga básico es el concebido por A.Wöhler (1819 -1914) en el cual una probeta lisa, entallada o el componente mismo es sometido a una carga variable de amplitud constante determinándose el número de ciclos necesarios para que se produzca la iniciación de la fisura por fatiga o una dada cantidad de propagación, P.Ej. 50% de la sección.

FIGURA No. 38 Máquina de Moore para Ensayo de Fatiga
Fuente: JOSÉ CAIZA

Se muestra la máquina de ensayo a la fatiga por flexión rotativa. La probeta se encuentra sometida a un estado de flexión pura y las tensiones actuantes en una fibra a cierta distancia del eje neutro cambian de signo cada medio giro de la probeta. De esta manera las fibras estarán sometidas a una tensión alternativa cuya amplitud será máxima para las más alejadas del eje de la probeta.

**Vida a la fatiga controlada por tensión**

Los métodos para caracterizar la resistencia a la fatiga en términos de amplitudes de tensión nominales utilizando datos experimentales obtenidos a partir de probetas lisas emergieron de los trabajos de Wöhler (1860) sobre fatiga de ejes

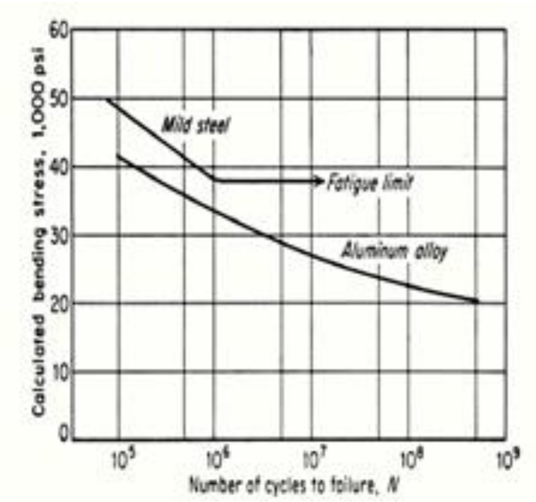

GRAFICO No. 4 Curvas de Wöhler
Fuente: Norma ASTM E 8 – 01

Dos probetas cilíndricas lisas son ensayadas a la fatiga por flexión, flexión rotativa, tracción-compresión, o tracción-tracción uniaxiales. Los métodos de ensayo para determinar la vida a la fatiga están detallados en las normas ASTM E 466-E 468 de la American Society for Testing and Materials (Philadelphia). En tales ensayos, la amplitud de tensión $\sigma_a = (\sigma_{Máx} - \sigma_{Mín})/2$ , , o el rango de tensión $\Delta\sigma = \sigma_{Máx} - \sigma_{Mín}$ se grafica en función del número de ciclos a la falla.

FIGURA No. 39 Probeta sin Metalizar (15 KG)
Fuente: JOSÉ CAIZA

FIGURA No. 40 Probeta sin Metalizar (13 KG)
Fuente: JOSÉ CAIZA

FIGURA No. 41 Probeta sin Metalizar (10 KG)
Fuente: JOSÉ CAIZA

FIGURA No. 42 Probeta Metalizada (15 Kg**)**
Fuente: JOSÉ CAIZA

FIGURA No. 43 Probeta Metalizada (13 KG)

Fuente: JOSÉ CAIZA

FIGURA No. 44 Probeta Metalizada (10 Kg)

Fuente: JOSÉ CAIZA

## 6.7 ADMINISTRACIÓN DE LA PROPUESTA

El equipo que estará encargado de la administración de la propuesta está conformado por las siguientes personas:

| CARGO | FUNCIÓN PRINCIPAL |
|---|---|
| Supervisor del área técnica | Evalúa el estado de ingreso del cigüeñal y recomienda la metalización |
| Jefe de planta | Analiza el informe enviado por el supervisor del área técnica y verifica. |
| Operario de la Metalizadora | Realiza todo el proceso para la recuperación del cigüeñal |
| Pasante-Investigador | Diseñar, elaborar e implementar la propuesta planteada; además proporcionada la debida capacitación para su aplicación |

TABLA No. 14 Administración de la Propuesta

## 6.8 PREVISIÓN DE LA EVALUACIÓN

Con el propósito de tomar decisiones oportunas en cuanto al desempeño y eficacia de la propuesta planteada. Se considera que el manual estará a prueba durante un año para realizar todos los ajustes necesarios.

## 6.9 MODELO OPERATIVO

| FASE | ETAPA | ACTIVIDADES | METAS | RESPONSABLES | TIEMPO | PRESUPUESTO | RECURSO |
|---|---|---|---|---|---|---|---|
| Establecer los procedimientos | Análisis de la Situación Actual | Recopilación de Información | Conocer el proceso actual de metalizado | Pasante-Investigador | 2 semanas | 5 USD | Humano, Material, Económico, Tecnológico, Tiempo |
| | | Análisis de todos los factores que intervienen en el proceso de metalizado | | | | 20 USD | |
| | Evaluación de cada Procedimiento | Establecer la cantidad de procedimientos | Conocer cada proceso de la metalización | Pasante-Investigador | 2 semanas | 20 USD | |
| | | | | Operario de la metalizadora | | 20 USD | |
| | Orden de los procedimientos | Importancia de cada proceso | Establecer y modificar cada proceso para optimizar los mismos | Pasante-Investigador | 2 semanas | 10 USD | |
| Elaborar ensayos destructivos | Cuantificación de metales | Elaboración de probeta para análisis | Comparar resultados de una probeta metalizada versus una sin metalizar | Pasante-Investigador | 2 semanas | 120 USD | |
| | | Realización del análisis y resultados | | | | | |
| | Ensayos a tracción | Elaboración de probeta para análisis | | | 2 semanas | 80 USD | |
| | | Realización de los ensayos y resultados | | | | | |
| | Ensayos a Fatiga | Elaboración de probeta para análisis | | | 2semanas | 1000 USD | |
| | | Realización de los ensayos y resultados | | | | | |
| Diseñar y aplicar | Elaborar una Guía | Creación de la Guía | Poder establecer una calidad real sobre la metalización | Pasante-Investigador | 2 meses | 200 USD | |
| | Aplicar la guía | Velar por la correcta aplicación de la guía | | Área administrativa | 1 mes | 83,70 USD | |
| | | | | | | 1558,70 USD | |

## 6.10 CRONOGRAMA DE LA PROPUESTA

| **FASES – ETAPAS DE LA PROPUESTA** | **Oct/10** | | | | **Nov/10** | | | | **Dic/10** | | | | **Ene/11** | | | | **Feb/11** | | | | **Mar/11** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **ESTABLECER LOS PROCEDIMIENTOS** | | | | | | | | | | | | | | | | | | | | | | | | |
| Análisis de la situación actual | ■ | ■ | | | | | | | | | | | | | | | | | | | | | | |
| Evaluación de cada procedimiento | | | ■ | ■ | | | | | | | | | | | | | | | | | | | | |
| Orden de los procedimientos | | | | | ■ | ■ | | | | | | | | | | | | | | | | | | |
| **ELABORAR ENSAYOS DESTRUCTIVOS** | | | | | | | | | | | | | | | | | | | | | | | | |
| Cuantificación de metales | | | | | | | ■ | ■ | | | | | | | | | | | | | | | | |
| Ensayos a tracción | | | | | | | | | ■ | ■ | | | | | | | | | | | | | | |
| Ensayos a Fatiga | | | | | | | | | | | ■ | ■ | | | | | | | | | | | | |
| **DISEÑAR Y APLICAR** | | | | | | | | | | | | | | | | | | | | | | | | |
| Elaborar una Guía | | | | | | | | | | | | | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | | | | |
| Aplicar la Guía | | | | | | | | | | | | | | | | | | | | | ■ | ■ | ■ | ■ |

## 6.11 PRESENTACIÓN DE LA PROPUESTA:

GUÍA DEL PROCESO DE METALIZADO EN LA EMPRESA RECTIFICADORA PAZMIÑO S.A. DE CIGÜEÑALES DE MOTORES A GASOLINA RECUPERADOS MEDIANTE EL PROCESO DE METALIZACIÓN CON LA MÁQUINA METALIZADORA TAFA MODELO 8830 PARA GARANTIZAR LA CALIDAD DEL PRODUCTO TERMINADO.

# GUIA INTERNA DEL PROCESO DE TERMO ROCIADO

**GUÍA DEL PROCESO DE METALIZADO EN LA EMPRESA RECTIFICADORA PAZMIÑO S.A. DE CIGÜEÑALES DE MOTORES A GASOLINA RECUPERADOS MEDIANTE EL PROCESO DE METALIZACIÓN CON LA MÁQUINA METALIZADORA TAFA MODELO 8830 PARA GARANTIZAR LA CALIDAD DEL PRODUCTO TERMINADO**

| **ÁREA:** | **FECHA:** | **PAGINA** | **HOJA** |
|---|---|---|---|
| RECUPERACIÓN DE CIGÜEÑALES | MARZO DE 2011 | 02 | 1/1 |

## ÍNDICE

PAZMIÑO S.A
Rectificadora

# GUÍA DEL PROCESO DE METALIZADO EN LA EMPRESA RECTIFICADORA PAZMIÑO S.A. DE CIGÜEÑALES DE MOTORES A GASOLINA RECUPERADOS MEDIANTE EL PROCESO DE METALIZACIÓN CON LA MÁQUINA METALIZADORA TAFA MODELO 8830 PARA GARANTIZAR LA CALIDAD DEL PRODUCTO TERMINADO

| **ÁREA:** | **FECHA:** | **PAGINA** | **HOJA** |
|---|---|---|---|
| RECUPERACIÓN DE CIGÜEÑALES | MARZO DE 2011 | 03 | 1/1 |

## INTRODUCCIÓN

*Frente a la necesidad de seguir brindado a sus clientes la mayor seriedad posible en la realización de sus trabajos la empresa Rectificadora Pazmiño S.A. decide implementar la garantía sobre los cigüeñales recuperados mediante el proceso de termo rociado.*

*El presente documento es diseñado para servir como guía procedimental en el proceso de ¨metalización de cigüeñales¨, permitiendo conocer un resultado real de dicho proceso aplicado sobre los cigüeñales, con lo cual el área administrativa puede analizar la garantía que puede ofrecer*

*El objetivo principal es que sea utilizado como instrumento de apoyo por el operario y le permita realizar su trabajo de mejor manera, mitigando el riesgo de realizar un mal metalizado.*

*Además serviría como fuente de consulta, de estudio y de referencia para el personal de toda la empresa Rectificadora Pazmiño S.A. proporcionado un apoyo para la correcta toma de decisiones frente algún problema q se pueda suscitar.*

PAZMIÑO S.A
Rectificadora

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## OBJETIVO

*Proporcionar un instrumento de apoyo técnico determinado un marco procedimental que sirva de guía para el desarrollo en forma integrada de las actividades que conforman el "Proceso de metalización de cigüeñales", a efecto de mitigar el riesgo de realizar una metalizado de mala o desconocida calidad en la empresa Rectificadora Pazmiño.*

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## CONCEPTOS

### METALIZADO

*La Metalización o "Thermal Spray" es un proceso que consiste en la aplicación de recubrimientos a un sustrato, para impartirle propiedades distintas o semejantes a las que posee su material base. Los materiales del recubrimiento incluyen metales, aleaciones, carburos, cerámicas, plásticos y estructuras especiales que combinan diversas propiedades.*

### TAFA MODELO 8830

*Es un equipo para realizar procesos de Rociado Térmico ó metalización por ARC SPRAY cuenta con una salida ligera, alta de material es unidad resistente diseñada para una operación automática y manual.*

### ALAMBRE 75B (ALAMBRE BASE)

*Es el alambre que se utiliza como adherente entre el material original del cigüeñal y el alambre que va hacer utilizado para la recuperación del mismo.*

### ALAMBRE 60T (ALAMBRE DE RECUPERACIÓN)

*Es el alambre que es aplicado después del alambre base y es el encargado de recuperar las medidas que se necesitan del cigüeñal.*

## PERSONAL NECESARIO PARA EL PROCESO

*El personal que se enlista a continuación trabaja en el área de recuperación de cigüeñales en los talleres de Rectificadora Pazmiño S.A ubicado en la ciudad de Quito, los mismos que son:*

- *Personal Técnico de Recepción de Motores*
- *Operador de la Máquina TAFA 8830*
- *Operador de la Máquina BERCO 232 B*

PAZMIÑO S.A
Rectificadora

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## ETAPA 1: EVALUACIÓN DEL CIGÜEÑAL

**Responsables:** Personal Técnico de Recepción de Motores

### ACTIVIDADES:

- *Realizar una inspección total del cigüeñal tanto visual como técnica.*
- *Determinar en el siguiente orden los daños más comunes a los cuales están expuestos el cigüeñal.*
- *Verificar Torcedura.- Colocando a el cigüeñal un reloj palpador en los muñones de biela, punta y portaretén verificar torcedura de ser el caso, analizar si la torcedura puede ser eliminada con lo rectificación de los muñones de biela y bancada, la torcedura podrá ser eliminada cuando sus rangos no sea muy variables, de ser una torcedura con variables considerables sugerir enderezar el cigüeñal sin responsabilidad de rotura.*
- *Verificar Ovalamiento.- Mediante las medidas realizadas en los muñones del cigüeñal con un micrómetro de exteriores en el eje de las abscisas y ordenadas determinar si los codos se encuentran ovalados de ser el caso verificar si se encuentra dentro de los límites para ser corregido mediante la rectificación de los muñones, y de la disponibilidad de repuestos.*
- *Verificar desgaste.- Con el micrómetro de exteriores verificar medidas de los muñones comparándolas con el que nos brinda el sistema informático PRO-SIS, con lo cual se determina a qué medida se rectificaran los muñones del cigüeñal, también se analizara si se encuentra entre de los límites de repuestos disponibles dentro del mercado.*
- *De encontrar algún inconveniente en estas tres evaluaciones se analizará la factibilidad de utilizar el proceso de recuperación dimensional del cigüeñal a través del rociado térmico de material, para poder volver a utilizar el mismo cigüeñal.*
- *Determinar las medias a las cuales se necesitan ser recuperados uno o más muñones del cigüeñal e informar al operario dichas medidas*

## ETAPA 2: PREPARACIÓN DE LAS PARTES DEL CIGÜEÑAL A SER METALIZADAS

**Responsables:** OPERADOR DE LA MAQUINA TAFA 8830

### ACTIVIDADES:

- *Indicar la medida requerida de las partes que van a ser recuperadas.*
- *Señalar correctamente las partes del cigüeñal que van hacer recuperadas mediante el proceso de termo rociado.*
- *Montar el cigüeñal en el torno para proceder a desbastar el o los muñones que sean necesarios, de no ser el caso mediante una sierra para metal crear la rugosidad necesaria para aplicar la base y el material de recuperación del proceso de termorociado*

FIGURA No. 1 CIEGUÑAL
FUENTE: TALLERES RECTIFICADORA PAZMIÑO S.A

PAZMIÑO S.A
Rectificadora

## GUÍA DEL PROCESO DE METALIZADO EN LA EMPRESA RECTIFICADORA PAZMIÑO S.A. DE CIGÜEÑALES DE MOTORES A GASOLINA RECUPERADOS MEDIANTE EL PROCESO DE METALIZACIÓN CON LA MÁQUINA METALIZADORA TAFA MODELO 8830 PARA GARANTIZAR LA CALIDAD DEL PRODUCTO TERMINADO

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## ETAPA 2: PREPARACIÓN DE LAS PARTES DEL CIGÜEÑAL A SER METALIZADAS

- *Limpiar con un agente disolvente mediante un aspersor en este caso se debe utiliza thiñer, para remover impurezas como remanentes de aceite, grasas etc.*

FIGURA No. 2 PROBETA
FUENTE: TALLERES RECTIFICADORA PAZMIÑO S.A

- *Proteger las partes del cigüeñal que no van hacer metalizadas si son áreas pequeñas se utilizará masquin de ser grandes áreas se utilizará grasa.*

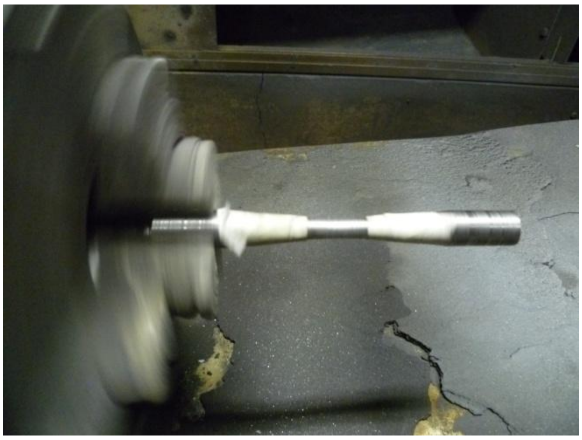

FIGURA No. 1 PROBETA LISTA METALIZAR
FUENTE: TALLERES RECTIFICADORA PAZMIÑO S.A

## ETAPA 3: PROCESO DE ROCIADO TÉRMICO

**Responsables:** OPERADOR DE LA MAQUINA TAFA 8830

### ACTIVIDADES:

- *Encender el botón general de la máquina metalizadora.*
- *Verificar que los niveles de la máquina TAFA 8830 sean los siguientes la presión de aire en 4,2 bar (62 psi), la presión de inyección de alambre fundido 4,8 bar (70 psi)*

FIGURA No. 4VERIFICAR PRESION DE LA MAQUINA METALIZADORA TAFA 8830
FUENTE: TALLERES RECTIFICADORA PAZMIÑO S.A

## ETAPA 3: PROCESO DE ROCIADO TÉRMICO

- *Después de verificar los niveles encender el paso de aire hacia la pistola mediante le botón situado en la consola de la metalizadora como se indica en la foto poner en posición ON o de encendido.*

FIGURA No. 5 ENCENDIDO DE LA MAQUINA METALIZADORA TAFA 8830
FUENTE: TALLERES RECTIFICADORA PAZMIÑO S.A

- *Verificar el nivel de voltaje que debe ser de 40 voltios para el arco eléctrico que funde los alambres que van hacer rociados , de estar en el nivel apropiado se encenderá una luz indicando que el equipo está listo para ser utilizado*

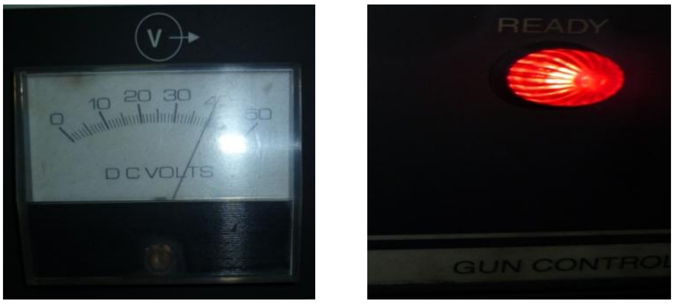

FIGURA No. 6 INDICADORES DE VOLTAJE DE LA MAQUINA METALIZADORA TAFA8830
FUENTE: TALLERES RECTIFICADORA PAZMIÑO S.A

**GUÍA DEL PROCESO DE METALIZADO EN LA EMPRESA RECTIFICADORA PAZMIÑO S.A. DE CIGÜEÑALES DE MOTORES A GASOLINA RECUPERADOS MEDIANTE EL PROCESO DE METALIZACIÓN CON LA MÁQUINA METALIZADORA TAFA MODELO 8830 PARA GARANTIZAR LA CALIDAD DEL PRODUCTO TERMINADO**

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## ETAPA 3: PROCESO DE ROCIADO TÉRMICO

- *Verificar que el amperaje del arco eléctrico sea de 120 amperios mientras se utiliza la pistola para el rociado del material fundido, este rociado no debe hacer sobre el cigüeñal hasta verificar que todos los parámetros se cumplan.*

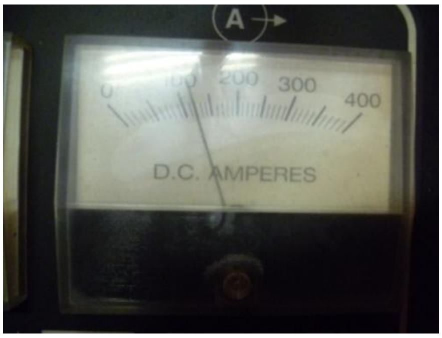

FIGURA No. 7 LECTOR DE AMPERAJE MAQUINA METALIZADORA TAFA 8830
FUENTE: TALLERES RECTIFICADORA PAZMIÑO S.A

- *Colocar el alambre base 75 B en las entradas de la pistola y asegurarlos, para proceder a rociarlo sobre la superficie hacer recuperada la capa debe ser de 0.20 milésima de pulgada o 0.05 mm de espesor, tener en cuenta que la metalizadora deposita el material a razón de 1 milésima de pulgada por segundo de termo rociado.*

FIGURA No. 8 DISPARO DE MATERIAL CON LA MAQUINA METALIZACIÓN TAFA 8830
FUENTE: TALLERES RECTIFICADORA PAZMIÑO S.A

## ETAPA 3: PROCESO DE ROCIADO TÉRMICO

- *Accionar el torno para que el cigüeñal empiece a rotar a 80 rpm, acto seguido encender el flujo de aire en la pistola mediante el accionamiento del botón verde que se encuentra sobre la pistola, empezar el rociado térmico a una distancia de entre 12 y 15 cm del codo de biela, además de simular el efecto de biela manivela q sufre el codo para tener un mejor alcance y rociado de material uniforme, encender el extractor de vapores de metalización, colocarse los protectores de oídos, el overol y la mascarilla protectora de respiración de uso obligatorio.*

FIGURA No. 9 MOMENTO DEL DISPARO DE MATERIAL PARA METALIZAR
FUENTE: TALLERES RECTIFICADORA PAZMIÑO S.A

## ETAPA 3: PROCESO DE ROCIADO TÉRMICO

- *Después de realizar el termorociado desactivar el flujo de la pistola mediante el botón rojo que se encuentra sobre la misma.*

- *Verificar constantemente el espesor de la capa de material depositado sobre la parte que fue metalizada mediante la utilización de un calibrador pie de rey.*

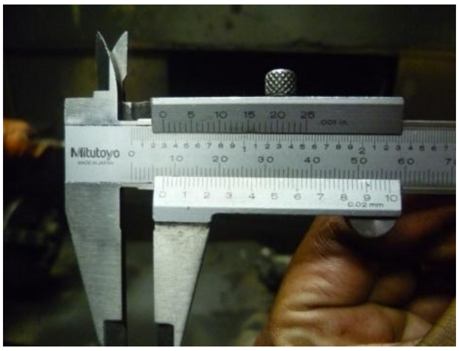

FIGURA No. 10 CALIBRADOR PIE DE REY
FUENTE: TALLERES RECTIFICADORA PAZMIÑO S.A

- *Reemplazar el alambre base 75 B por el alambre de recuperación 60 T en la pistola de termorociado y asegurarlos, de igual manera la maquina proporciona un recubrimiento a razón de 1 milésima de pulgada por segundo de rociado térmico, con lo cual determinamos la cantidad de segundos o minutos q se debe rociar la parte hacer recuperada teniendo en cuenta que se debe sobre dimensionar con 2 milésimas de pulgada mas la parte metalizada para poder posteriormente ser rectificada.*

- *Verificar que las partes metalizadas se encuentren con el sobredimensionamiento de las dos milésimas de pulgada sobre la medida requerida.*

- *Después de verificar y estar conforme el operario de la metalizadora con las medidas en el cigüeñal recuperado, procede a pagar la maquinaria y su botón general de apagado. Dejar activado el extractor de gases hasta que disipe los gases producidos por la operación de metalizado.*

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Rectificadora

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## ETAPA 4: PROCESO DE RECTIFICACIÓN DE CIGÜEÑAL

**Responsables:** OPERADOR DE LA MAQUINA BERCO 232 B

### ACTIVIDADES:

- *Encender el botón general de la máquina rectificadora.*
- *Montar el cigüeñal en las muelas de la rectificadora de cigüeñales, balancear dinámicamente mediante el movimiento de las contrapesas y colocando el reloj palpador hasta que el mismo se mantenga constante y poder trabajar en el cigüeñal.*
- *Rectificar las partes metalizadas hasta la medida requerida.*
- *Pulir las partes rectificadas para darle el acabo superficial que requiere el cigüeñal para un correcto desempeño.*
- *Apagar la maquina rectificadora de cigüeñales.*

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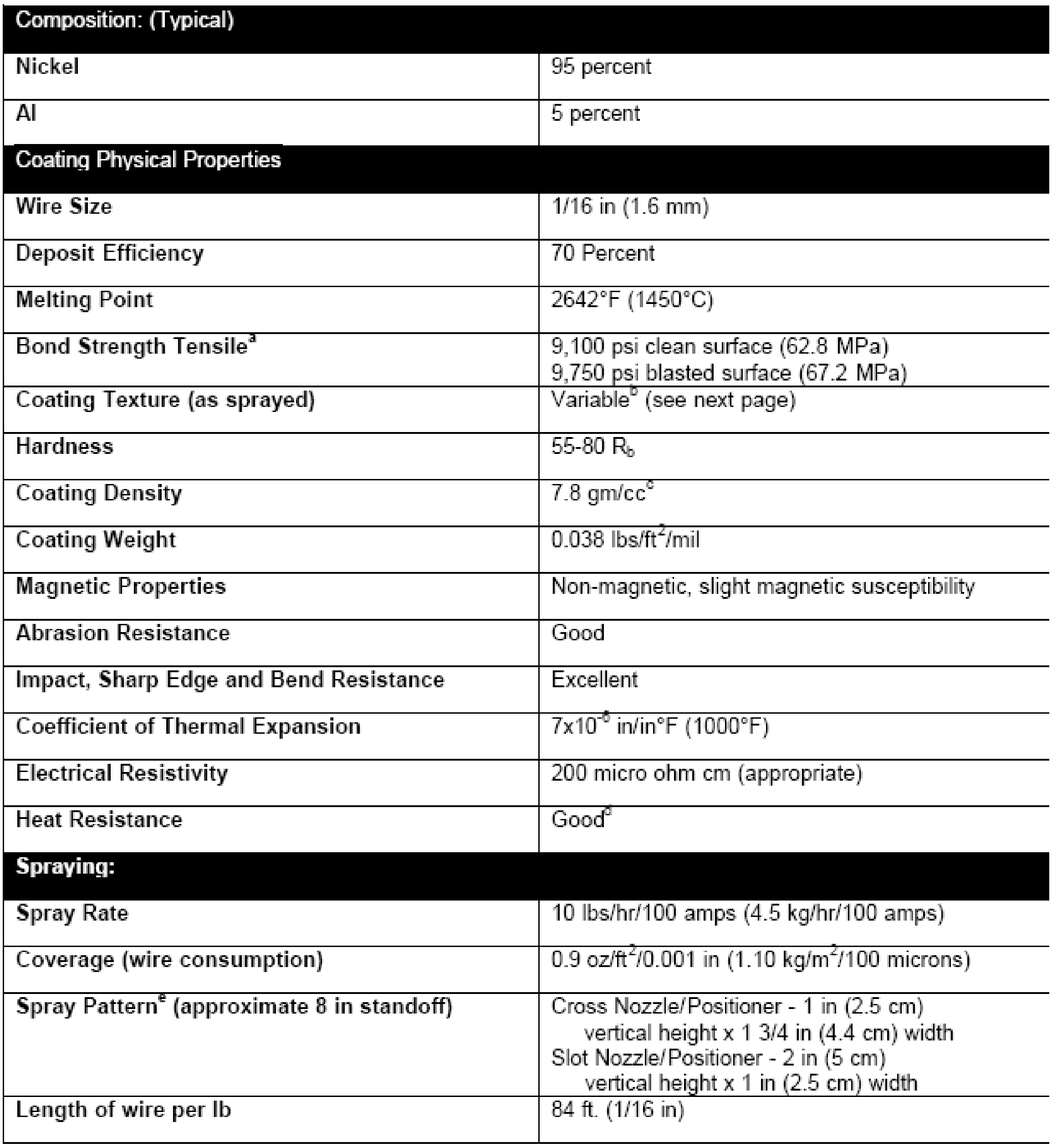
# Anexos

# ANEXO 1

## ALAMBRE 75 B

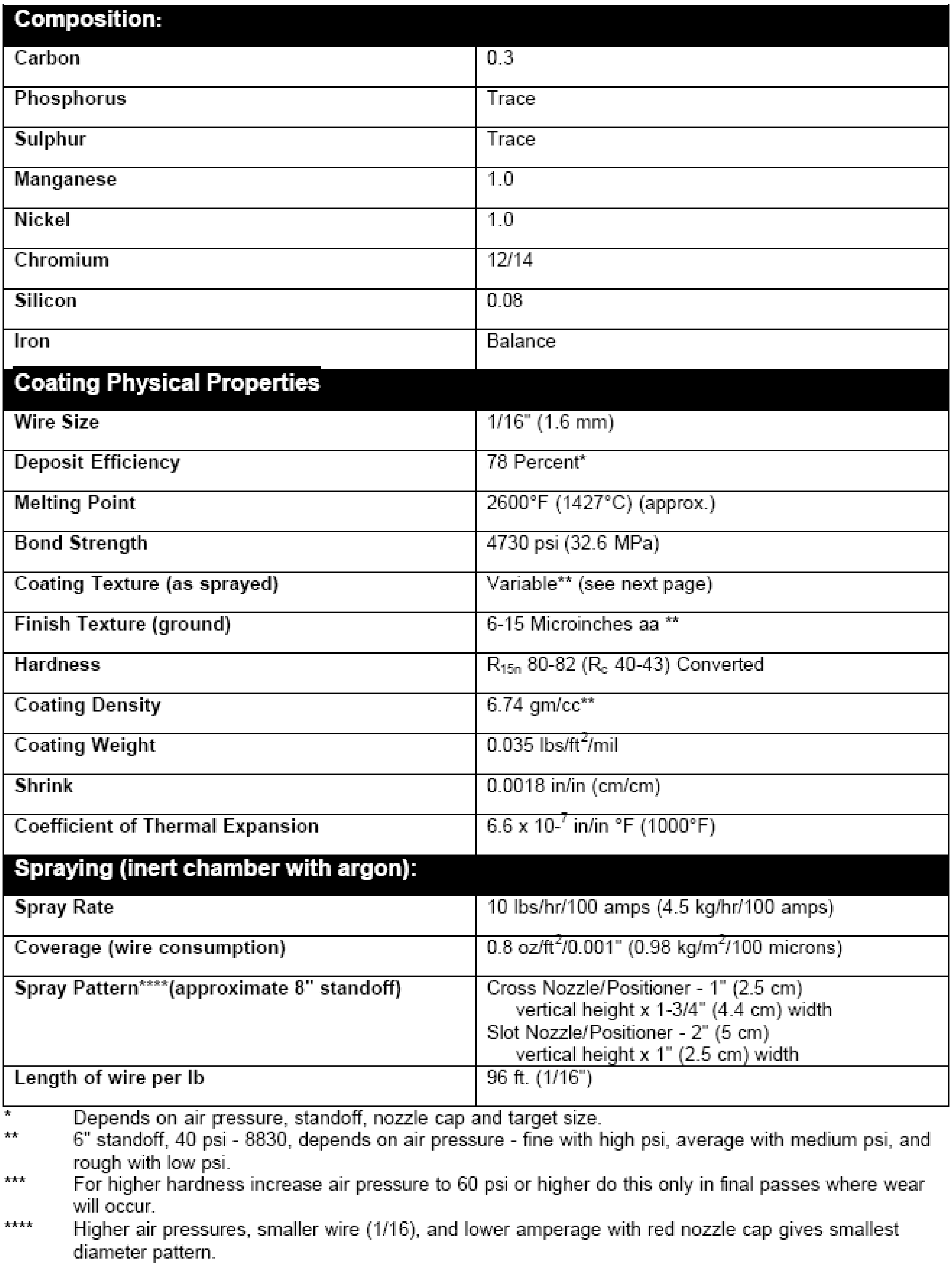


| Composition: (Typical) | |
|---|---|
| Nickel | 95 percent |
| Al | 5 percent |
| **Coating Physical Properties** | |
| Wire Size | 1/16 in (1.6 mm) |
| Deposit Efficiency | 70 Percent |
| Melting Point | 2642°F (1450°C) |
| Bond Strength Tensile[a] | 9,100 psi clean surface (62.8 MPa)<br>9,750 psi blasted surface (67.2 MPa) |
| Coating Texture (as sprayed) | Variable[b] (see next page) |
| Hardness | 55-80 $R_b$ |
| Coating Density | 7.8 gm/cc[c] |
| Coating Weight | 0.038 lbs/ft$^2$/mil |
| Magnetic Properties | Non-magnetic, slight magnetic susceptibility |
| Abrasion Resistance | Good |
| Impact, Sharp Edge and Bend Resistance | Excellent |
| Coefficient of Thermal Expansion | 7x10$^{-6}$ in/in°F (1000°F) |
| Electrical Resistivity | 200 micro ohm cm (appropriate) |
| Heat Resistance | Good[d] |
| **Spraying:** | |
| Spray Rate | 10 lbs/hr/100 amps (4.5 kg/hr/100 amps) |
| Coverage (wire consumption) | 0.9 oz/ft$^2$/0.001 in (1.10 kg/m$^2$/100 microns) |
| Spray Pattern[e] (approximate 8 in standoff) | Cross Nozzle/Positioner - 1 in (2.5 cm) vertical height x 1 3/4 in (4.4 cm) width<br>Slot Nozzle/Positioner - 2 in (5 cm) vertical height x 1 in (2.5 cm) width |
| Length of wire per lb | 84 ft. (1/16 in) |

**Fuente Sagger Del Ecuador**

## ANEXO 2

## ALAMBRE 60T 13% Chrome steel wire



| **Composition:** | |
|---|---|
| Carbon | 0.3 |
| Phosphorus | Trace |
| Sulphur | Trace |
| Manganese | 1.0 |
| Nickel | 1.0 |
| Chromium | 12/14 |
| Silicon | 0.08 |
| Iron | Balance |
| **Coating Physical Properties** | |
| Wire Size | 1/16" (1.6 mm) |
| Deposit Efficiency | 78 Percent* |
| Melting Point | 2600°F (1427°C) (approx.) |
| Bond Strength | 4730 psi (32.6 MPa) |
| Coating Texture (as sprayed) | Variable** (see next page) |
| Finish Texture (ground) | 6-15 Microinches aa ** |
| Hardness | $R_{15n}$ 80-82 ($R_c$ 40-43) Converted |
| Coating Density | 6.74 gm/cc** |
| Coating Weight | 0.035 lbs/ft$^2$/mil |
| Shrink | 0.0018 in/in (cm/cm) |
| Coefficient of Thermal Expansion | 6.6 x 10-$^{7}$ in/in °F (1000°F) |
| **Spraying (inert chamber with argon):** | |
| Spray Rate | 10 lbs/hr/100 amps (4.5 kg/hr/100 amps) |
| Coverage (wire consumption) | 0.8 oz/ft$^2$/0.001" (0.98 kg/m$^2$/100 microns) |
| Spray Pattern****(approximate 8" standoff) | Cross Nozzle/Positioner - 1" (2.5 cm) vertical height x 1-3/4" (4.4 cm) width<br>Slot Nozzle/Positioner - 2" (5 cm) vertical height x 1" (2.5 cm) width |
| Length of wire per lb | 96 ft. (1/16") |

* Depends on air pressure, standoff, nozzle cap and target size.

** 6" standoff, 40 psi - 8830, depends on air pressure - fine with high psi, average with medium psi, and rough with low psi.

*** For higher hardness increase air pressure to 60 psi or higher do this only in final passes where wear will occur.

**** Higher air pressures, smaller wire (1/16), and lower amperage with red nozzle cap gives smallest diameter pattern.

**Fuente Sagger Del Ecuador**

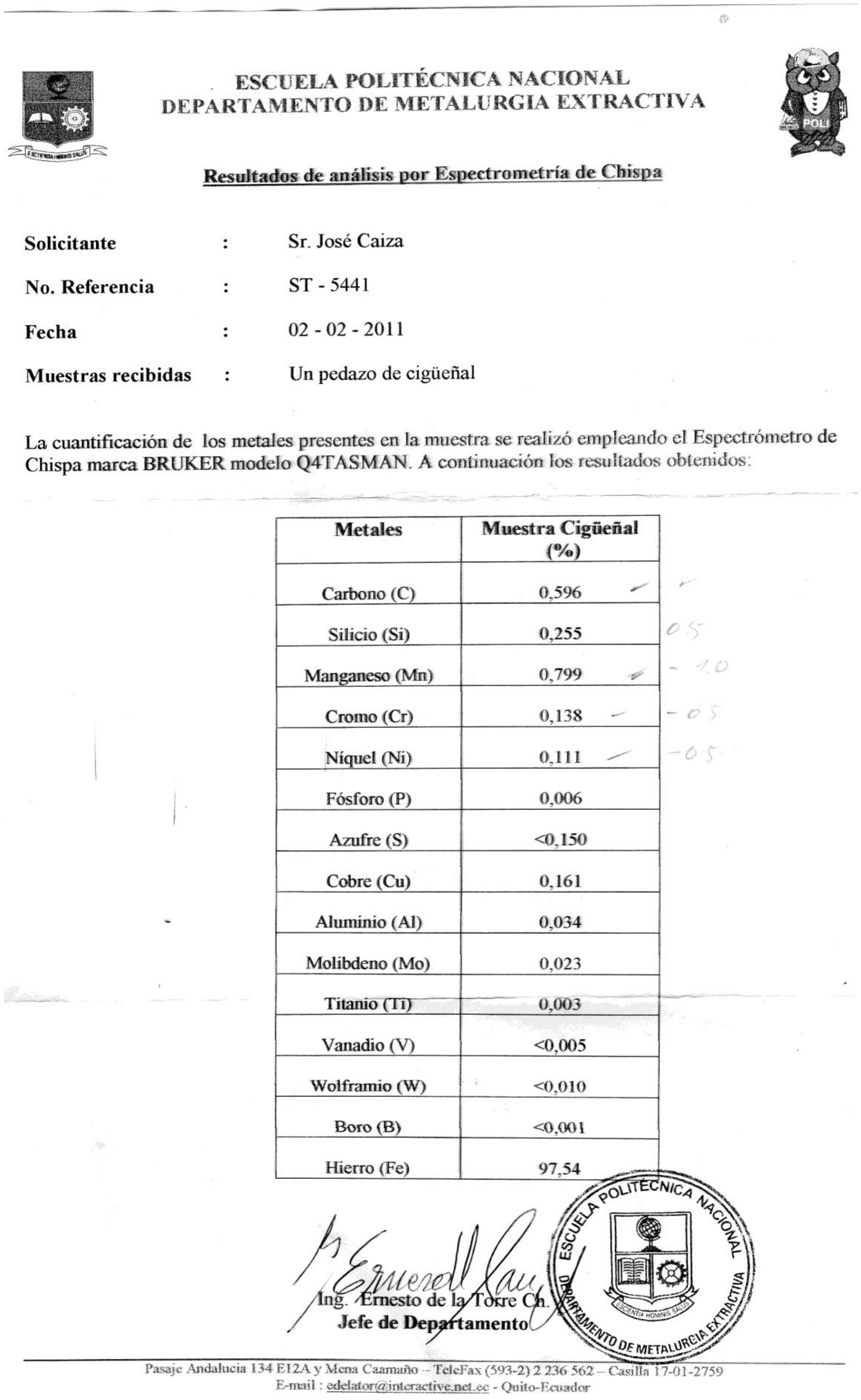
# ANEXO 3

# RESPALDO MAGNÉTICO DE LAS NORMAS APLICADAS A LA INVESTIGACIÓN

# ANEXO 4

# INFORMES DE LOS ENSAYOS REALIZADOS EN LOS LABORATORIOS DE UNIVERSIDAD POLITÉCNICA NACIONAL

# SEDE QUITO



## ESCUELA POLITÉCNICA NACIONAL
## DEPARTAMENTO DE METALURGIA EXTRACTIVA

### Resultados de análisis por Espectrometría de Chispa

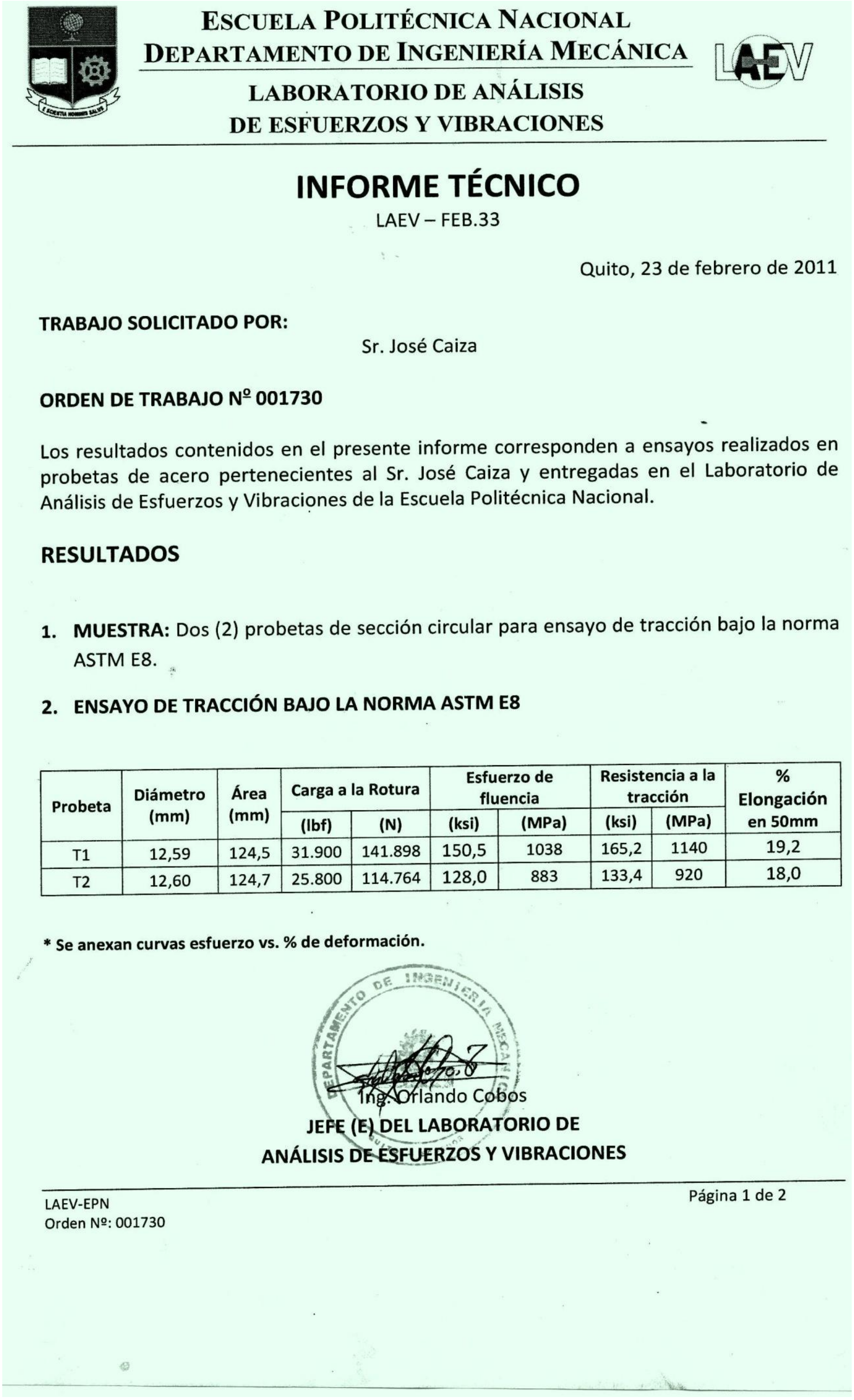
|  |  |  |
|---|---|---|
| **Solicitante** | : | Sr. José Caiza |
| **No. Referencia** | : | ST - 5441 |
| **Fecha** | : | 02 - 02 - 2011 |
| **Muestras recibidas** | : | Un pedazo de cigüeñal |

La cuantificación de los metales presentes en la muestra se realizó empleando el Espectrómetro de Chispa marca BRUKER modelo Q4TASMAN. A continuación los resultados obtenidos:

| Metales | Muestra Cigüeñal (%) |  |
|---|---|---|
| Carbono (C) | 0,596 ✓ | ✓ |
| Silicio (Si) | 0,255 | 0.5 |
| Manganeso (Mn) | 0,799 ✓ | - 1.0 |
| Cromo (Cr) | 0,138 | - 0.5 |
| Níquel (Ni) | 0,111 | -0.5 |
| Fósforo (P) | 0,006 |  |
| Azufre (S) | <0,150 |  |
| Cobre (Cu) | 0,161 |  |
| Aluminio (Al) | 0,034 |  |
| Molibdeno (Mo) | 0,023 |  |
| Titanio (Ti) | 0,003 |  |
| Vanadio (V) | <0,005 |  |
| Wolframio (W) | <0,010 |  |
| Boro (B) | <0,001 |  |
| Hierro (Fe) | 97,54 |  |

Ing. Ernesto de la Torre Ch.
**Jefe de Departamento**

Pasaje Andalucia 134 E12A y Mena Caamaño – TeleFax (593-2) 2 236 562 – Casilla 17-01-2759
E-mail : edelator@interactive.net.ec - Quito-Ecuador



ESCUELA POLITÉCNICA NACIONAL
DEPARTAMENTO DE INGENIERÍA MECÁNICA
LABORATORIO DE ANÁLISIS
DE ESFUERZOS Y VIBRACIONES

# INFORME TÉCNICO

LAEV – FEB.33

Quito, 23 de febrero de 2011

**TRABAJO SOLICITADO POR:**

Sr. José Caiza

**ORDEN DE TRABAJO Nº 001730**

Los resultados contenidos en el presente informe corresponden a ensayos realizados en probetas de acero pertenecientes al Sr. José Caiza y entregadas en el Laboratorio de Análisis de Esfuerzos y Vibraciones de la Escuela Politécnica Nacional.

## RESULTADOS

1. **MUESTRA:** Dos (2) probetas de sección circular para ensayo de tracción bajo la norma ASTM E8.

2. **ENSAYO DE TRACCIÓN BAJO LA NORMA ASTM E8**

| Probeta | Diámetro (mm) | Área (mm) | Carga a la Rotura | | Esfuerzo de fluencia | | Resistencia a la tracción | | % Elongación en 50mm |
|---|---|---|---|---|---|---|---|---|---|
| | | | (lbf) | (N) | (ksi) | (MPa) | (ksi) | (MPa) | |
| T1 | 12,59 | 124,5 | 31.900 | 141.898 | 150,5 | 1038 | 165,2 | 1140 | 19,2 |
| T2 | 12,60 | 124,7 | 25.800 | 114.764 | 128,0 | 883 | 133,4 | 920 | 18,0 |

*** Se anexan curvas esfuerzo vs. % de deformación.**

Ing. Orlando Cobos
**JEFE (E) DEL LABORATORIO DE**
**ANÁLISIS DE ESFUERZOS Y VIBRACIONES**

LAEV-EPN
Orden Nº: 001730

Página 1 de 2

**Anexo**

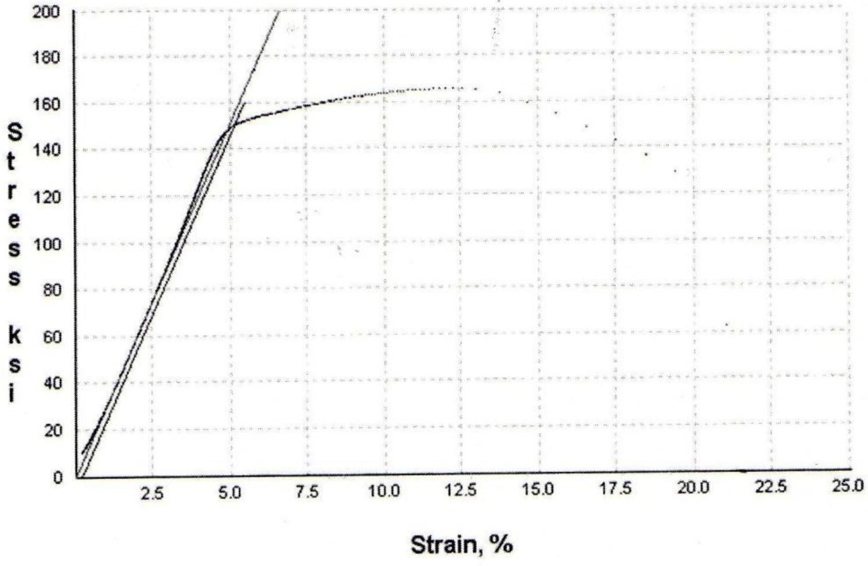


**Figura 1.** Esfuerzo vs. % deformación para la probeta T1.

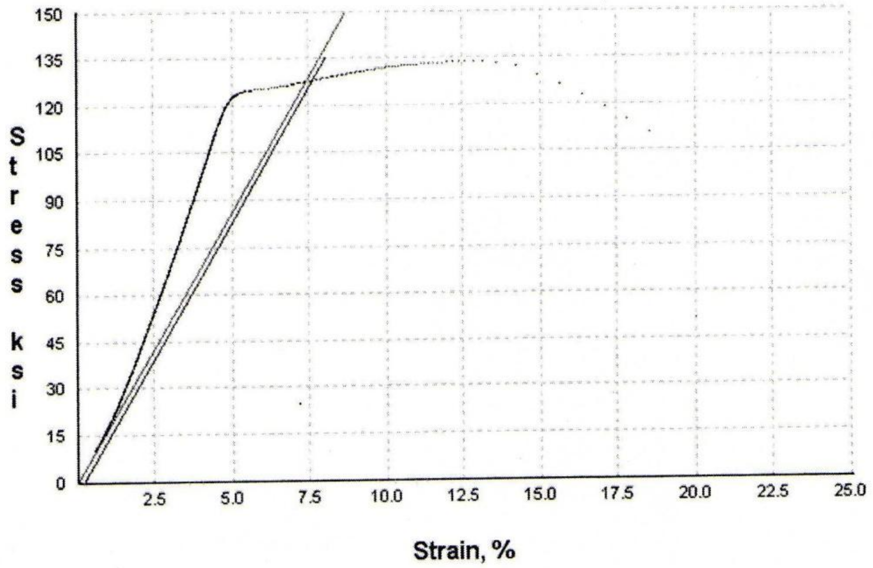


**Figura 2.** Esfuerzo vs. % deformación para la probeta T2.

**ESCUELA POLITÉCNICA NACIONAL**
**DEPARTAMENTO DE INGENIERÍA MECÁNICA**
**LABORATORIO DE MÁQUINAS HERRAMIENTAS**

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# INFORME TÉCNICO

Quito, 18 de marzo de 2011

**TRABAJO SOLICITADO POR:** Sr. José Caiza

Los resultados consignados en el presente informe corresponden a ensayos realizados en un solo tipo de acero AISI 4140 entregados en el Laboratorio de Máquinas Herramientas de la Facultad de Ingeniería Mecánica de la Escuela Politécnica Nacional.

## 1. MUESTRAS:

Se recibió muestras del material, 1 varilla de diámetro ϕ16.8 mm, para la construcción de las probetas, para luego proceder al ensayo de fatiga de viga rotatoria en estas probetas, según norma ASTM E 466-E 468:

## 2. ENSAYO DE FATIGA SEGÚN NORMA ASTM E 466-E 468

El material ensayado es acero proveniente de las muestras recibidas. Se procedió a realizar el ensayo de fatiga con diferentes valores de carga para 6 muestras. Las primeras 3 se realizaron con el material base sin metalizar y las 3 restantes con el proceso de metalizado.

Los resultados obtenidos se resumen a continuación:

- **RESULTADOS DEL MATERIAL SIN METALIZAR:**

| Probeta N° | Diámetro muestra (mm) | Carga [kg] | Ciclos [N] | Tiempo [min] | Sut (kpsi) | Sf (Kpsi) | Observación |
|---|---|---|---|---|---|---|---|
| 1 | ϕ16.8 | 10 | 207074 | 118.37 | 63 | 35,062 | Si falló |
| 2 | ϕ16.8 | 13 | 35649 | 20.37 | 63 | 39,521 | Si falló |
| 3 | ϕ16.8 | 15 | 212 | 0.121 | 63 | 56,010 | Falló por fluencia |

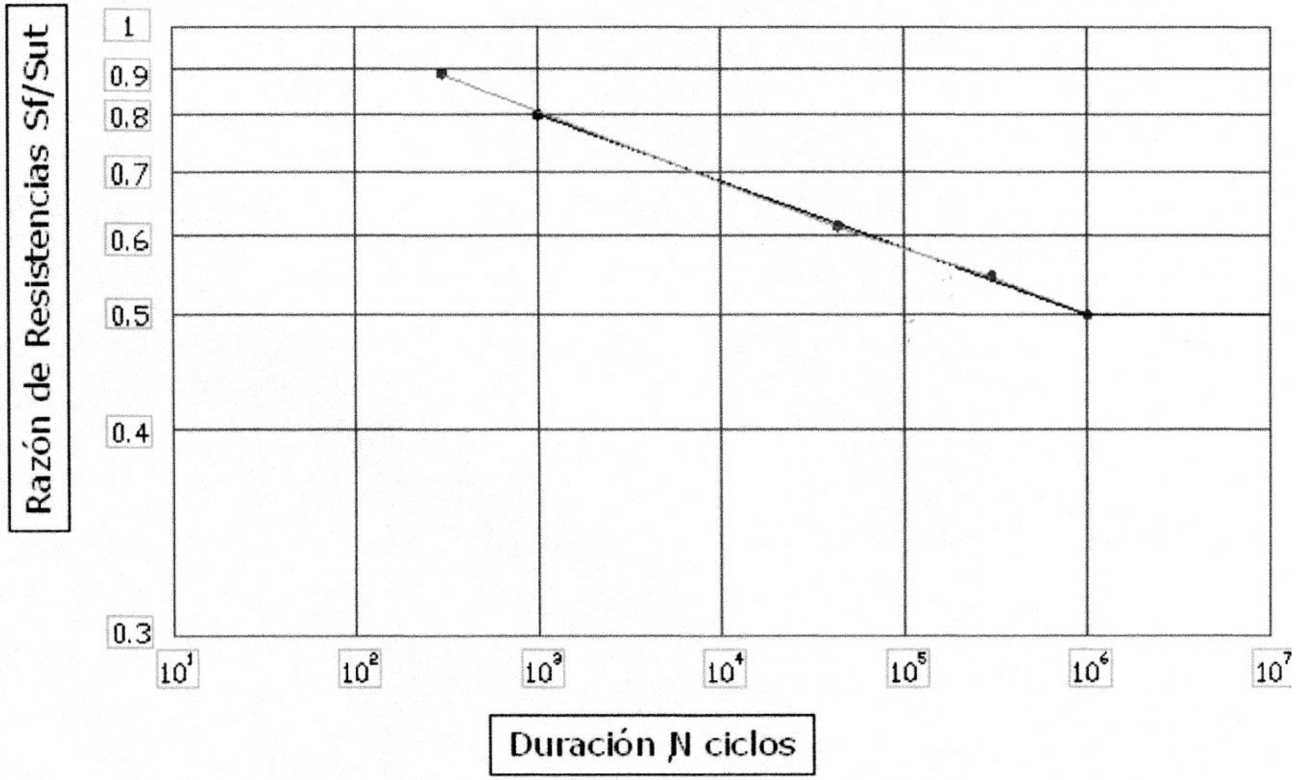
**Tabla 1: Datos de la prueba de Viga Rotatoria para material sin metalizar**

En el anexo 1 se nuestra el grafico de resistencia a la fatiga vs el numero de ciclo referente a la tabla 1.

## Anexo 1: Gráfico Sf'/Sut vs N

**Pobeta sin metalizar** (Cumple con la teoría de la fatiga)

| N | Sf'/sut |
|---|---|
| 207074 | 0.557 |
| 35649 | 0.627 |
| 212 | 0.889 |



- **RESULTADOS DEL MATERIAL METALIZADO:**

| Probeta Nº | Diámetro muestra (mm) | Carga [kg] | Ciclos [N] | Tiempo [min] | Observación |
|---|---|---|---|---|---|
| 1 | ϕ16.8 | 10 | 2378 | 1.36 | Si falló |
| 2 | ϕ16.8 | 13 | 1269 | 0.725 | Si falló |
| 3 | ϕ16.8 | 15 | 43 | 0.02 | Falló por fluencia |

**Tabla2: Datos de la prueba de Viga Rotatoria para material metalizado**

En el anexo 2 se indica el diagrama de carga aplicada vs el número de ciclos tanto para la tabla 1 y como para la tabla 2.

## 3. CONCLUSIONES

- Para graficar la resistencia a la fatiga vs el numero de ciclos, se obtuvo la resistencia a la tensión del Manual de Josehp Shigley; Ed.4; Mcgraw Hill; Pág. 866, de acuerdo a la especificación del materia proporcionada por el Sr. José Caiza (AISI 4041 HR), cuyo dato es de 63 Kpsi.

  El valor de la resistencia a la tensión de las probetas metaliza se desconoce, por lo que no se pudo obtener un grafico de resistencia a la fatiga vs el numero de ciclos, solamente se pudo realizar un grafico de la carga vs numero de ciclos (ver anexo 2).

- Las probetas se ensayaron con cargas de 10, 13y 15kg, las probetas ensayadas tanto metalizadas como no metalizadas con la carga de 15kg (39.6lbf) fallaron por resistencia estática, por falla de fluencia, por lo que no llegó al campo de la fatiga (la probeta metalizada fallo a los 43 ciclos y la no metalizada 212 ciclos).

- De acuerdo al gráfico del anexo 2, la probeta metalizada tiene un resistencia a la fatiga mucho menor que la probeta sin metalizar, en conclusión el metalizado realizado disminuye notablemente la resistencia en general.

Ing. Tito Velasteguí
**JEFE DEL LABORATORIO DE**
**MÁQUINAS HERRAMIENTAS**

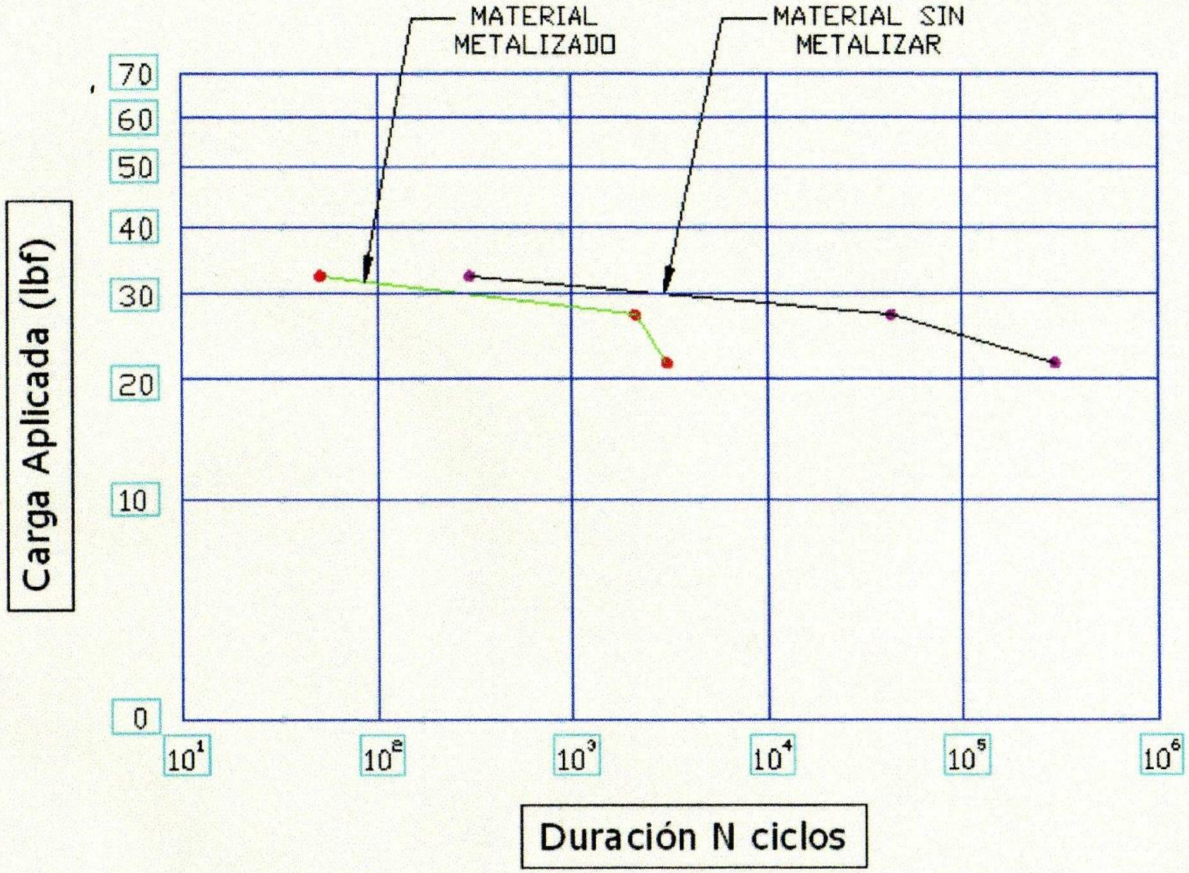
## Anexo 2: Gráfico Carga-N

MATERIAL
METALIZADO

| N | Carga (lbf) |
|---|---|
| 2378 | 22 |
| 1269 | 28.6 |
| 43 | 33 |

MATERIAL SIN
METALIZAR

| N | Carga (lbf) |
|---|---|
| 207074 | 22 |
| 35649 | 28.6 |
| 212 | 33 |



**ESCUELA POLITÉCNICA NACIONAL**

**DEPARTAMENTO DE MATERIALES**

**LABORATORIO DE METALOGRAFÍA**

# INFORME TÉCNICO

## Orden de Trabajo No. 001930

Solicitado por: José Sebastián Calza Vega

Muestras entregadas por: José Sebastián Calza Vega

Tipo de trabajo: Análisis metalográfico
Fecha: **02 de Junio del 2011**

### 1. ANTECEDENTES.

Se recibe en el Laboratorio de Metalografía de la Escuela Politécnica Nacional cuatro muestra metálicas. Se solicita realizar los análisis metalográficos.

### 2. IDENTIFICACIÓN DE MUESTRAS.

Tabla Nº1. Identificación de las muestras.

| *Muestra* | Observaciones |
|---|---|
| 1 | Sección de probeta de fatiga con una longitud de 62.45 mm y con diámetros de 7.65 mm y 12.65 mm. Fotografía Nº 1 |
| 2 | Sección de probeta de fatiga con una longitud de 62.00 mm y con diámetros de 7.85 mm y 12.65 mm. Se observa un recubrimiento metálico.Fotografía Nº 1 |
| 3 | Sección metálica con una longitud de 52.05 mm y un espesor de 20.90 mm. Fotografía Nº 1 |
| 4 | Sección de probeta de tracción con una longitud de 33.80 mm y con diámetros de 12.70 mm. Fotografía Nº 1 |

## 3. ANÁLISIS METALOGRÁFICO

Tabla Nº2. Análisis Metalográfico

| Muestra | Observaciones |
|---|---|
| **1**<br>**Transversal** | **100X:** Estructura del acero con matriz perlítica con contenido medio de carbono. Se observa la presencia de inclusiones del tipo silicato con tamaños no superiores a 47 um. Fotografía Nº2.<br>**500X:** Estructura del acero con matriz perlítica. Se observa que la perlita es gruesa y se descompone en glóbulos. Fotografía Nº3. |
| **2**<br>**Transversal** | **100X:** Estructura del acero con matriz perlítica con contenido medio de carbono. Se observa la presencia de inclusiones del tipo silicato con tamaños no superiores a 50 um. Fotografía Nº4.<br>**500X:** Estructura del acero con matriz perlítica. Se observa la presencia de perlita gruesa y zonas con la formación de cementita globular . Fotografía Nº5. |
| **3**<br>**Transversal** | **100X:** Estructura del acero con matriz perlítica con contenido medio de carbono. Se observa la presencia de inclusiones del tipo silicato con tamaños no superiores a 46 um. Fotografía Nº6.<br>**500X:** Estructura del acero con matriz perlítica. Se observa que la ferrita ha precipitado en los bordes de grano. Se observa también la presencia de sulfuro de manganeso. Fotografía Nº7. |
| **4**<br>**Transversal** | **100X:** Se observa una estructura de acero bainítico con gran cantidad de inclusiones del tipo silicato con tamaños no mayores a los 52 um. Fotografía Nº8.<br>**500X:** Se observa una estructura de acero bainítico con gran cantidad de inclusiones del tipo silicato. Se observa también la presencia de austenita retenida en la matriz. Fotografía Nº9. |

## 4. MAPEO DE DUREZAS

Tabla Nº3. Mapeo de durezas (Durezas medidas en Rockwell B).

| POSICIÓN | MUESTRA 1 | MUESTRA 2 (MATERIAL BASE) | MUESTRA 2 (RECUBRIMIENTO) | MUESTRA 3 |
|---|---|---|---|---|
| 1 | 85 | 79 | 84 | 91 |
| 2 | 81 | 78 | 85 | 99 |
| 3 | 79 | 80 | 85 | 95 |
| 4 | 82 | 77 | 92 | 98 |
| 5 | 86 | 86 | 87 | 97 |
| 6 | 83 | 82 | 80 | 100 |
| 7 | 85 | 75 | 82 | 101 |
| **PROMEDIO** | **83** | **79** | **85** | **98** |

## 5. CONCLUSIÓN

Las muestras analizadas corresponden a aceros de matriz perlítica con contenido medio de carbono. En las muestras 2 y 4 donde existe el metalizado, puede observarse que en el caso de la muestra 2 existe contacto entre el metalizado y el material base pero no existe una adherencia de las mismas. Mientras que en la muestra 4 existe separación entre el metalizado y el material base.

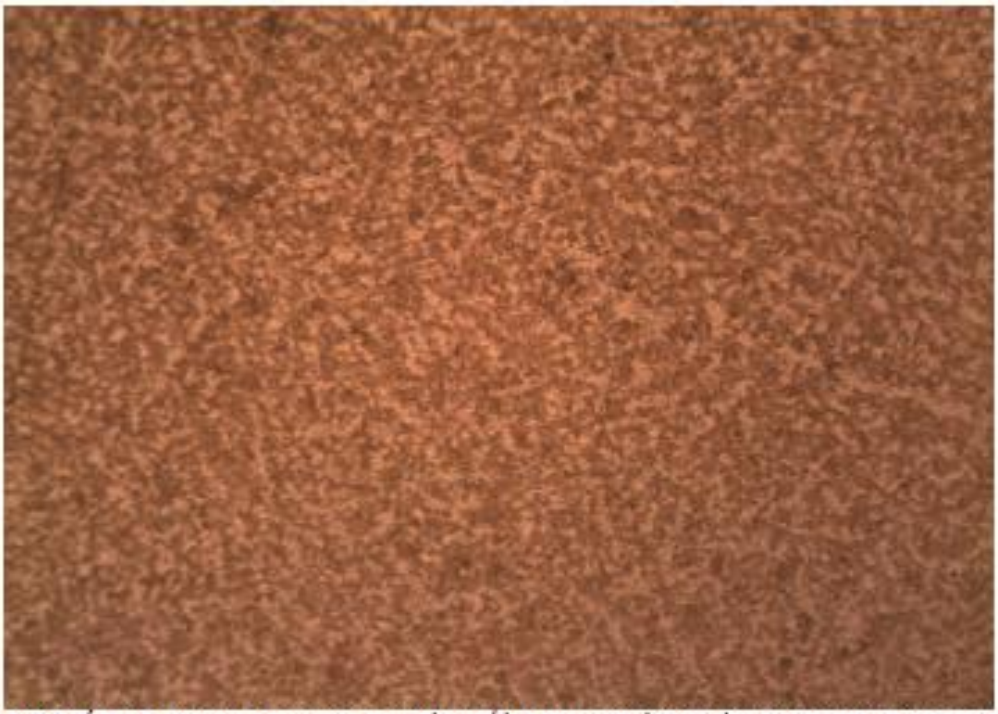
**Atentamente:**

Ing. Patricio Estupiñán, MSc.
**Jefe del Laboratorio de**
**Metalografía.**

**Nota**: Se anexan 13 fotografías.

## ANEXO

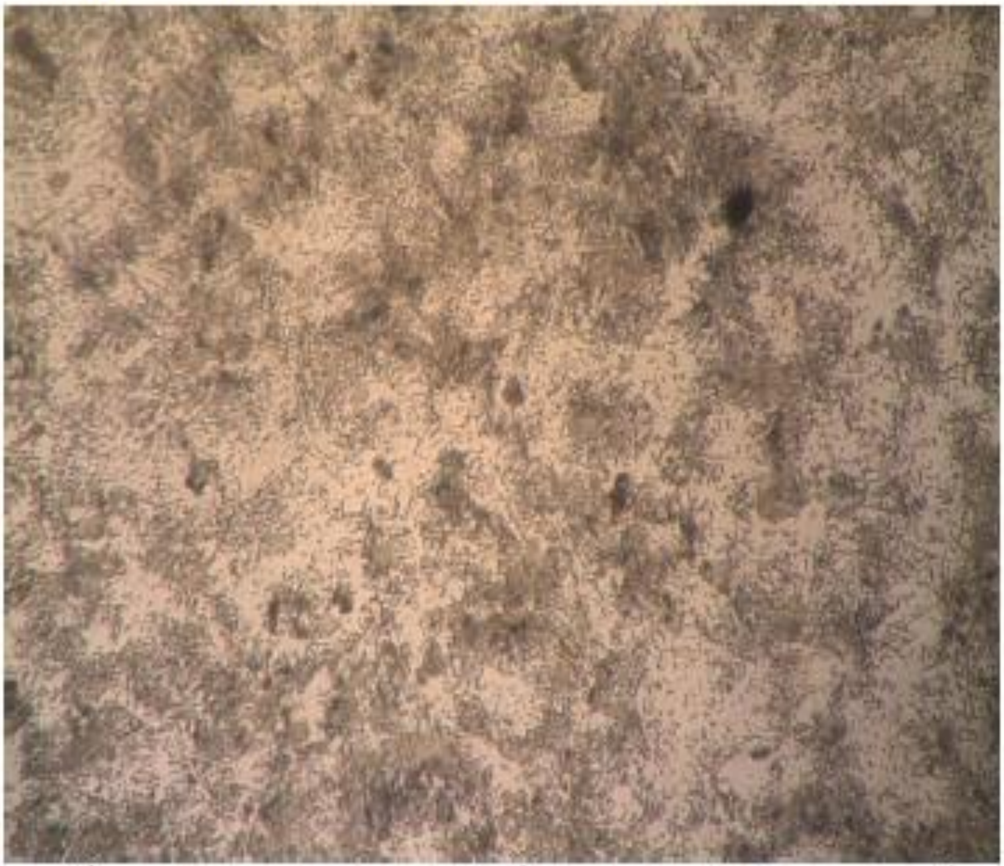
**Fotografía Nº1.** Muestras de las probetas que han sido analizadas vía metalografía.



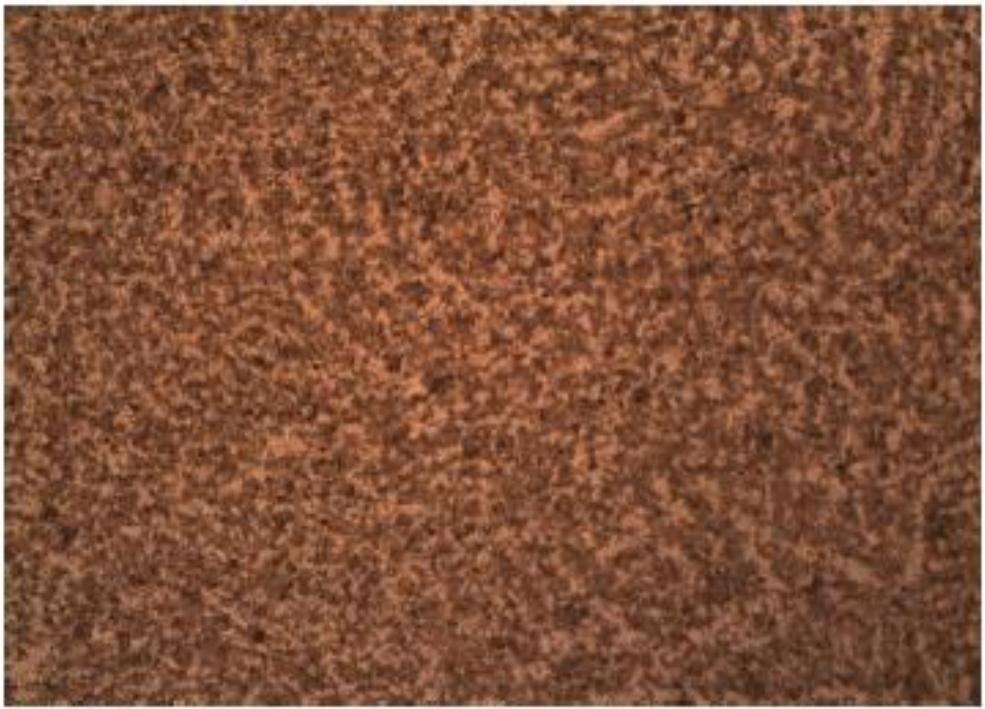
**Fotografía Nº2.** Estructura de acero de matriz perlítica con contenido medio de carbono. Se observa la presencia de inclusiones del tipo silicato con tamaños no superiores a 47 um. 100X.

**Fotografía Nº3.** Estructura del acero con matriz perlítica. Se observa que la perlita es gruesa y se descompone en glóbulos. 500X.

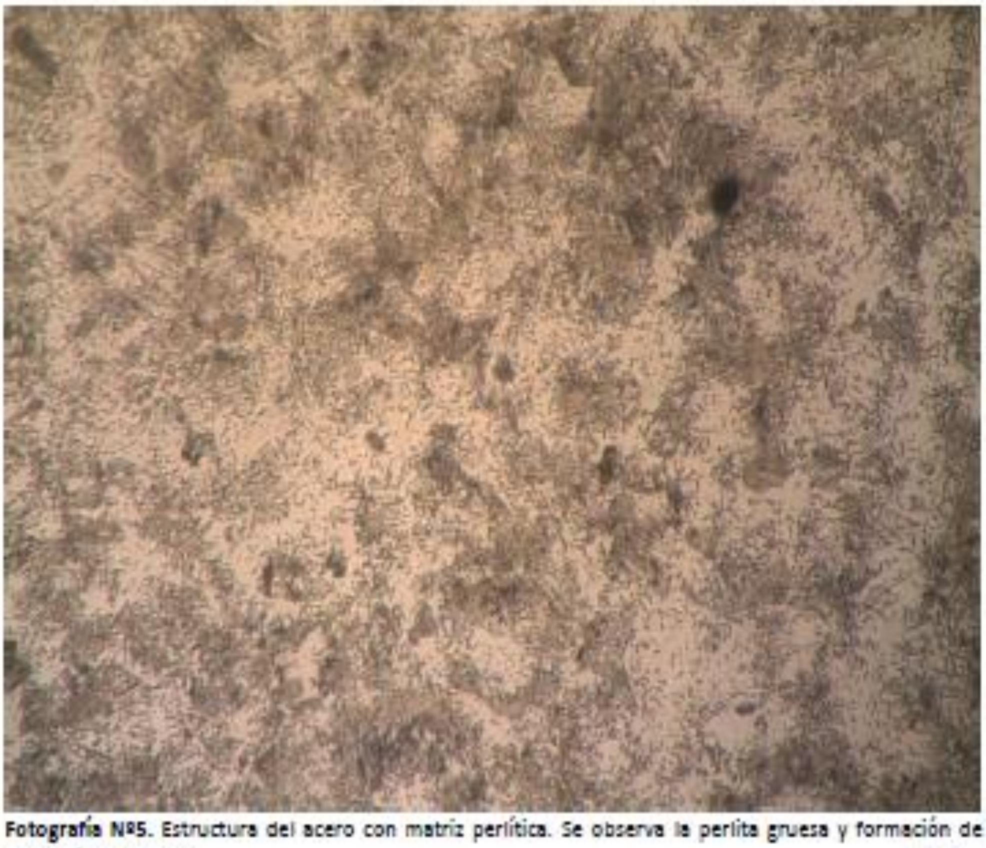
**Fotografía Nº4.** Estructura del acero con matriz perlítica con contenido medio de carbono. Se observa la presencia de inclusiones del tipo silicato con tamaños no superiores a 50 um. 100X.



**Fotografía Nº5.** Estructura del acero con matriz perlítica. Se observa la perlita gruesa y formación de cementita globular. 500X.



**Fotografía Nº4.** Estructura del acero con matriz perlítica con contenido medio de carbono. Se observa la presencia de inclusiones del tipo silicato con tamaños no superiores a 50 um. 100X.



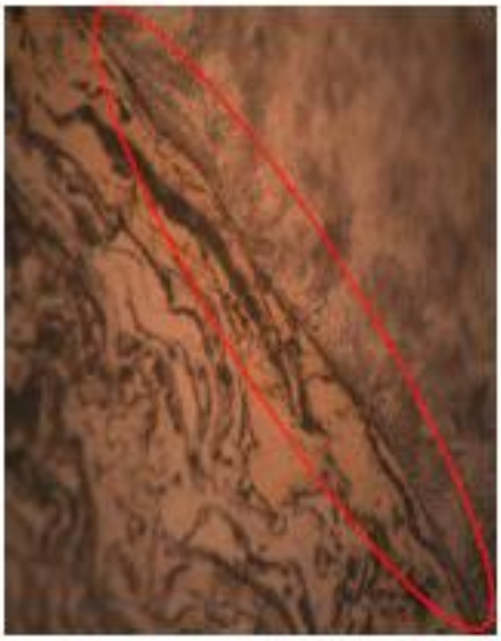
**Fotografía Nº5.** Estructura del acero con matriz perlítica. Se observa la perlita gruesa y formación de cementita globular. 500X.

**Fotografía Nº6.** Estructura del acero con matriz perlítica con contenido medio de carbono. Se observa la presencia de inclusiones del tipo silicato con tamaños no superiores a 46 um. 100X.

**Fotografía Nº7.** Estructura del acero con matriz perlítica. Se observa que la ferrita ha precipitado en los bordes de grano. Se observa también la presencia de sulfuro de manganeso. 500X.

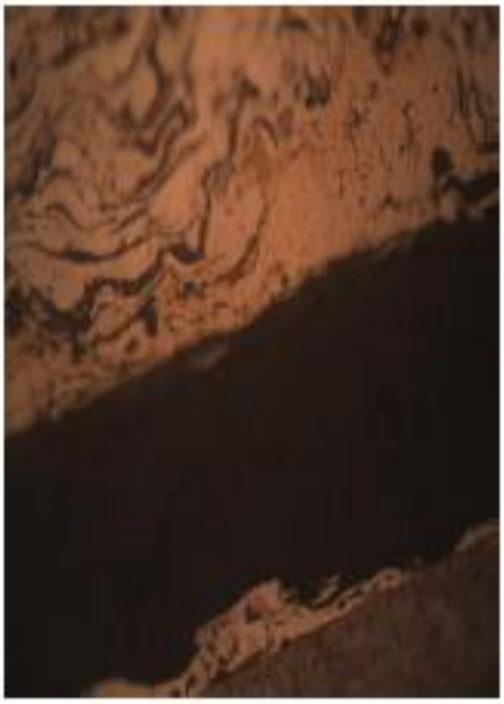
**Fotografía Nº8.** Se observa una estructura de acero bainítico con gran cantidad de inclusiones del tipo silicato con tamaños no mayores a los 52 um 100X.

**Fotografía Nº9.** Se observa una estructura de acero bainítico con gran cantidad de inclusiones del tipo silicato. Se observa también la presencia de austenita retenida en la matriz 500X.

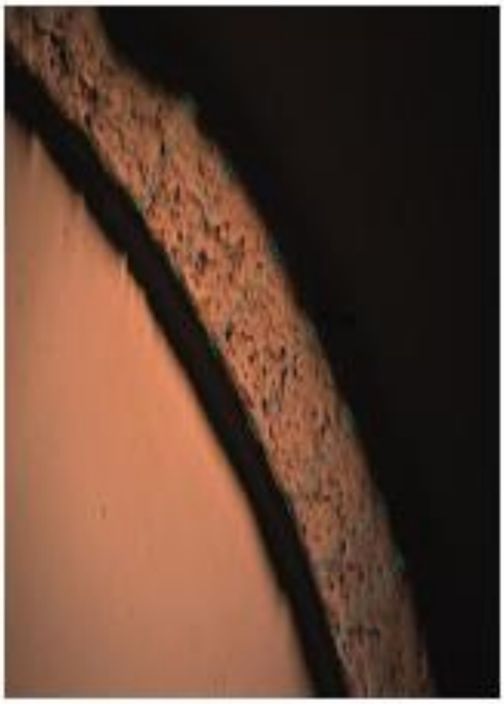


**Fotografía N°10.-** Muestra 2. Se puede observar que no existe buena adherencia entre el metalizado y el material base. 500X.

**Fotografía N°11.-** Muestra 2. Se puede observar que no existe adherencia entre el metalizado y el material base. Espesor promedio metalizado 435um. 100X.



**Fotografía N°12.-** Muestras 4. Se observa que existe desprendimiento del metalizado y el material base, observándose separación entre losmismos 500X.



**Fotografía N°13.-** Muestra 4. Se puede observar que existe separación del metalizado con el material base. Espesor promedio metalizado 520 um. 100X.

# ANEXO 5

## TABLA E – 23

## PROPIEDADES ESFUERZOS – DEFORMACIÓN MEDIA MONÓTONAS Y CÍCLICAS DE ACEROS SELECCIONADOS (continuación)

## Tabla E-23

Propiedades esfuerzo-deformación media monótonas y cíclicas de aceros seleccionados (*continuación*)

*Fuente*: *ASM Metals Reference Book*, 2a. ed., American Society for Metals, Metals Park, Ohio, 1983, p. 217.

| Grado (a) | Orientación (e) | Descripción (f) | Dureza HB | *Resistencia a la tensión* | | Reducción en área, % | Deformación verdadera a la fractura, $\varepsilon_f$ | *Módulo de elasticidad, E* | | *Coeficiente de resistencia a la fatiga,* $\sigma'_f$ | | Exponente de resistencia a la fatiga, b | Coeficiente de ductilidad a la fatiga, ef | Exponente de ductilidad a la fatiga, c |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | MPa | ksi | | | GPa | $10^4$ psi | MPa | ksi | | | |
| 4140 | L | T&R, DAT | 310 | 1 075 | 156 | 60 | 0.69 | 200 | 29.2 | 1 825 | 265 | −0.08 | 1.2 | −0.59 |
| 4142 | L | DAT | 310 | 1 060 | 154 | 29 | 0.35 | 200 | 29 | 1 450 | 210 | −0.10 | 0.22 | −0.51 |
| 4142 | L | DAT | 335 | 1 250 | 181 | 28 | 0.34 | 200 | 28.9 | 1 250 | 181 | −0.08 | 0.06 | −0.62 |
| 4142 | L | T&R | 380 | 1 415 | 205 | 48 | 0.66 | 205 | 30 | 1 825 | 265 | −0.08 | 0.45 | −0.75 |
| 4142 | L | T&R y deformado | 400 | 1 550 | 225 | 47 | 0.63 | 200 | 29 | 1 895 | 275 | −0.09 | 0.50 | −0.75 |
| 4142 | L | T&R | 450 | 1 760 | 255 | 42 | 0.54 | 205 | 30 | 2 000 | 290 | −0.08 | 0.40 | −0.73 |
| 4142 | L | T&R y deformado | 475 | 2 035 | 295 | 20 | 0.22 | 200 | 29 | 2 070 | 300 | −0.082 | 0.20 | −0.77 |
| 4142 | L | T&R y deformado | 450 | 1 930 | 280 | 37 | 0.46 | 200 | 29 | 2 105 | 305 | −0.09 | 0.60 | −0.76 |
| 4142 | L | T&R | 475 | 1 930 | 280 | 35 | 0.43 | 205 | 30 | 2 170 | 315 | −0.081 | 0.09 | −0.61 |
| 4142 | L | T&R | 560 | 2 240 | 325 | 27 | 0.31 | 205 | 30 | 2 655 | 385 | −0.089 | 0.07 | −0.76 |
| 4340 | L | HR, A | 243 | 825 | 120 | 43 | 0.57 | 195 | 28 | 1 200 | 174 | −0.095 | 0.45 | −0.54 |
| 4340 | L | T&R | 409 | 1 470 | 213 | 38 | 0.48 | 200 | 29 | 2 000 | 290 | −0.091 | 0.48 | −0.60 |
| 4340 | L | T&R | 350 | 1 240 | 180 | 57 | 0.84 | 195 | 28 | 1 655 | 240 | −0.076 | 0.73 | −0.62 |
| 5160 | L | T&R | 430 | 1 670 | 242 | 42 | 0.87 | 195 | 28 | 1 930 | 280 | −0.071 | 0.40 | −0.57 |
| 52100 | L | SH, T&R | 518 | 2 015 | 292 | 11 | 0.12 | 205 | 30 | 2 585 | 375 | −0.09 | 0.18 | −0.56 |
| 9262 | L | A | 260 | 925 | 134 | 14 | 0.16 | 205 | 30 | 1 040 | 151 | −0.071 | 0.16 | −0.47 |
| 9262 | L | T&R | 280 | 1 000 | 145 | 33 | 0.41 | 195 | 28 | 1 220 | 177 | −0.073 | 0.41 | −0.60 |
| 9262 | L | T&R | 410 | 565 | 227 | 32 | 0.38 | 200 | 29 | 1 855 | 269 | −0.057 | 0.38 | −0.65 |
| 950C (d) | LT | Placa HR | 159 | 565 | 82 | 64 | 1.03 | 205 | 29.6 | 1 170 | 170 | −0.12 | 0.95 | −0.61 |
| 950C (d) | L | Barra HR | 150 | 565 | 82 | 69 | 1.19 | 205 | 30 | 970 | 141 | −0.11 | 0.85 | −0.59 |
| 950X (d) | L | Canal placa | 150 | 440 | 64 | 65 | 1.06 | 205 | 30 | 625 | 91 | −0.075 | 0.35 | −0.54 |
| 950X (d) | L | Placa HR | 156 | 530 | 77 | 72 | 1.24 | 205 | 29.5 | 1 005 | 146 | −0.10 | 0.85 | −0.61 |
| 950X (d) | L | Canal placa | 225 | 695 | 101 | 68 | 1.15 | 195 | 28.2 | 1 055 | 153 | −0.08 | 0.21 | −0.53 |

*Notas*: (a) grado AISI/SAE, a menos que se indique lo contrario. (b) Designación ASTM. (c) Designación propietaria. (d) Grado SAE HSLA. (e) Orientación de eje de la probeta, relativa a la dirección de laminado; L es longitudinal (paralela a la dirección de laminado); LT es transversal larga (perpendicular a la dirección de laminado. (f) STA, solución tratada y envejecida; HR, laminado en caliente; CD, laminado en frío; T&R, templado y revenido; CDSR, estirado en frío aliviado de deformaciones; DAT, estirado a temperatura; A, recocido.

# ANEXO 6

## TABLA 1

ASTM E 140 – 07

**TABLE 1 Approximate Hardness Conversion Numbers for Non-Austenitic Steels (Rockwell C Hardness Range)[A, B]**

| Rockwell C Hardness Number 150 kgf (HRC) | Vickers Hardness Number (HV) | Brinell Hardness Number[C] | | Knoop Hardness, Number 500-gf and Over (HK) | Rockwell Hardness Number | | Rockwell Superficial Hardness Number | | | Scleroscope Hardness Number[D] | Rockwell C Hardness Number 150 kgf (HRC) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 10-mm Standard Ball, 3000-kgf (HBS) | 10-mm Carbide Ball, 3000-kgf (HBW) | | A Scale, 60-kgf (HRA) | D Scale, 100-kgf (HRD) | 15-N Scale, 15-kgf (HR 15-N) | 30-N Scale, 30-kgf (HR 30-N) | 45-N Scale, 45-kgf (HR 45-N) | | |
| 68 | 940 | ... | ... | 920 | 85.6 | 76.9 | 93.2 | 84.4 | 75.4 | 97.3 | 68 |
| 67 | 900 | ... | ... | 895 | 85.0 | 76.1 | 92.9 | 83.6 | 74.2 | 95.0 | 67 |
| 66 | 865 | ... | ... | 870 | 84.5 | 75.4 | 92.5 | 82.8 | 73.3 | 92.7 | 66 |
| 65 | 832 | ... | (739) | 846 | 83.9 | 74.5 | 92.2 | 81.9 | 72.0 | 90.6 | 65 |
| 64 | 800 | ... | (722) | 822 | 83.4 | 73.8 | 91.8 | 81.1 | 71.0 | 88.5 | 64 |
| 63 | 772 | ... | (705) | 799 | 82.8 | 73.0 | 91.4 | 80.1 | 69.9 | 86.5 | 63 |
| 62 | 746 | ... | (688) | 776 | 82.3 | 72.2 | 91.1 | 79.3 | 68.8 | 84.5 | 62 |
| 61 | 720 | ... | (670) | 754 | 81.8 | 71.5 | 90.7 | 78.4 | 67.7 | 82.6 | 61 |
| 60 | 697 | ... | (654) | 732 | 81.2 | 70.7 | 90.2 | 77.5 | 66.6 | 80.8 | 60 |
| 59 | 674 | ... | 634 | 710 | 80.7 | 69.9 | 89.8 | 76.6 | 65.5 | 79.0 | 59 |
| 58 | 653 | ... | 615 | 690 | 80.1 | 69.2 | 89.3 | 75.7 | 64.3 | 77.3 | 58 |
| 57 | 633 | ... | 595 | 670 | 79.6 | 68.5 | 88.9 | 74.8 | 63.2 | 75.6 | 57 |
| 56 | 613 | ... | 577 | 650 | 79.0 | 67.7 | 88.3 | 73.9 | 62.0 | 74.0 | 56 |
| 55 | 595 | ... | 560 | 630 | 78.5 | 66.9 | 87.9 | 73.0 | 60.9 | 72.4 | 55 |
| 54 | 577 | ... | 543 | 612 | 78.0 | 66.1 | 87.4 | 72.0 | 59.8 | 70.9 | 54 |
| 53 | 560 | ... | 525 | 594 | 77.4 | 65.4 | 86.9 | 71.2 | 58.6 | 69.4 | 53 |
| 52 | 544 | (500) | 512 | 576 | 76.8 | 64.6 | 86.4 | 70.2 | 57.4 | 67.9 | 52 |
| 51 | 528 | (487) | 496 | 558 | 76.3 | 63.8 | 85.9 | 69.4 | 56.1 | 66.5 | 51 |
| 50 | 513 | (475) | 481 | 542 | 75.9 | 63.1 | 85.5 | 68.5 | 55.0 | 65.1 | 50 |
| 49 | 498 | (464) | 469 | 526 | 75.2 | 62.1 | 85.0 | 67.6 | 53.8 | 63.7 | 49 |
| 48 | 484 | 451 | 455 | 510 | 74.7 | 61.4 | 84.5 | 66.7 | 52.5 | 62.4 | 48 |
| 47 | 471 | 442 | 443 | 495 | 74.1 | 60.8 | 83.9 | 65.8 | 51.4 | 61.1 | 47 |
| 46 | 458 | 432 | 432 | 480 | 73.6 | 60.0 | 83.5 | 64.8 | 50.3 | 59.8 | 46 |
| 45 | 446 | 421 | 421 | 466 | 73.1 | 59.2 | 83.0 | 64.0 | 49.0 | 58.5 | 45 |
| 44 | 434 | 409 | 409 | 452 | 72.5 | 58.5 | 82.5 | 63.1 | 47.8 | 57.3 | 44 |
| 43 | 423 | 400 | 400 | 438 | 72.0 | 57.7 | 82.0 | 62.2 | 46.7 | 56.1 | 43 |
| 42 | 412 | 390 | 390 | 426 | 71.5 | 56.9 | 81.5 | 61.3 | 45.5 | 54.9 | 42 |
| 41 | 402 | 381 | 381 | 414 | 70.9 | 56.2 | 80.9 | 60.4 | 44.3 | 53.7 | 41 |
| 40 | 392 | 371 | 371 | 402 | 70.4 | 55.4 | 80.4 | 59.5 | 43.1 | 52.6 | 40 |
| 39 | 382 | 362 | 362 | 391 | 69.9 | 54.6 | 79.9 | 58.6 | 41.9 | 51.5 | 39 |
| 38 | 372 | 353 | 353 | 380 | 69.4 | 53.8 | 79.4 | 57.7 | 40.8 | 50.4 | 38 |
| 37 | 363 | 344 | 344 | 370 | 68.9 | 53.1 | 78.8 | 56.8 | 39.6 | 49.3 | 37 |
| 36 | 354 | 336 | 336 | 360 | 68.4 | 52.3 | 78.3 | 55.9 | 38.4 | 48.2 | 36 |
| 35 | 345 | 327 | 327 | 351 | 67.9 | 51.5 | 77.7 | 55.0 | 37.2 | 47.1 | 35 |
| 34 | 336 | 319 | 319 | 342 | 67.4 | 50.8 | 77.2 | 54.2 | 36.1 | 46.1 | 34 |
| 33 | 327 | 311 | 311 | 334 | 66.8 | 50.0 | 76.6 | 53.3 | 34.9 | 45.1 | 33 |
| 32 | 318 | 301 | 301 | 326 | 66.3 | 49.2 | 76.1 | 52.1 | 33.7 | 44.1 | 32 |
| 31 | 310 | 294 | 294 | 318 | 65.8 | 48.4 | 75.6 | 51.3 | 32.5 | 43.1 | 31 |
| 30 | 302 | 286 | 286 | 311 | 65.3 | 47.7 | 75.0 | 50.4 | 31.3 | 42.2 | 30 |
| 29 | 294 | 279 | 279 | 304 | 64.8 | 47.0 | 74.5 | 49.5 | 30.1 | 41.3 | 29 |
| 28 | 286 | 271 | 271 | 297 | 64.3 | 46.1 | 73.9 | 48.6 | 28.9 | 40.4 | 28 |
| 27 | 279 | 264 | 264 | 290 | 63.8 | 45.2 | 73.3 | 47.7 | 27.8 | 39.5 | 27 |
| 26 | 272 | 258 | 258 | 284 | 63.3 | 44.6 | 72.8 | 46.8 | 26.7 | 38.7 | 26 |
| 25 | 266 | 253 | 253 | 278 | 62.8 | 43.8 | 72.2 | 45.9 | 25.5 | 37.8 | 25 |
| 24 | 260 | 247 | 247 | 272 | 62.4 | 43.1 | 71.6 | 45.0 | 24.3 | 37.0 | 24 |
| 23 | 254 | 243 | 243 | 266 | 62.0 | 42.1 | 71.0 | 44.0 | 23.1 | 36.3 | 23 |
| 22 | 248 | 237 | 237 | 261 | 61.5 | 41.6 | 70.5 | 43.2 | 22.0 | 35.5 | 22 |
| 21 | 243 | 231 | 231 | 256 | 61.0 | 40.9 | 69.9 | 42.3 | 20.7 | 34.8 | 21 |
| 20 | 238 | 226 | 226 | 251 | 60.5 | 40.1 | 69.4 | 41.5 | 19.6 | 34.2 | 20 |

[A] In the table headings, *force* refers to total test forces.

[B] Appendix X1 contains equations converting determined hardness scale numbers to Rockwell C hardness numbers for non-austenitic steels. Refer to 1.11 before using conversion equations.

[C] The Brinell hardness numbers in parentheses are outside the range recommended for Brinell hardness testing in 8.1 of Test Method E 10.

[D] These Scleroscope hardness conversions are based on Vickers—Scleroscope hardness relationships developed from Vickers hardness data provided by the National Bureau of Standards for 13 steel reference blocks, Scleroscope hardness values obtained on these blocks by the Shore Instrument and Mfg. Co., Inc., the Roll Manufacturers Institute, and members of this institute, and also on hardness conversions previously published by the American Society for Metals and the Roll Manufacturers Institute.

## ANEXO 7

# Historial de Ordenes de Trabajo Rectificadora Pazmiño S.A

PAZMIÑO S.A
Rectificadora

## Cuadro Valor Trabajos y Repuestos
## Periodo Enero 2010 - Abril 2010

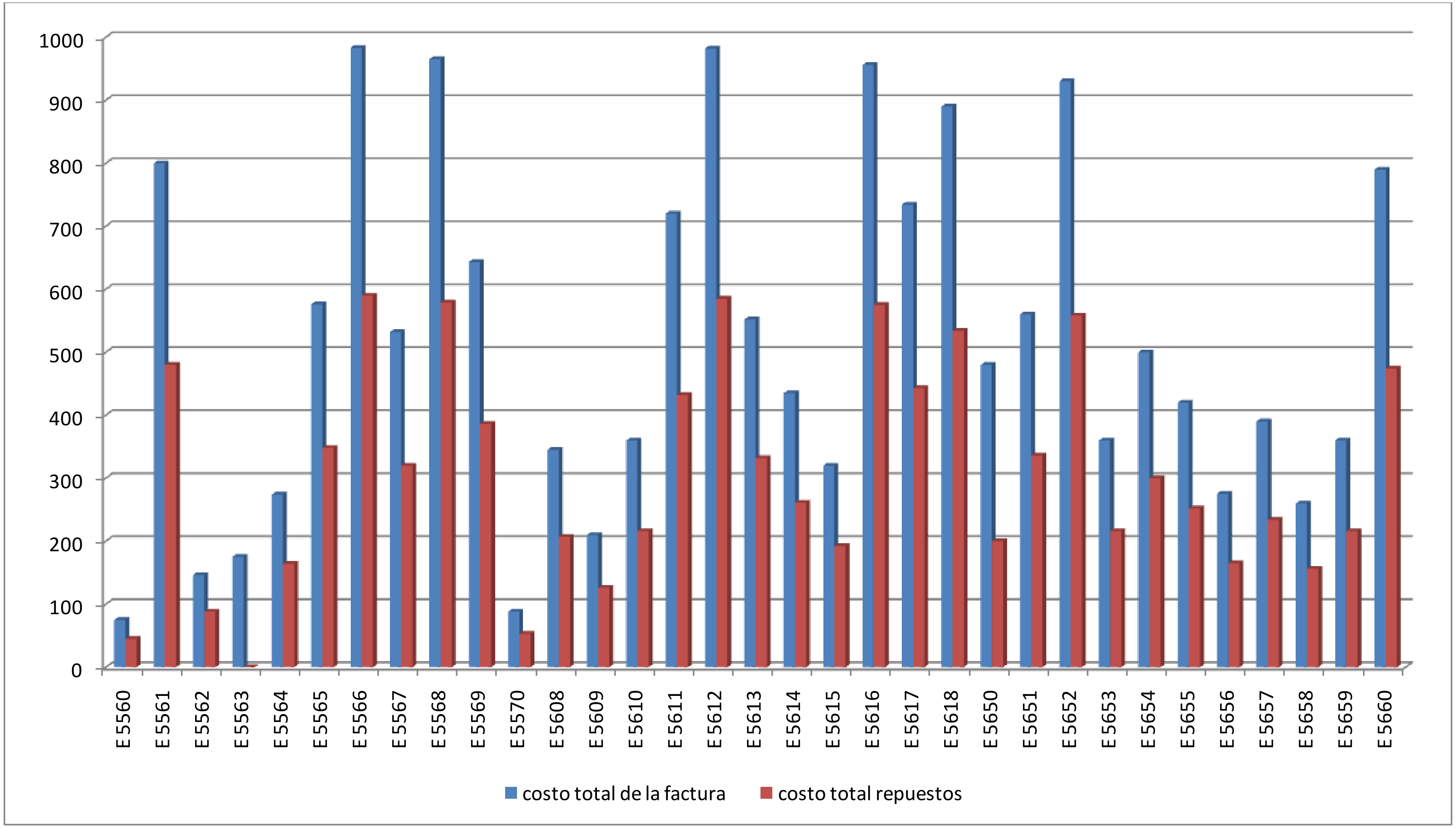
| Orden de trabajo | Valor en dólares americanos | | |
|---|---|---|---|
| | Trabajos | Repuestos | V.T.Factura |
| E 5560 | 30 | 45 | 75 |
| E 5561 | 320 | 480 | 800 |
| E 5562 | 58 | 88 | 146 |
| E 5563 | 175 | 0 | 175 |
| E 5564 | 110 | 164 | 274 |
| E 5565 | 228 | 348 | 576 |
| E 5566 | 393 | 590 | 983 |
| E 5567 | 212 | 320 | 532 |
| E 5568 | 386 | 579 | 965 |
| E 5569 | 257 | 386 | 643 |
| E 5570 | 35 | 53 | 88 |
| E 5571 | 15 | 0 | 15 |
| E 5572 | 580 | 400 | 980 |
| E 5573 | 138 | 207 | 345 |
| E 5574 | 95 | 148 | 243 |
| E 5575 | 216 | 330 | 546 |
| E 5576 | 315 | 474 | 789 |
| E 5577 | 240 | 0 | 240 |
| E 5578 | 144 | 216 | 360 |
| E 5579 | 56 | 84 | 140 |
| E 5580 | 94 | 143 | 237 |
| E 5581 | 301 | 452 | 753 |
| E 5582 | 228 | 346 | 574 |
| E 5583 | 190 | 0 | 190 |
| E 5584 | 94 | 141 | 235 |
| E 5585 | 220 | 330 | 550 |
| E 5586 | 258 | 387 | 645 |
| E 5587 | 75 | 0 | 75 |
| E 5588 | 25 | 0 | 25 |
| E 5589 | 150 | 225 | 375 |
| E 5590 | 182 | 274 | 456 |
| E 5591 | 252 | 384 | 636 |
| E 5592 | 49 | 78 | 127 |
| E 5593 | 398 | 597 | 995 |
| E 5594 | 184 | 270 | 454 |
| E 5595 | 224 | 340 | 564 |
| E 5596 | 264 | 390 | 654 |
| E 5597 | 385 | 582 | 967 |

PAZMIÑO S.A
Rectificadora

## Cuadro Valor Trabajos y Repuestos
## Periodo Enero 2010 - Abril 2010

| Orden de trabajo | Valor en dólares americanos | | |
|---|---|---|---|
| | Trabajos | Repuestos | V.T.Factura |
| E 5598 | 94 | 144 | 238 |
| E 5599 | 354 | 525 | 879 |
| E 5600 | 308 | 445 | 753 |
| E 5601 | 332 | 502 | 834 |
| E 5602 | 212 | 320 | 532 |
| E 5603 | 128 | 195 | 323 |
| E 5604 | 135 | 207 | 342 |
| E 5605 | 70 | 105 | 175 |
| E 5606 | 15 | 0 | 15 |
| E 5607 | 44 | 66 | 110 |
| E 5608 | 138 | 207 | 345 |
| E 5609 | 84 | 126 | 210 |
| E 5610 | 144 | 216 | 360 |
| E 5611 | 288 | 432 | 720 |
| E 5612 | 397 | 585 | 982 |
| E 5613 | 220 | 332 | 552 |
| E 5614 | 174 | 261 | 435 |
| E 5615 | 128 | 192 | 320 |
| E 5616 | 381 | 575 | 956 |
| E 5617 | 291 | 443 | 734 |
| E 5618 | 356 | 534 | 890 |
| E 5619 | 316 | 474 | 790 |
| E 5620 | 332 | 450 | 782 |
| E 5621 | 84 | 130 | 214 |
| E 5622 | 36 | 54 | 90 |
| E 5623 | 48 | 72 | 120 |
| E 5624 | 180 | 270 | 450 |
| E 5625 | 300 | 450 | 750 |
| E 5626 | 332 | 498 | 830 |
| E 5627 | 48 | 72 | 120 |
| E 5628 | 224 | 336 | 560 |
| E 5629 | 450 | 350 | 800 |
| E 5630 | 295 | 375 | 670 |
| E 5631 | 356 | 534 | 890 |
| E 5632 | 68 | 102 | 170 |
| E 5633 | 100 | 150 | 250 |
| E 5634 | 172 | 258 | 430 |
| E 5635 | 240 | 360 | 600 |

| PAZMIÑO S.A<br>Rectificadora | Cuadro Valor Trabajos y Repuestos<br>Periodo Enero 2010 - Abril 2010 | | |
|---|---|---|---|
| Orden de trabajo | Valor en dólares americanos | | |
| | Trabajos | Repuestos | V.T.Factura |
| E 5636 | 180 | 270 | 450 |
| E 5637 | 75 | 0 | 75 |
| E 5638 | 224 | 336 | 560 |
| E 5639 | 264 | 396 | 660 |
| E 5640 | 164 | 246 | 410 |
| E 5641 | 140 | 210 | 350 |
| E 5642 | 224 | 336 | 560 |
| E 5643 | 300 | 450 | 750 |
| E 5644 | 328 | 492 | 820 |
| E 5645 | 48 | 72 | 120 |
| E 5646 | 76 | 114 | 190 |
| E 5647 | 152 | 228 | 380 |
| E 5648 | 160 | 240 | 400 |
| E 5649 | 88 | 132 | 220 |
| E 5650 | 280 | 200 | 480 |
| E 5651 | 224 | 336 | 560 |
| E 5652 | 372 | 558 | 930 |
| E 5653 | 144 | 216 | 360 |
| E 5654 | 200 | 300 | 500 |
| E 5655 | 168 | 252 | 420 |
| E 5656 | 110 | 165 | 275 |
| E 5657 | 156 | 234 | 390 |
| E 5658 | 104 | 156 | 260 |
| E 5659 | 144 | 216 | 360 |
| E 5660 | 316 | 474 | 790 |


1000
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E 5660
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Issue: 010624
Supercedes: K10320

# Praxair and TAFA Arc Spray 13% Chrome Steel Wire - 60T

## Material Review:

Made exclusively for arc spraying. Characteristics of the coating are its excellent wearing quality and fair resistance to corrosion. It is excellent all-purpose steel for basic machine element work.

Arc Spray 60T Chrome Steel wire can be sprayed with any Praxair and TAFA Arc Spray gun.

Arc Spray 60T Chrome Steel wire meets Department of Defense Specification MIL-W-6712C, Table I, Stainless Steel, Chrome and Rolls Royce's MSRR 9507/103 Specification.

CAUTION: All Praxair and TAFA wires have been optimized for arc spraying. Use of alternate wires usually cause problems such as excessive tip wear, spitting and feeding problems. We only recommend Praxair and TAFA Certified wires.

## Application Review:

This is by far the most widely used reclamation spray wire because of its wear resistance and low shrink. Recommended when a hard coating requiring some corrosion resistance is desired. The high chrome content provides fair high temperature oxidation resistance and provides a fair amount of corrosion protection.

In addition, the chrome steel serves as an electrical resistance coating. Successful shop applications have been resurfaced journal sections, cylinder liners, pistons, crankshaft bearings, hydraulic rams, and numerous other machine elements.

Some electrical power stations use only this steel for repair work.

## Composition:

| | |
|---|---|
| **Carbon** | 0.3 |
| **Phosphorus** | Trace |
| **Sulphur** | Trace |
| **Manganese** | 1.0 |
| **Nickel** | 1.0 |
| **Chromium** | 12/14 |
| **Silicon** | 0.08 |
| **Iron** | Balance |

## Coating Physical Properties

| | |
|---|---|
| **Wire Size** | 1/16" (1.6 mm) |
| **Deposit Efficiency** | 78 Percent* |
| **Melting Point** | 2600°F (1427°C) (approx.) |
| **Bond Strength** | 4730 psi (32.6 MPa) |
| **Coating Texture (as sprayed)** | Variable** (see next page) |
| **Finish Texture (ground)** | 6-15 Microinches aa ** |
| **Hardness** | R$_{15n}$ 80-82 (R$_{c}$ 40-43) Converted |
| **Coating Density** | 6.74 gm/cc** |
| **Coating Weight** | 0.035 lbs/ft$^{2}$/mil |
| **Shrink** | 0.0018 in/in (cm/cm) |
| **Coefficient of Thermal Expansion** | 6.6 x 10-$^{7}$ in/in °F (1000°F) |

## Spraying (inert chamber with argon):

| | |
|---|---|
| **Spray Rate** | 10 lbs/hr/100 amps (4.5 kg/hr/100 amps) |
| **Coverage (wire consumption)** | 0.8 oz/ft$^{2}$/0.001" (0.98 kg/m$^{2}$/100 microns) |
| **Spray Pattern****(approximate 8" standoff)** | Cross Nozzle/Positioner - 1" (2.5 cm) vertical height x 1-3/4" (4.4 cm) width<br>Slot Nozzle/Positioner - 2" (5 cm) vertical height x 1" (2.5 cm) width |
| **Length of wire per lb** | 96 ft. (1/16") |

* Depends on air pressure, standoff, nozzle cap and target size.

** 6" standoff, 40 psi - 8830, depends on air pressure - fine with high psi, average with medium psi, and rough with low psi.

*** For higher hardness increase air pressure to 60 psi or higher do this only in final passes where wear will occur.

**** Higher air pressures, smaller wire (1/16), and lower amperage with red nozzle cap gives smallest diameter pattern.

# Spraying Procedure:

| Coating Type | | | | |
|---|---|---|---|---|
| | Normal 8830/8835 | Arc Jet 8830/8835 | Arc Jet 9000 | 9000 |
| Atomizing Air Pressure:Primary<br>Secondary | 50[c]<br>--- | 50[c]<br>40[c] | 60[c]<br>60[c] | 60[c]<br>--- |
| Nozzle Cap | Blue | * | Green | Green |
| Nozzle/Positioner | Short Cross | ** | Long Cross | Long Cross |
| Arc Load Volts[a] | 29-30 | 29-30 | 30-32 | 30-32 |
| Amps[b] | 50-300 | 50-300 | 50-300 | 50-300 |
| Standoff Inches | 5-7 | 3-5 | 3-5 | 5-7 |
| Coating Thickness/Pass-mils | 5 | 5 | 5 | 5 |
| Coating Texture-microinches aa | 200-350 | 150-250 | 150-250 | 200-350 |

Using excessive voltage reduces quality of coating. Voltage should be adjusted to give minimum noise and smooth arc operation. Excessive voltage causes larger particles and poor spray pattern. Too low a voltage will cause popping.

Be sure not to overheat substrate even if this means stopping to allow cooling, use air jet cooling if greater speed is required. Note that on some applications where preheating is tolerable, preheating work to 300°F can improve bond and deposit efficiency.

NOTE: Standard air caps and positioners can be used in 8830, 8835 or 9000 systems.

| | | |
|---|---|---|
| * | P/N 450729 | 8830 Arc Jet Air cap |
| ** | P/N 620074 | Arc Jet Modified Short Cross (8830 & 8835) |

---

[a] When using power lead extensions other than the normal 12 foot furnished, the voltage must be increased by approximately 3.4 volts per 50 foot extension; i.e. add 3.4 volts to the recommended voltage setting for a given wire if the extension is increased to a 50 foot length.

[b] Can vary between 50-300 depending on size of workpiece and traverse speed.

[c] For finer finish, raise air pressure at point of finish.

## Use of Praxair and TAFA's 75B™ Wire as a Bond Coat:

In most applications Praxair and TAFA's 75B BondArc® wire eliminates the need for surface roughening. The following section outlines steps to be followed when using this material.

Note again that the 75B coating does not self bond on many non-ferrous materials and normal surface preparation must be used.

Clean the surface to a white virgin metal by grit blasting, grinding or polishing clean surface with emery cloth.

It must be a clean white metal surface free of grease, oil and handprints.

DO NOT HANDLE AFTER THE SURFACE HAS BEEN PREPARED.

1. Use short nozzle/positioner and blue nozzle cap.

2. Set spray pressure air at 50-60 psig (do this while air is "ON" or flowing).

3. Run at 150 amps at 30 load volts

4. Gun distance from work 3 to 4 inches.
5.
6. Move gun over surface uniformly to give coverage over complete surface.

7. Continue buildup with selected material using 50 psig spray pressure on console (this 50 psig is for general metallizing; for coarser coatings decrease 5 psig; for finer coatings increase 5 to 10 psig, depending on the finish required).

## Finishing:

The coating is usually best finished by grinding. The user may experiment with carbide tools, which gives only a medium finish. The preferred method of i.d. work is to carbide turn leaving a 0.020" deposit for honing to finish size. If deposit is initially ground, leave 0.005 inches for honing. Grind with silicon or alumina wheel with particle size of 30-50.

## Shop Experience:

| **Spray Parameters** | |
|---|---|
| Amps: | 150 |
| Volts: | 29 |
| Atomizing Pressure: | 60 psi |
| Nozzle Cap: | Blue |
| Nozzle/Positioner: | Short Cross |

Spraying was done by hand.
The parts were returned to the machine shop for finishing.

| **Grinding Parameters:** | |
|---|---|
| Machine: | Brown & Sharpe 6" x 18" surface grinder |
| RPM: | 3600 |
| Wheel Size & Type: | Norton 32A46-H8VBE 7" x 1/2" x 1-1/4" |
| Coolant: | IRMCO (International Refining & Mfg. Co.) #120 Spray Mist |
| Feed: | Manual |
| Depth of Cut: | 0.0015" roughening<br>0.0005" finish |

Results:
A 32 microinch aa finish was obtained from both wheel face and side. Spray material did not chip from base metal or show cracks from heat in grinding.

## Hazards:

All chromium alloys produce hazardous fumes. While spraying, all personnel should be made aware of the need for proper respirator protection. Observe normal spraying practices, and proper air flow patterns. For general spray practices, see AWS Publication AWS C2.1-73, "Recommended Safe Practices for Thermal Spraying" and AWS TSS-85, "Thermal Spraying, Practice, Theory and Application". Thermal spraying is a completely safe process when performed in accordance with proper safety measures. Become familiar with local safety regulations before starting spray operations. DO NOT operate your spraying equipment or use the spray material supplied before you have thoroughly read the Praxair and TAFA Instruction Manual.

A Material Safety Data Sheet will be sent with each initial purchase and updated as required.

DISREGARDING THESE INSTRUCTIONS MAY BE DANGEROUS TO YOUR HEALTH.

**The Information provided herein is believed to be accurate and reliable; however, results may vary with workpiece preparation and operator technique. Praxair and TAFA warrants only that the wires are free of defects in material and workmanship. No other warranty is expressed or implied.**

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TAFA is constantly improving its products, therefore specifications are subject to change without notice

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| | |
|---|---|
| File: | 1.9.1.2-75B |
| Issue: | L11111 |
| Supercedes: | K10328 |

# Praxair and TAFA Arc Spray BondArc® Wire75B®

## Material Review:

BondArc 75B wire, a unique nickel-aluminum alloy for use in arc spray systems, is available from Praxair and TAFA on an exclusive license under U.S. Patent No. 4,027,367 and corresponding foreign patents. Tradenamed BondArc, the pre-alloyed wire produces superior bond coats that are dense and resistant to high temperature oxidation, thermal shock and abrasion. The material is equally suitable as a one-coat system; for example, a finish of 5 microinch is attainable. BondArc wire is manufactured exclusively for wire arc spraying. The unusual self-bonding ability of the alloy is attributed to the exceptionally high temperatures the nickel-aluminum reaches and which on impact with the base material, diffuses to form a metallurgical bond. Measured bond strengths have been determined to be 55 percent higher than those formed by exothermic reactions of nickel and aluminum mixtures -- the previous materials available to demonstrate such self-bonding characteristics. One of the major problems in achieving high quality, well-bonded coatings in any thermal spray process is the costly, extensive preparation of the substrate. BondArc alloy eliminates the problem. The coating, through extensive testing, has also been found to be superior to exothermic materials in sharp edge and impact loading.

BondArc wire is self-bonding to a broad range of smooth metal surfaces including annealed or hardened carbon steels, annealed or hardened alloy steels, stainless steels, aluminum, nickel, cast iron, titanium and tantalum. It is not self-bonding to copper-based alloys or tungsten. BondArc wire does not exhibit the same self-bonding characteristics when sprayed with a conventional combustion flame or when rendered into powders and applied by plasma spray apparatus. BondArc 75B wire can be sprayed with any Praxair and TAFA arc spray gun.

BondArc 75B meets the following specifications PWA-36937 (PWA 271-37 Rev D), GE Manual operation number 70-49-38 as an alternate to 70-49-10, Avco M3951B, Rolls Royce OMAT #3/229, SNECMA DMR33-011, Garrett FP5045 and BF Goodrich Service Letter 1623.

CAUTION: All Praxair and TAFA wires have been optimized for arc spraying. Use of alternate wires usually cause problems such as excessive tip wear, spitting and feeding problems. We only recommend Praxair and TAFA certified wires.

## Application Review:

Arc spray coatings from 0.004 to 0.006 inch (0.01 to 0.015 mm) can be readily applied in one pass. Thicker coatings up to 0.250 inch (6.3 mm) have been applied by continuous spraying. Thus, in some cases, BondArc can be used as a one-coat system. BondArc coatings can be machined to a rough finish with tungsten carbide tools or ground to smooth finish with aluminum oxide or silicon carbide wheels. BondArc wire can be sprayed directly on a smooth, chemically clean surface without conventional blasting, turning or roughening, thereby, eliminating the need for expensive preparation equipment and the associated labor and quality control. However, where possible, the surface should be prepared by rough cutting (thread), rough grinding, grit blasting (24 mesh steel shot or aluminum oxide at 80 psig pressure blast) or using a clean coarse emery cloth since this increases bond strength by an additional 600 psi. In any case, note that the surface to be sprayed must be clean, freshly exposed metal. Since BondArc coatings look like stainless steel, it is cosmetically acceptable to many end users as a finish coat.

Typical properties of the Praxair and TAFA nickel-aluminum arc spray coating when sprayed on a clean but unroughened (unprepared) steel surface include: bond strength - 9100 psi; with a typical coating hardness of 55-80 $R_b$.

Figure 1

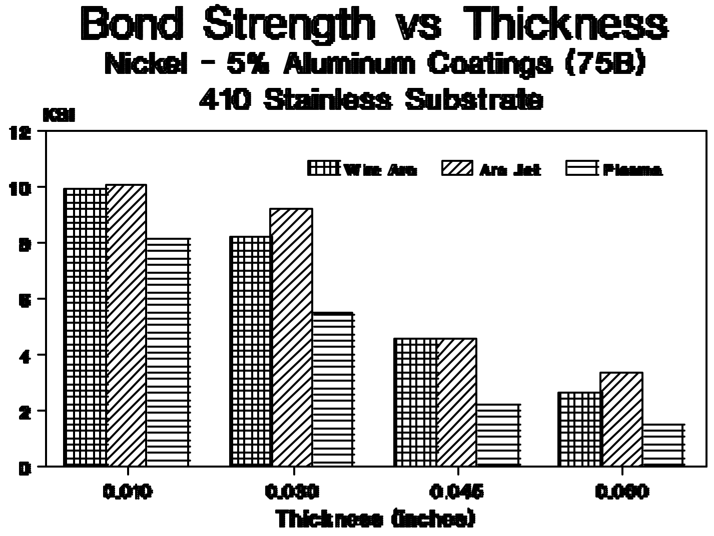


Figure 2

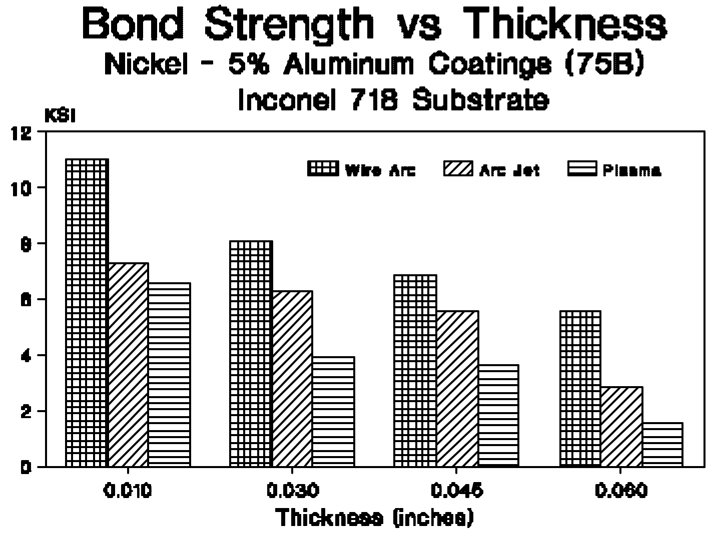
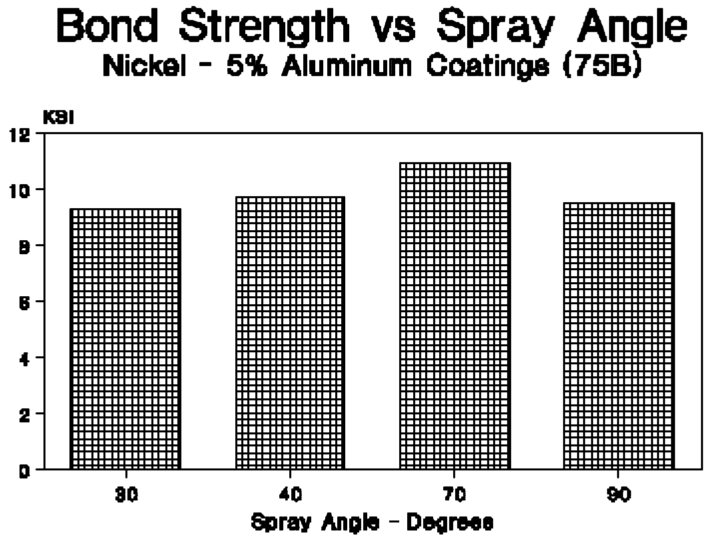


Figure 3



| Composition: (Typical) | |
|---|---|
| **Nickel** | 95 percent |
| **Al** | 5 percent |
| Coating Physical Properties | |
| **Wire Size** | 1/16 in (1.6 mm) |
| **Deposit Efficiency** | 70 Percent |
| **Melting Point** | 2642°F (1450°C) |
| **Bond Strength Tensile**[a] | 9,100 psi clean surface (62.8 MPa)<br>9,750 psi blasted surface (67.2 MPa) |
| **Coating Texture (as sprayed)** | Variable[b] (see next page) |
| **Hardness** | 55-80 $R_b$ |
| **Coating Density** | 7.8 gm/cc[c] |
| **Coating Weight** | 0.038 lbs/ft$^2$/mil |
| **Magnetic Properties** | Non-magnetic, slight magnetic susceptibility |
| **Abrasion Resistance** | Good |
| **Impact, Sharp Edge and Bend Resistance** | Excellent |
| **Coefficient of Thermal Expansion** | 7x10$^{-6}$ in/in°F (1000°F) |
| **Electrical Resistivity** | 200 micro ohm cm (appropriate) |
| **Heat Resistance** | Good[d] |
| **Spraying:** | |
| **Spray Rate** | 10 lbs/hr/100 amps (4.5 kg/hr/100 amps) |
| **Coverage (wire consumption)** | 0.9 oz/ft$^2$/0.001 in (1.10 kg/m$^2$/100 microns) |
| **Spray Pattern**[e] **(approximate 8 in standoff)** | Cross Nozzle/Positioner - 1 in (2.5 cm) vertical height x 1 3/4 in (4.4 cm) width<br>Slot Nozzle/Positioner - 2 in (5 cm) vertical height x 1 in (2.5 cm) width |
| **Length of wire per lb** | 84 ft. (1/16 in) |

[a] Values are for steel substrates according to ASTM C633-69. For bond strengths on other substrate materials, see Figures 1, 2 and 3 on Page 2 and also Bulletin 1.9.1.2-75B.1.

[b] 6 inch standoff, 40 psi - 8830, depends on nozzle cap, air pressure - fine with high psi, average with medium psi, and rough with low psi.

[c] Density depends on air pressure - 80 percent "Bond Coat" setting, 90 percent subsequent buildup.

[d] No evident nickel alloy/substrate scaling with 0.020 inch coating after:

| | | |
|---|---|---|
| Five days | @ | 1000°F |
| Three days | @ | 1800°F |
| 15 minutes | @ | 2200°F |

[e] Higher air pressures, smaller wire (1/16), and lower amperage with red nozzle cap gives smallest diameter pattern.

## Spraying Procedure:

| Coating Type | | | | |
|---|---|---|---|---|
| | Normal 8830/8835 | Arc Jet 8830/8835 | Arc Jet 9000 | 9000 |
| Atomizing Air Pressure:Primary<br>Secondary | 50[c]<br>--- | 50 [c]<br>40 [c] | 60 [c]<br>60 [c] | 60[c]<br>--- |
| Nozzle Cap | Green | * | Green | Green |
| Nozzle/Positioner (Cross=C; Slot=S) | Long C | ** | Long C | Long C |
| Arc Load Volts[a] | 30 | 30 | 30 | 30 |
| Amps[b] | 100-300 | 100-300 | 100-300 | 100-300 |
| Standoff Inches | 5-7 | 3-6 | 3-6 | 5-7 |
| Coating Thickness/Pass-mils | 5 | 5 | 5 | 5 |
| Coating Texture-microinches aa | 200-350 | 150-250 | 150-250 | 200-350 |

Using excessive voltage reduces quality of coating. Voltage should be adjusted to give minimum noise and smooth arc operation. Excessive voltage causes larger particles and poor spray pattern. Too low a voltage will cause popping.

Be sure not to overheat substrate even if this means stopping to allow cooling, use air jet cooling if greater speed is required. Note that on some applications where preheating is tolerable, preheating work to 300°F can improve bond and deposit efficiency.

NOTE: Standard air caps and positioners can be used in 8830 or 9000 systems.

| | | |
|---|---|---|
| * | P/N 450729 | 8830 Arc Jet Air Cap |
| ** | P/N 620074 | Arc Jet Modified Short Cross (8830 & 9000) |

---

[a] When using power lead extensions other than the normal 12 foot furnished, the voltage must be increased by approximately 3.4 volts per 50 foot extension; i.e. add 3.4 volts to the recommended voltage setting for a given wire if the extension is increased to a 50 foot length.

[b] Can vary between 50-300 depending on size of workpiece and traverse speed.

[c] For finer finish, raise air pressure at point of finish.

## Finishing:

An exceptionally good finish can be achieved by turning:

| | |
|---|---|
| **Surface Speed** | 1.27 m/s (250 fpm) |
| **Traverse Speed** | 38 cuts/cm (96 cuts/in) (0.0105 in) |
| **Depth of Cut** | 250 micron (0.010 in) for first few cuts then 125 micron (0.005 in) to finish |

Tungsten carbide tools can be used to obtain a rough finish and grinding to obtain a good smooth finish. Use light cuts for roughing and finishing. Dress frequently and do not permit coating to overheat.

High nickel alloys are difficult to finish. If a grinding wheel is used, it may tend to load up which in turn tends to smear the coating or increase pull-out. If a cutting tool is used, even a ceramic or diamond tool, pull out may be a problem on the very hardest coatings. However, it is fairly easy to generate a 20 microinch finish using the correct grinding wheel and grinding technique. A 15 microinch finish can be obtained with care. Secondary finishing is required below 10 microinch. Grinding must be taken in stages, working down in finish with successively finer finishing surfaces.

A typical grinding wheel specification obtained from Norton and others could be:

- Silicon carbide
- 37 C
- I hardness
- 8 porosity
- Vitrified open wheel

Typical Grinding Setup

- Wheel rpm: Med/High
- Shaft rpm: Low
- SFPM: High with the work running opposite the wheel
- Amount removed per pass 0.0005

Use very light pressure and clean wheel.

Secondary finishing with either silicon carbide or diamond cloth using a mineral base (non-sulfur) 5 to 10 weight hydraulic oil or kerosene can produce finishes below 10 with effort and art. Typically, it is a good idea to start with a 240 grit paper, then progress to 320, 400 and perhaps to 600, 1200, even 4000. If diamond cloth is selected, one should use a 9 to 15 micron particle size (obtained from 3M or others).

The objective is to use the 240 cloth to completely remove the grinding marks from the 37C wheel. Then, use the 320 cloth to remove the marks from the 240 cloth. Then use the 400 -- and so on. If one switches to the finer cloths too soon, a high polish will result on the "high spots", but many of the original deep grinding marks will remain. Patience is the secret to the art.

A recent series of a 1/2" diameter shafts were finished at Praxair TAFA following these principles. The finish on the Bond Arc-coated shafts was judged to be "approaching 8 microinches"; i.e., definitely better than 16, but clearly not as good as 4.

| Speeds & Feeds | Dry Grinding | Wet Grinding |
|---|---|---|
| Wheel Speed SFPM | 6000 | 6000 |
| Work Speed SFPM | 60 | 70 rough |
| Wheel Traverse IPM | 7 rough<br>2.5 finish | 12 |
| In Feed (inches) | 0.001 rough<br>0.0005 finish | 0.001<br>0.0005 |
| Coolant | -- | Water Sol, 1-50 |

## Hazards:

Observe normal spraying practices, respiratory protection and proper airflow patterns advised. For general spray practices, see AWS Publications AWS C2.1-73, "Recommended Safe Practices for Thermal Spraying" and AWS TSS-85, "Thermal Spraying, Practice, Theory and Application." Thermal spraying is a completely safe process when performed in accordance with proper safety measures. Become familiar with local safety regulations before starting spray operations. DO NOT operate your spraying equipment or use the spray material supplied before you have thoroughly read the Praxair and TAFA Instruction Manual.

A Material Safety Data Sheet will be sent with each initial purchase and updated as required.

DISREGARDING THESE INSTRUCTIONS MAY BE DANGEROUS TO YOUR HEALTH.

**The Information provided herein is believed to be accurate and reliable; however, results may vary with workpiece preparation and operator technique. Praxair and TAFA warrants only that the wires are free of defects in material and workmanship. No other warranty is expressed or implied.**

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# Model 8830® Arc Spray System

The purpose of this bulletin is to give a detailed description of the 8830 arc spray system components, specifications, advantages, and service requirements.

The 8830 was developed as a totally new high performance 350 ampere gun. Modular design benefits you through highest performance, lowest cost and expandability as your needs change - no need to worry about obsolescence.

"Meets customer demand
for high reliability
and economical needs"

Praxair and TAFA has developed a broad line of interchangeable arc spray components: one basic gun, one improved control unit and one power unit. This provides many benefits--especially the easy assembly of many different systems--each designed to do the job best.

## Modular Design Yields

**Optimized Coating Quality:**

The 8830 gun is available with many spray configurations as well as various spray pattern shapes. This optimizes coating quality with both low melt and high melt metals and gives the right coating density and finishability for each job.

**Minimum Weight and Size:**

The 8830 gun can be assembled from selected components to match the spray rate of the power unit. Result: minimum gun weight for each system.

8830 Arc Spray Gun

Small Simplified Control Console:

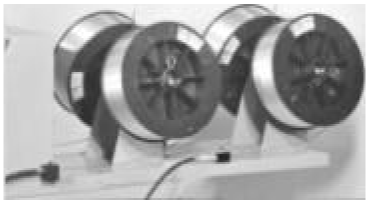
One basic control console is use to control and monitor spray parameters.

## The Power Supply

All Praxair TAFA power units provide a relatively flat, constant, potential volt/ampere characteristic with a continuous control included for setting the open circuit voltage while operating. In the power supply the characteristics are developed exclusively for metal spraying. These features hold noise emission during spraying to the lowest possible level by carefully matching capacitance and inductance. The dimensions of the power supply are H-26¼ in. (67cm), W-16¼ in. (41cm), D-30¼ in. (77cm). The net weight of the unit is 346 pounds (157kg).

This unit operates with three-phase, 60 or 50 Hz, AC power. Casters on each power supply make the power supply portable.

**Optional Feature:**



Console Wire Reel Extension

- Model 839 Inside Diameter Gun: Available as an add on feature or a separate unit, the Model 839 can spray into pipes and small spaces only three inches in diameter and eight feet long. See Bulletin 1.1.8.3 for more information.
- Longer gun Leads: Extra length gun leads for operation in hard to get at places.
- ArcJet Option: This high velocity option is being universally used in the aircraft engine overhaul market (See Bulletin 1.1.8.4).

## Spray Gun Specifics

The gun is rated at 350 amperes, 100 percent duty cycle. Note that all Praxair and TAFA arc spray guns are designed so that the serrations produced by the wire drive rollers are on the top and bottom of the wire as they pass through the contact tips, while the actual electrical contact (rubbing on the tips) occurs at 90 degrees. This reduces contact tip wear considerably compared with competitive units.

### Contact Tubes & Atomizing Systems

The purposes of the contact tip and tube are to transfer current to the wire, to direct the wire at the appropriate angle to the axis of the torch, and to precisely maintain the relative position of the wires.

The 8830 arc head system maintains a constant wire position, arc length and atomizing gas geometry. Coating type (density, particle size, surface roughness and finishability) are simply varied by selecting air nozzle cap and atomizing gas pressure. Inexpensive contact tips are used to guide the wire into the arc region. These screw into contact tubes from the front of the gun thereby making tip change very rapid. Tips should be considered a consumable and changed regularly when 0.005 inch (125 microns) wear occurs. This consumable cost is very low and is a worthwhile expenditure to keep coating quality consistent; i.e., misaligned wires produce an erratic spray pattern and variable coating quality.

### Wire Sizes

Praxair and TAFA recommends the use of 1/16 inch and 2 mm diameter wires. From our experience, this small diameter gives a more uniform particle distribution and a better looking, superior coating. It has been our experience that 11 gauge wire is more difficult to handle relative to stiffness when attached to the gun, increases tip wear, and gives a coarser coating with wider particle size distribution and subsequent poorer finishing characteristics. Because of this and gun design characteristics Praxair and TAFA does not recommend that 11 gauge wire be used in the 8830.

### Wire Drive Motor

A number of wire drive motors are available for special applications for all Praxair and TAFA guns. The specific air motor selected and shipped as standard on the 8830 rotates at a high speed and through a reduction gear, reduces to a roll speed range which permits 1/16 inch wires to be sprayed over the range of amperages permissible in the gun (25 to 350 amperes). The unit can be removed from the gun by simply unscrewing from the main body.

### Wire Feed Unit

This unit uses a proven, double yoke system which retains constant mesh of all gearing, both in the open and closed position. Ball and needle bearings are used throughout. The wire is easily fitted into the gun. The infinitely variable roller tensioning mechanism is controlled by a simple thumb operated lever. Specially designed and hardened rollers contact the wire, give long life and are simply replaced. Roller covers protect this area from dust yet are easily removed. All four wire drive rollers are driven. Both drive rolls open. This assures centering of all wire diameters in wire guides.

### Arc Shield

A permanent arc shield is built into the gun to shield the operator from arc radiation (arc temperatures reach 4000°C (7232°F) at the point where the two wires meet). With such a shield, the operator needs to wear only safety glasses. (NOTE: Plastic does not screen out ultraviolet which gives eye burn). This shield is made only long enough to do an adequate job of shielding the operator. Caution must be used when spraying on reflective surfaces; in such applications wear tinted glass safety glasses with side shields.

### Amperage Rating of Gun

The maximum continuous amperage rating (100 percent duty cycle) of the 8830 gun is 350 amperes. The following table indicates the spray rates as a function of wire type and amperage.

| Spray Rates for 8830 Gun | |
|---|---|
| | Lbs/hr/100 amps |
| Steel | 10 |
| Aluminum Bronze | 9 |
| Bronze | 11 |
| Copper | 11 |
| Aluminum | 6 |
| Zinc | 24 |

All 8830 Guns are furnished with a hand operated trigger on the handle for turning on and off the wire feed. A small needle valve for wire speed control (spray rate), which is located on the same handle, is standard on all 8830 guns. Note that in special cases, this can be replaced with a simple manual valve. The purpose of these two valves is as follows. During normal operation, the needle valve is adjusted to give the proper wire feed rate and is no longer touched during constant operating periods. The trigger valve is used to turn the wire feed on and off.

It has the following advantages:

- Permits instant on/off operation of the unit without moving the hand or changing grip.
- Permits reproduction of exact wire feed speeds from operating period to operating period without waste of wire and going through and adjustment period, thus providing assurance that the exact spray rates previously used are reproduced.
- Conserves wire

### Advantages of Arc Spray over Combustion

- The arc spray is a far more simplified system for reproducibility. If the air pressure is kept constant with proper regulation and the amperages set (indicating constant wire feed), then one can always reproduce the same melt power and coating conditions. This is not the case in a combustion gun which involves adjustment of flame intensity, oxy/fuel ration, etc.
- The arc spray gun is an instant on/off device. When the air control lever is pressed, one immediately begins to spray at the proper rate. In addition, there is no need to allow the wire to pass through the gun after the flame is shut down to assure that plugging of tips does not occur.
- The arc spray gun is very reproducible from operator to operator and Friday night to Monday morning. There is only one setting. When the air system is shut down, you do not need to readjust any of the air flow or current settings. Thus, when the unit is started up with a single push button, exact settings are reproduced.
- All of the above characteristics of the arc spray gun lead to less operator judgment and, therefore, more reproducible coatings.
- Because the arc spray melts the wire with an electric arc, a higher particle temperature is achieved and one is guaranteed of complete melting. This results in higher bond strengths with the higher melting point materials-- with most materials, two and one-half times that of a gas gun.
- Considerably less energy is consumed by the arc spray gun (1/9th that of a gas gun). This combined with instant on/off results in considerable cost savings.

## The System

The system consists of a control unit which turns the power and air supply on and off with toggle switches. A wire feed motor, pressure regulator, an oil lubricator for the air motor, and an atomizing air pressure regulator (which controls coating smoothness and density and improves first pass bond strength) are also provided. The power supply is a constant potential unit especially designed for operation with the Praxair and TAFA arc spray system to give a better, more consistent spray pattern, easy starting, reduced noise level, and can be adjusted under load for proper voltage setting. Pressure gauges indicate atomizing pressure and wire drive pressure to permit reproducible coatings. An inlet auto dumping filter regulator is furnished to regulate air pressure to the system. A built in run time meter is also included. The available automatic control unit provides for remote operation or interlocking with other process equipment.

### Coating Selection

For specific spraying details, amperage levels, coating properties, standoffs, etc. see wire series Bulletins 1.9.1.2_.

For further details on coating selection, surface preparation, use of bond coats and other useful application and spray knowledge – See Bulletin 2.1.1.1.

Note that the Model 8830 arc spray gun can reproduce optimum spray patterns for each wire type and thus produce the highest quality coating with the highest density and bond strength. The basic design is keyed to the smallest diameter wires and operates under the lowest possible air pressure and flow rates with low to moderate amperage (spray rates) for each application; i.e., the gun setup is tailored to the specific coating properties.

For example, by using the finest spray setting with 1/16 inch (1.6 mm) aluminum, a dense, smooth coating can be laid down at very reasonable air pressure (40 psi). This lower pressure reduces noise and increases deposit efficiency, while maintaining a consistent coating quality. Finer, denser coatings can be achieved by increasing spray pressures. Fineness and density of the coating can be varied by adjusting console spray pressure and nozzle cap diameter. Low pressures give coarse coatings; exceptionally low pressures in the range of 15 psi produce very rough coatings with 1/8 inch (3.2 mm) peak-to-valley coating roughnesses. With pressures above 45 psi; for example, 80 psi, the 8830/350/350 system gives extremely fine particle size distribution, densest coatings, and smoothest coating surfaces.

The spray pattern shape can be varied by changing the nozzle/positioner insert in the spray head. The slot orifice gives an oval pattern, while the cross nozzle/positioner produces a circular pattern. Either spray pattern shape can be made fine or coarse by adjusting pressure and nozzle cap diameter as discussed previously.

Again see specific wire bulletins (series 1.9.1.2-__) for detailed settings for each wire and dimensions of spray patterns.

Note that extreme care should be exercised when changing pressures and nozzle caps from those recommended because coating properties such as hardness, bond strength, oxide content, finishability, density and deposit efficiency can vary widely from the optimum. When in doubt, run test coupons.

### Noise Level

The noise level from these devices is related to amperage and material sprayed. At 350 amperes, decibel ranges of 102-105 are achieved. However, as the amperage is reduced, noise level is reduced. With prolonged exposure to the gun, the operator should wear ear protection. See Bulletin 1.11.7, for more detailed information on sound generated by Praxair and TAFA Arc Spray Guns and control procedures. Note that different atomizing heads, air pressures, and wires also influence sound level.

### Operation

See instruction manual for details. Operation is simple and initial operator training takes less than one hour. Bulletin series 1.9.1.2-__ give specific spraying conditions.

### Coatings

Generally, the arc spray coatings appear dense and quite attractive to the experienced eye. See Bulletin 1.9.1.1.1 for description of some coatings and Bulletin series 1.9.1.2-__ for specific coating properties. Consult Praxair and TAFA for more detailed information and references on specific applications.

### Spray Pattern

With 8 inch standoff, two patterns are possible: 1" (2.1 cm) x 1 3/4" (4.4 cm) width or 2" (5 cm) x 1" width.

### Remote Reel Holders

Specially designed remote reel holders some with or without casters are available for mounting wire reels remote from the console. These units permit the spray gun (with limited distance for the wire reels) to operate at any distance from the control console, for example, inside a tank or on scaffolding. The remote reel holders can either be pulled along by the operator as he sprays, or located on a boom.

These remote reel holders also useful on installations where the gun is permanently mounted. In this case, wire reels can be located directly behind the gun, thereby eliminating the need for conduits.

### Payoff Paks

Payoff Paks are available for some wires. Payoff Paks are used in permanent installations where large volumes of wire are sprayed. Purchase of wire, in this bulk form, also leads to some savings in wire cost.

### Service Requirements

Compressed Air 50 cfm at 80 psig (includes air motor at 6 cfm). Air should be free from foreign matter and moisture. Actual flow 15 cfm at 16 psi, 40 cfm at 53 psi, 50 cfm at 84 psi. 2 cfm on air motor.

Voltages 230/460, 200(208)/380/415, 460/575 at 50 or 60 Hertz available. The kVA input and line amperage depend on power unit:

Model 30*8A 200 amp max. kVA 7, line amps 18.6/9.3

Model 30*8B35 350 amp max. kVA 17, line amps 47/24

To calculate, Duty cycle at 70% = $(100\%\ \text{rating})^2$
0.7

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# Thermal Spraying

## Practice, Theory, and Application

AMERICAN WELDING SOCIETY

# Thermal Spraying

## Practice, Theory, and Application

# Thermal Spraying

## Practice, Theory, and Application

Prepared by
AWS Committee on Thermal Spraying

Under the Direction of
AWS Technical Activities Committee

Approved by
AWS Board of Directors

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# Foreword

The Thermal Spraying manual published by the American Welding Society presents the considerations required to appraise any application of thermal spraying. This manual also surveys the basic methods that can be used and the equipment and consumables involved in thermal spraying.

Although thermal spraying has been used since the early part of the twentieth century, many of the first applications were concerned mainly with reclamation. Since 1960, there has been a dramatic expansion in the number and diversity of thermal spray applications. Technological advances and material developments have resulted in a multitude of new and potential applications. The present range and scope of the processes and uses can only be indicated in this manual.

The American Welding Society Committee on Thermal Spraying has prepared this first edition as a guide to the equipment and consumables available, and as a reference for selecting the process suitable for a particular application. The reader can acquire knowledge of the thermal spray processes and technology to investigate potential uses. Emphasis is placed on practical shop and field procedures, including factual, supportive data.

Comments and suggestions regarding this first edition are welcome. Please address them to the Secretary, AWS Committee on Thermal Spraying, American Welding Society, 550 N. W. LeJeune Road, P. O. Box 351040, Miami, Florida 33135.

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# Chapter 1

# Fundamentals of the Process

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# Chapter 1

# Fundamentals of the Process

## 1.1 General

The thermal spraying processes are specialized, yet have a wide ranging utilization in both manufacturing and maintenance. The nature of the processes is truly synergistic. That is, there are many components and variables involved, which, when working together and properly applied, produce an effect far greater than indicated when they are considered individually. Yet each component and variable must be understood to permit the proper selection and operation of a particular process. With this background, the user is then in a position to tailor the process to a particular application.

## 1.2 Definition

Thermal spraying is a group of processes in which finely divided metallic or nonmetallic surfacing materials are deposited in a molten or semimolten condition on a prepared substrate to form a spray deposit. (Also, see the terms *arc spraying, flame spraying,* and *plasma spraying* in the Glossary.) The surfacing material may be in the form of powder, rod, cord or wire. The thermal spraying gun generates the necessary heat by using combustible gases or an electric arc. As the materials are heated, they change to a plastic or molten state, and are accelerated by a compressed gas. The confined stream of particles are conveyed to the substrate. The particles strike the surface, flatten, and form thin platelets (splats) that conform and adhere to the irregularities of the prepared surface and to each other. As the sprayed particles impinge upon the substrate, they cool and build up, particle by particle, into a lamellar structure, thus a coating is formed.

## 1.3 Process Variations

The basic variations of the thermal spraying processes occur in the spray materials used, the method of heating, and the method of propelling the materials to the substrate.

**1.3.1 Spraying Materials.** The spray materials are used in the form of wire, rod, cord (a continuous length of plastic tubing), or powder. Cord spraying is primarily used in Europe. Many metals, oxides, cermets, and intermetallic compounds, some organic plastics, and certain glasses can be deposited by one or more of the various processes.

**1.3.2 Processes.** Thermal spraying processes may be categorized into two basic groups according to the method of heat generation.

| Group I<br>Combustion | Group II<br>Electrical |
|---|---|
| Flame | Plasma (nontransferred arc) |
| Detonation | Plasma (transferred arc) |
|  | Wire arc |
|  | Induction plasma |

The first group uses combustible gases as the heat source. Processes using electrical power as the heat source such as plasma (transferred and nontransferred arc), electric arc, and induction plasma comprise the second group. Consumables used in this group are in powder or wire form.

## 1.4 Nature of Sprayed Coatings

Success in the use of thermally sprayed coatings relies on careful adherence to specific process procedures. A basic rule of thermal spraying is that any deviation from the standards for a particular application or inattention to detail will produce unreliable results. Succeeding chapters will discuss the process procedures in detail. The sprayed coating has three basic aspects, as follows:

**1.4.1 Substrates.** Substrates onto which the thermal sprayed coatings are applied include metals, oxides, ceramics, glass, most plastics, and wood. All spray materials cannot be applied to all substrates; some require special techniques.

Substrate preparation prior to spraying is required for every thermal spraying process, and is virtually the same for each process. Two important steps are as follows:

(1) Cleaning the surface to eliminate contamination that will inhibit the bonding of the coating to the substrate

(2) Roughening the surface to provide minute asperities or irregularities to enhance coating adhesion and provide a greater effective surface area

Proper substrate preparation prior to bond coat application is the most critical step influencing the bond strength and the adhesion of the coating to the substrate.

**1.4.2 Bond Coats.** The bond between the coating and the substrate may be mechanical or metallurgical. Adhesion is influenced by a number of factors: coating material, substrate condition, degree of surface roughness, cleanliness, the surface temperature before, during, and after spraying, and particle impact velocity.

**1.4.3 Coating Structure.** The deposited structure and chemistry of coatings sprayed in ambient air are different from those of the same material in the wrought or presprayed form (Fig. 1.4.3A).

The differences in structure and chemistry are due to the incremental nature of the coating, the reaction with process gases, and the atmosphere surrounding the material while in the molten state. For example, when air or oxygen are used as process gases, oxides of the applied material are formed and become a part of the coating. Metal coatings tend to be porous and brittle, and to have a hardness different from that of the original material. The as-sprayed structures of coatings will be similar in their lamellar nature but will exhibit varying characteristics, depending on the particular spraying process used, process parameters, technique employed, and the material applied.

The spray deposit density ratio will vary with the particle velocity and the heat source temperature of the coating process (Table 1.4.3 and Fig. 1.4.3B).

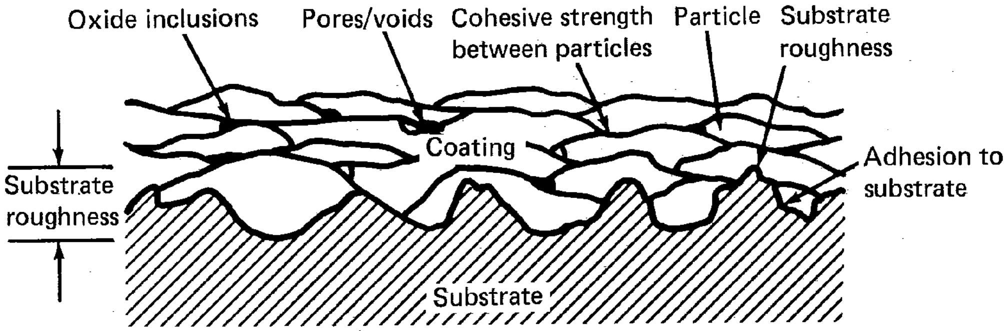

Fig. 1.4.3A — Typical coating cross section to illustrate lamellar structure of oxides and inclusions

**Table 1.4.3**
**Heat source temperatures**

| Source | Temperature, °F | Temperature, °C |
|---|---|---|
| Propane, oxygen | 4785 | 2640 |
| Natural gas, oxygen | 4955 | 2735 |
| Hydrogen, oxygen | 4875 | 2690 |
| Acetylene, oxygen | 5625 | 3100 |
| Arcs & plasmas | 4000-15,000 | 2200-8300 |

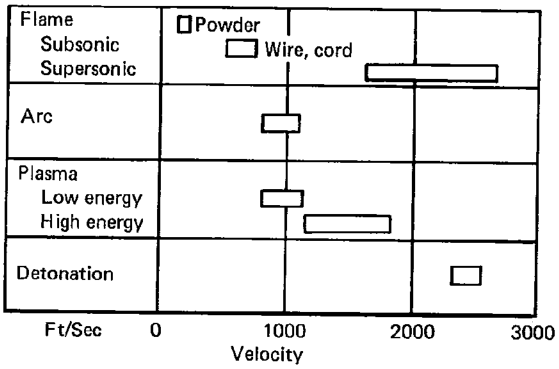

**Fig. 1.4.3B—Average particle impact velocities**

## 1.5 Applications

The end use determines the properties needed in coating, the type of consumable, and the kind of equipment required.

**1.5.1 Manufacturing.** Thermal spraying is used extensively in the manufacture of original equipment components. The aerospace industry has provided hundreds of applications. In addition, marine, automotive, petroleum, electrical, power generation, and electronic industries use thermally sprayed coatings.

**1.5.2 Maintenance.** In maintenance, hundreds of millions of dollars are saved annually through the use of thermal spraying. This is not limited to in-plant applications, but also includes on-site applications to coat structures and equipment parts. Repair of components by thermal spraying, where applicable, is generally both economical and time saving.

Where corrosion or wear, or both, are problems, thermal spraying should be investigated. The use of sprayed coatings, often impregnated with sealers, has received worldwide acceptance by industry for such applications.

# Chapter 2

# Methods of Deposition

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# Chapter 2

# Methods of Deposition

## 2.1 Basic Methods

The thermal spraying processes, and related equipment in commercial use, can be divided into two basic categories: combustion and electric heating.

## 2.2 Combustion

Thermal spraying utilizing the heat from a chemical reaction is known as *combustion gas* or *flame spraying.* Any substance which does not sublime and which melts at temperatures less than 5000°F (2760°C) may be flame sprayed. The materials used are metals and alloys in the form of wire, cord, or powder, and ceramics as powder, cord, or rod.

**2.2.1 Wire and Rod.** The equipment for flame spraying wire and rod is similar, as shown in Fig. 2.2.1A. A typical wire thermal spraying gun cross section is shown in Fig. 2.2.1B.

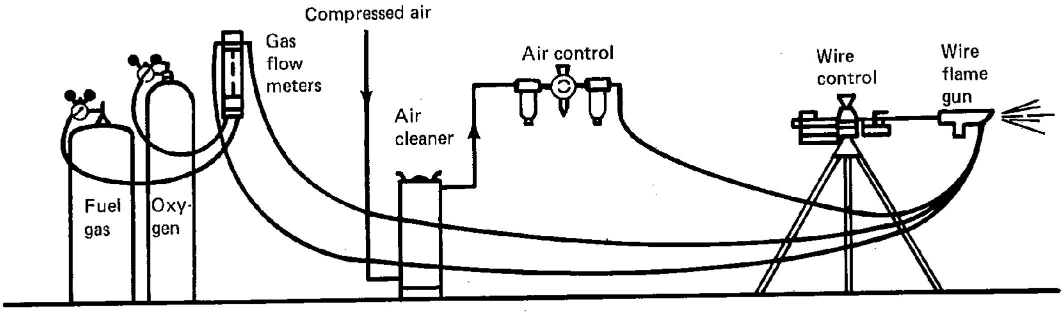

**Fig. 2.2.1A — Typical wire flame spraying installation adaptable to rod and cord**

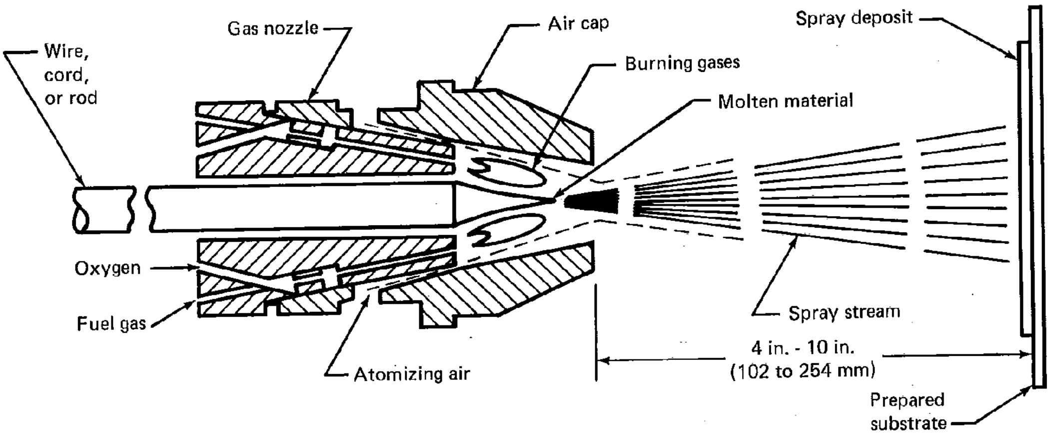

**Fig. 2.2.1B — Cross section of typical wire rod or cord flame spray gun**

The feedstock material is drawn by drive rolls into the rear of the gun. The rolls are powered by an electric motor, an air motor, or an air turbine. The feedstock proceeds through a nozzle where it is melted by a coaxial flame of burning gas.

One of the following fuel gases may be combined with oxygen for use in flame spraying: acetylene, methylacetylene-propadiene stabilized (MPS), propane, hydrogen, or natural gas. Acetylene is widely used, because higher flame temperatures are attainable (Table 1.4.3). However, in many cases, lower temperature flames can be used with economic advantages. A fuel gas flame is used for melting only, and not for propelling or conveying the coating material. To accomplish spraying, the flame is surrounded with a stream of compressed gas, usually air, used to atomize the molten material and to propel it onto the substrate. In special applications, an inert gas may be used.

Different gun feed parts are used to drive wire (a continuous metal feedstock), rod (a 24 inch long brittle ceramic), and cord (a flexible continuous length of plastic tubing containing powder).

**2.2.2 Powder.** Powder flame spray guns are lighter and more compact than other types of thermal spraying equipment. Due to the lower particle velocities and temperatures obtained, the coatings produced generally have lower adhesive strength, lower overall cohesive strength, and higher porosity than coatings produced by other spray processes.

The powder feedstock may be a pure metal, an alloy, a composite, a carbide, a ceramic, a cermet, or any combination of these. The process is generally used to apply "self-fluxing" metallic alloy coatings. These materials contain boron and silicon which serve as fluxing agents and oxidation is minimized. Fusion or metallurgical bonding to a metal substrate is accomplished by heating the coating to its melting temperature. The fusing temperature is usually in excess of 1900°F (1040°C), and is accomplished with any heat source including a flame, an induction coil, or a furnace.

Feedstock is stored in a hopper which may be integral with or connected to the gun. A small amount of gas is diverted to carry the powder into the oxygen-fuel gas stream, where the powder is melted and carried by the flame onto the substrate. The general arrangement of an installation for powder flame spraying is shown in Fig. 2.2.2A, and a typical gun cross section is shown in Fig. 2.2.2B.

Variations in the powder flame spraying process include (1) compressed gas to feed powder into the flame, (2) additional air jets to accelerate the molten particles, (3) a remote powder feeder with an inert gas to convey powder through a pressurized tube into the gun, and (4) devices for high speed acceleration at atmospheric pressure. Such refinements tend to improve powder flow rate, and sometimes to increase particle velocity, which enhances bond strength and spray deposit density.

Fused coatings are dense and nearly porosity free. The alloy compositions can result in Rockwell hardness levels greater than 50C. Coating thickness is limited to those ranges which can be heated to the melting temperature

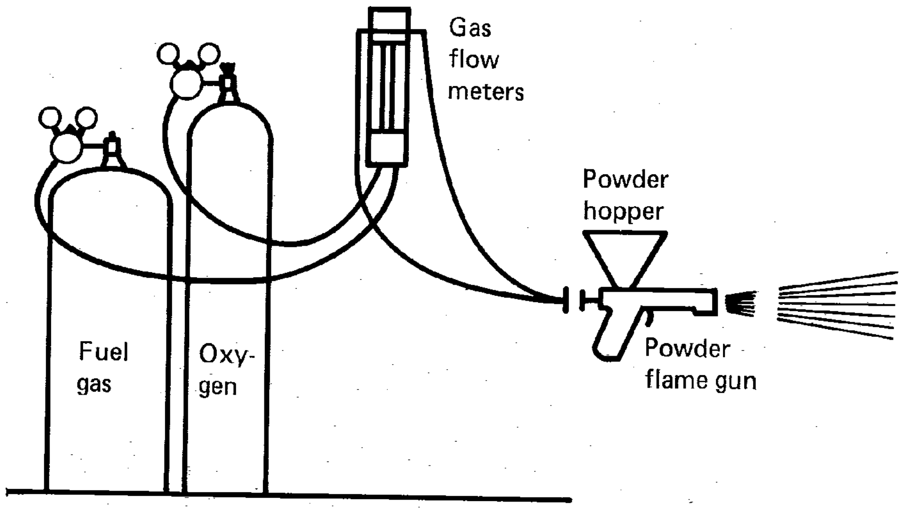

**Fig. 2.2.2A — Typical installation of a powder flame spray process**

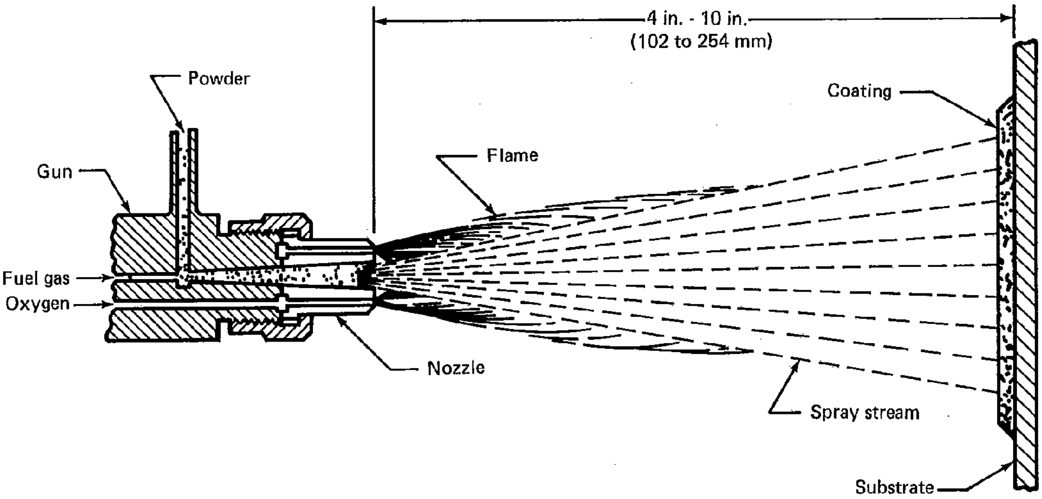

Fig. 2.2.2B — Cross section of a powder flame spray gun

without spalling. Self-fluxing coatings are limited to applications where the effects of the fusing temperatures and any distortion can be tolerated. Thick coatings of dissimilar metals can be applied in multiple passes. The surface to be recoated should be cleaned of all oxide residues after each fusing stage.

In all thermal spraying processes, the powder particle velocity feed rate affects the structure and the deposit efficiency of the coating. If the raw material is not properly heated, deposit efficiency will decrease rapidly, and the coating will contain trapped, unmelted particles. If the particle velocity is too low, some powder may be volatized and result in coating deterioration and elevated operating costs. The typical powder feeding mechanism incorporates a container and a metering device which regulates the feed rate of the material into the carrier gas stream.

**2.2.3 Oxygen Detonation Gun.** The detonation gun differs from other combustion spraying devices. It utilizes the energy of explosions of oxygen-acetylene mixtures, rather than a steadily burning flame, to thrust powdered materials onto the surface of the substrate. The resulting deposit is extremely hard, dense, and tightly bonded.

The detonation gun, shown in Fig. 2.2.3, consists of a long barrel into which a mixture of oxygen, fuel gas, and powdered coating material is introduced. When the gas mixture is ignited, a controlled detonation wave, or flame front, accelerates and heats the powder particles as they move down the barrel. Exit particle velocities of approximately 2,500 ft/s (760 m/s) are produced. After each injection of powder has been discharged, a pulse of nitrogen gas purges the barrel and chamber. Multiple detonations during each second build up the coating to

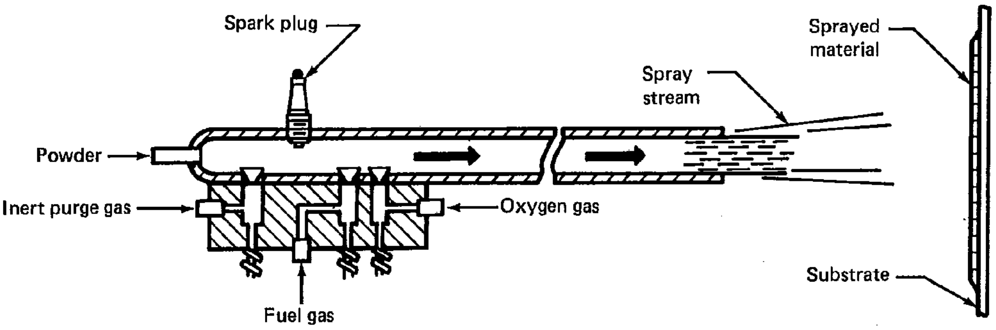

Fig. 2.2.3 — Schematic arrangement of an oxygen-fuel gas detonation gun

the specified thickness while the workpiece substrate is rotated or passed in front of the gun.

Temperatures above 6000°F (3315°C) are attained within the detonation gun while the substrate temperature is maintained below 300°F (150°C) by a carbon dioxide cooling system.

Coating thickness ranges between 0.002 and 0.020 in. (0.05 and 0.50 mm). The process produces a sound level in excess of 150 decibels, and is therefore housed in a sound isolating room. The actual coating operation is completely automatic and remotely controlled. The high particle impingement velocity results in a strong bond with the substrate. Excellent finishes are achievable because porosity in the coating is low.

## 2.3 Electrical Heating

**2.3.1 Wire Arc Process.** In the wire arc process, two consumable wire electrodes, that are at first insulated from each other, automatically advance to meet at a point in an atomizing gas stream. A potential difference of 18 to 40 volts applied across the wires, initiates an arc that melts the tips of the wire electrodes. An atomizing gas, usually compressed air, is directed across the arc zone, shearing off molten droplets which form the atomized spray.

The arc spray system is comprised of components as illustrated in Fig. 2.3.1A.

**Arc SprayGun.** The spray gun is illustrated in Fig. 2.3.1B. The wire electrodes (1) are fed through the wire guides (2) and into the contact tips (3). The atomizing nozzle (4) conducts the compressed air (5) and directs it across the arc zone. Insulated power cables connect the gun to the dc power source. Arc guns also include mechanisms for feeding the wire at a controlled rate. Contact tips are sized for a particular wire diameter. **ON** and **OFF** switches are provided on the gun to control the wire feed, compressed air supply, and electric power supply.

The arc temperatures considerably exceed the melting point of the spray material. During the melting cycle, the spray metal is super heated to the point where some volatilization may occur, especially with aluminum and zinc. The high particle temperatures produce metallurgical interactions or diffusion zones, or both, after impact with the substrate. These localized reactions form minute weld spots with good cohesive and adhesive strengths. Thus, the coatings develop excellent strengths.

The arc process normally has higher spray rates than other spray processes. Factors controlling the application rate are the current rating of the power source and the permissable wire feed rate to utilize the available power.

**Power Source.** A dc power source providing a voltage between 18 to 40 volts permits operation with various melts and alloys. Constant potential power sources are usually used. The arc gap and spray particle size increase with a rise in voltage. The voltage should be kept at the lowest level, consistent with arc stability, to provide smooth and dense coatings.

**Wire Control Unit.** The wire control unit is comprised of two reel or coil holders, which are insulated from each other. Wires of larger diameters are usually in coil form, while smaller diameter wires are preferably layer level wound on reels or in barrels. The unit is connected to the gun by flexible insulated cables.

**Control Console.** The control console incorporates the switches and regulators necessary for controlling and monitoring the operating circuits that power the gun.

**2.3.2 Plasma Nontransferred Arc.** The development of turbine and rocket engines presented conditions with increased severity for existing engineering materials. In many cases, the approaches used to cope with these conditions were based on oxides and carbides, which required thermal spraying equipment capable of producing temperatures higher than the capability of the then existing

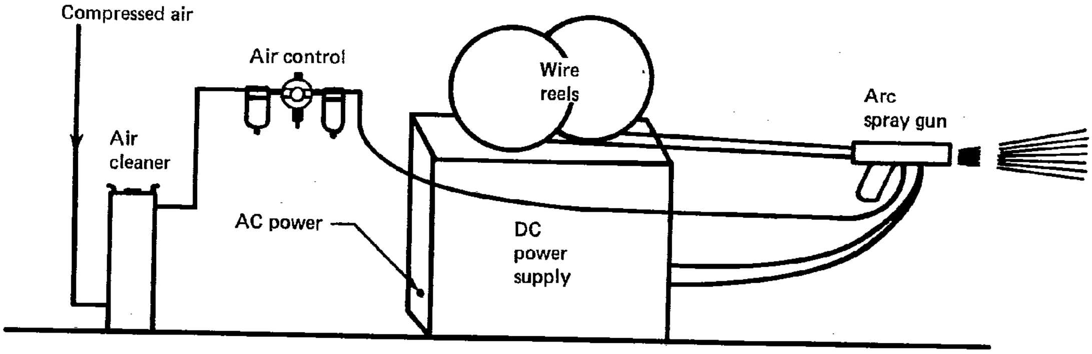

**Fig. 2.3.1A — Arc spray components combined into a single unit**

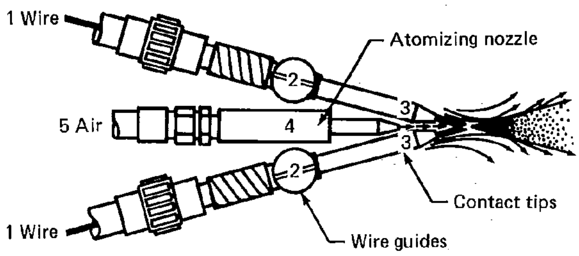

**Fig. 2.3.1B — Cross section schematic of an arc spray gun**

processes. The plasma spray process evolved to meet these needs. It also brought into existance a new family of coating materials and application techniques for a wide variety of industrial conditions.

This process uses powdered materials and a plasma (hot ionized gas) as the heat source. Plasma generators provide controllable temperatures well in excess of the melting range of most substances.

In the plasma process, a gas or gas mixture is passed through an electric arc between a coaxially aligned tungsten cathode and an orifice in a copper anode (Fig. 2.3.2A).

The gas passing through the orifice is heated to temperatures much higher than those obtained with a combustion flame (Table 1.4.3).

During heating, the gas is partially ionized, producing a plasma. As the plasma exits the gun, disassociated molecules of a diatomic gas recombine and liberate heat. The powder is introduced into the plasma, melted, and propelled onto the workpiece by a high velocity stream. The heat content, temperature, and velocity of the plasma jet are controlled by the nozzle type, the arc current, the mixture ratio of gases, and the gas flow rate.

The arc operates on direct current from a rectifier type power supply. The electric power to the arc is governed by a central control unit that also regulates the flow of plasma gas and cooling water, and sequences these elements to allow the process to be carried on reliably and precisely (Fig. 2.3.2B). Either nitrogen or argon is used as the primary plasma forming gas. A secondary gas, either hydrogen or helium, may be added to increase the heat content and velocity of the plasma.

**2.3.3 Plasma Transferred Arc.** The plasma transferred arc (PTA) process is a combination of welding and thermal spraying processes. Powder or wire is introduced into the plasma arc stream issuing from the nozzle. The emitted spray forms a molten puddle on the substrate, which cools and solidifies as a parent metal dilution (weldment). The process uses a power source, controls, and feedstock somewhat similar to the plasma nontransferred arc process previously described.

In the PTA process, the electrical arc from the nonconsumable electrode passes through the torch nozzle and is carried by the plasma to the conductive workpiece. The feedstock powder, or wire, which is usually a nickel-, cobalt-, or iron-based alloy similar to that used in flame spraying, is introduced into the arc as it exits the nozzle. Here, it is melted and puddled onto the surface, and a deposit is constructed. The deposit is usually applied to greater thicknesses than a thermal spraying coating, and it is metallurgically bonded to the base material. PTA deposition lends itself particularly to repetitive applications on conductive materials and is usually mechanized. The absence of slag removes a source of impurities, and the completed deposit is smoother and more uniform, because melting and puddling take place in an inert gas shroud. As compared to a thermal spraying deposit, a PTA deposit is generally more localized, denser, and metallurgically bonded to the base. However, the selection of coating materials and suitable substrates is more limited.

## 2.4 Controlled Atmosphere

Controlled atmosphere spraying offers the possibility of improving coating quality and bond strength. Immediate benefits are

1. Temperature regulation of both substrate and atmosphere.
2. Minimal chemical changes in the sprayed material, leading to closer control of the composition and morphology of the sprayed coating. This is demonstrated in greater structural homogeneity, absence of oxides, and improvements in hardness, thickness capability, and deposit efficiency.

When using inert atmosphere chamber spraying, improvements are achieved only with considerable capital cost. The need for the improved coating properties must be weighed against the additional expense of the equipment. A typical installation for controlled atmosphere thermal spraying is illustrated in Fig. 2.4.

A less expensive approach to achieve some of the improvements of chamber spraying is to provide an inert gas shroud around the molten particle stream to minimize oxidation while the material is in the molten state.

Other devices utilize higher velocity acceleration at atmospheric pressure to increase particle velocity and thus improve coating adhesion and density.

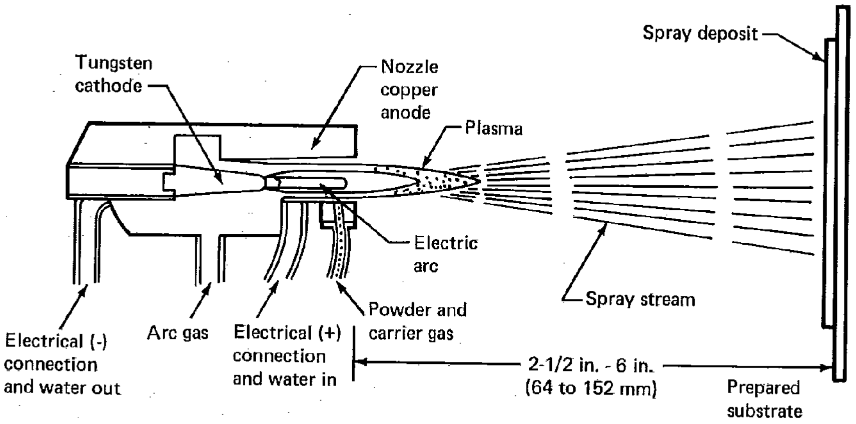

**Fig. 2.3.2A — Sectional view of plasma torch**

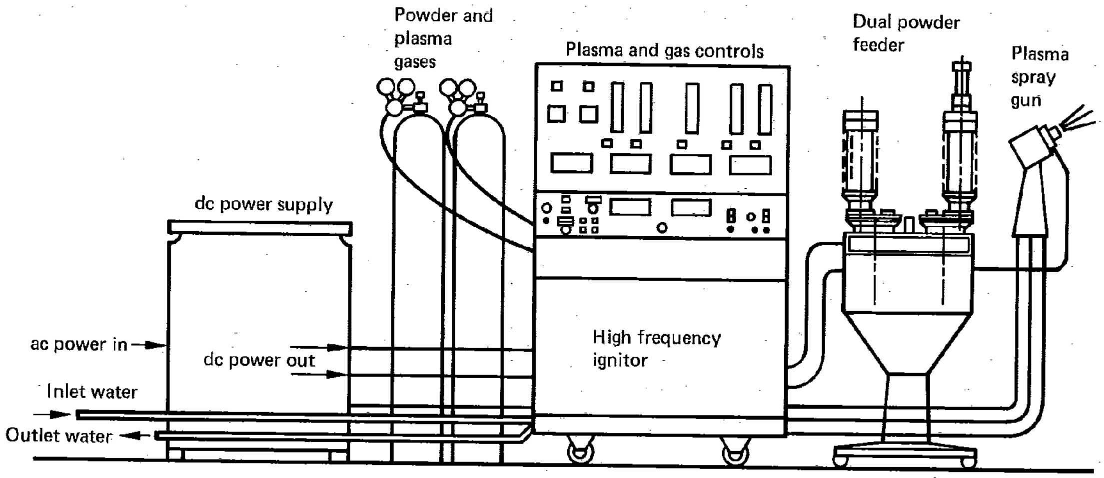

**Fig. 2.3.2B — Complete installation plasma spray system**

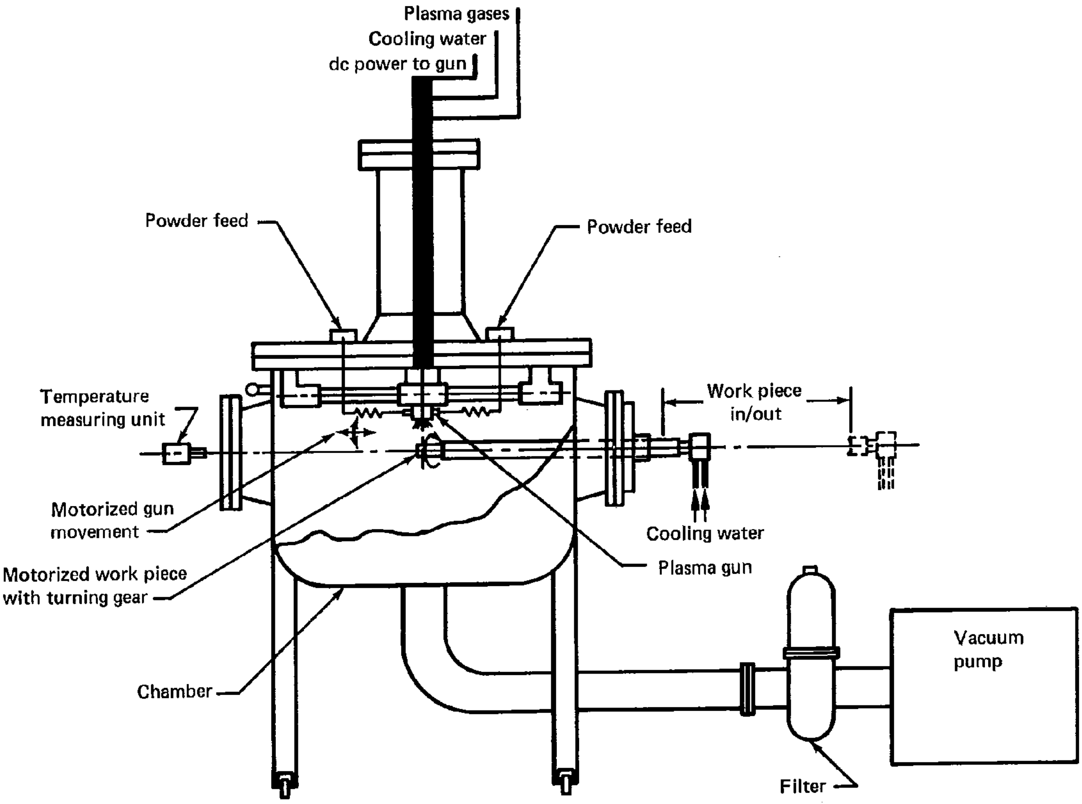

Fig. 2.4 — Controlled atmosphere thermal spray system

# Chapter 3

# Surface Preparation

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# Chapter 3

# Surface Preparation

## 3.1 General

Surface preparation is the most critical step in a thermal spraying operation. Coating adhesion quality is directly related to the cleanliness and the roughness of the substrate surface. Adherence to accepted procedures in preparing a substrate surface is necessary to ensure successful application of the thermal spray coating. The coating material and the substrate type are the major factors in determining what surface preparation is necessary to achieve consistent bonding.

On highly stressed mechanical parts, inspection prior to coating, is necessary to detect flaws in the base metal. This is done by nondestructive inspection methods. Structural flaws in the part will produce similar flaws in the coating. Cracks in the substrate cannot be repaired by thermal spraying. Sprayed deposits do not add strength to the substrate.

## 3.2 Cleaning and Handling

The first step in the preparation of a substrate for thermal spraying is to remove all surface contaminants such as scale, oil, grease, and paint. The heat of spraying will not remove contaminants, and contamination will inhibit bonding. After all contaminants have been removed, the cleanliness should be maintained until the spray cycle has been completed. Parts should be protected from airborne debris and fingerprints, and should be handled with clean fixtures and materials.

**3.2.1 Vapor Degreasing.** Hot vapor degreasing is a common, economical, and efficient method for removing organic contaminants. Parts should be soaked 15 to 30 minutes to remove oil from interstices and surface pores. Porous materials, such as sand castings or graphitic cast irons, should be soaked for longer periods. If objects are too large for vapor degreasing, steam cleaning, submerging in hot detergent solutions, or manually cleaning with an oil free solvent may be required. Residue should be mechanically removed.

The common degreaser solvents perchlorethylene, trichlorethylene, and 1,1,1 trichorethane, are normally selected for safety considerations and the temperature range needed for cleaning. Most hydrocarbon solvents are hazardous, and manufacturer's instructions should be followed regarding usage, location, and disposition.

Recycling of solvents should be investigated with the supplier. Chlorinated solvents leave a slight residue which can be removed by immersion washing or wiping with isopropyl alcohol or methylethyl ketone (MEK).

The use of chlorinated solvents on titanium and titanium alloy parts is prohibited, since chlorine can induce cracking in these materials. Alternative cleaning methods such as an alkaline wash, steam blasting, pickling, washing with flammable solvents, or all of these, may be necessary.

**3.2.2 Vapor Blasting.** Vapor blasting, wet abrasive blasting, and liquid honing use a dilute slurry of abrasive media projected by an air jet onto the surface. Cleaning is performed in an enclosure, similar to a grit blasting cabinet, using such abrasive media as aluminum oxide, novaculite, or garnet flour. Most abrasives fall within the 200 to 1200 mesh size range, and are mixed with water in the ratio of five pounds per gallon (0.6 kg/L). Other slurry additives include rust inhibitors and antisolidifying compounds. Parts should be thoroughly rinsed after cleaning.

Vapor blasting may be used for any of the following purposes:

(1) Remove light burrs
(2) Remove corrosion products
(3) Remove previous plating or coating material
(4) Roughen surfaces for plasma or arc coatings

**3.2.3 Acid Pickling.** Pickling or dilute acid etching is a more drastic cleaning procedure than vapor blasting. Pickling should be performed when the part is in the final machining stage, thereby minimizing the danger of acid entrapment or subsequent intergranular attack. The pickling procedure requires the total immersion of the part in an acid solution. The time cycle depends upon the tenacity of the surface condition, the stock removal desired, or both. After pickling, a hot water rinse, an alkaline solution immersion, and a thorough hot water or steam blast cleaning are used.

Acid contaminated surfaces may be neutralized by scrubbing with a sodium bicarbonate solution or immersing in a hot alkaline bath. Similarly, alkali contaminated surfaces may be neutralized by scrubbing with dilute 1% hydrochloric acid or with a 10% acetic acid solution. The surface should then be rinsed with clean cold water, and air or force air dried.

**3.2.4 Oven Baking.** Various machine elements manufactured from porous materials, such as sand castings, may absorb considerable quantities of oil, which may bleed out during a subsequent spraying operation. Welded assemblies that have received fluorescent penetrant inspection are particularly subject to this condition. Oven baking at 600°F (315°C) for four hours dries the oil and prevents bleed out.

**3.2.5 Ultrasonic.** Ultrasonic cleaning can be used when contaminants are lodged in confined areas. The equipment consists of a holding tank for the cleaning solution and a source producing ultrasonic vibrations within it. The cleaning solution is selected based on the problem encountered. Due to the heat generated, flammable or highly volatile solvents are not recommended for long term operations.

**3.2.6 Abrasive.** Dry abrasive blasting is an effective method for removing baked-on deposits, scale, or oxides. Abrasive blasting is accomplished by directing a compressed air stream containing abrasive particles through a nozzle and against the surface of the substrate. The blasting operation should be conducted by equipment other than the unit assigned for preparing substrates for spraying. This prevents contamination of the blasting materials. Careful consideration is required in selecting the type and size of abrasive.

Sheet metal panels, stampings, and weldments are more difficult to prepare than machined parts. Original sheet stock is usually identified by continuous printing of the manufacturer's name, material type, and heat number, using inks, dyes, or paint. The surface often contains rolled in mill scale or final heat treatment scale which should be removed. Subsequent manufacturing processes frequently add to or produce a surface oxide condition that should also be eliminated. There are numerous methods used for localized cleaning; however, vapor blasting or pickling is the most effective method for general cleaning purposes and very light stock removal.

**3.2.7 Brushing.** Wire brushing is used when only localized cleaning is needed. Small rotary wire brushes, driven by a power tool, clean by a scuffing action.

## 3.3 Roughening

After cleaning, several methods are used to produce a surface to which a sprayed coating will adhere. The principal methods are (1) abrasive grit blasting, (2) macroroughening, and (3) applying a bond coating. Combinations of these methods are often employed. These include grit blasting with a subsequent bond coating, or machine roughening followed by grit blasting.

Proper roughening is as important as cleaning. During thermal spraying, the plasticized or molten particles form platelets upon impact with the substrate. The platelets, as they cool and harden, must adhere to a surface that is conducive to mechanical adherence.

**3.3.1 Purpose.** Surface roughening is used to strengthen both the coating and the bond by

(1) providing compressive surface stresses
(2) interlocking laminations (or layers)
(3) increasing the bond area
(4) decontaminating the surface

**3.3.2 Degree.** The degree of roughness required to produce a sound and serviceable coating is dependent upon the material being applied, the process, and the subsequent service conditions of the finished part.

**3.3.3 Measurement.** Surface roughness values are expressed in micro ($\mu$) inch and meter units. The American National Standard[1] for surface roughness measurement specifies an arithmetical average (AA) deviation from the mean surface. Mean surface designates a perfectly flat surface with no asperities, also referred to as the center line. AA values are obtained by an instrument (profilometer) using a very fine stylus that moves over the surface of the part. It takes measurements of the heights (h) of the peaks and valleys (distances from the center line) and averages them.

The arithmetical average is calculated by adding all of the distances or heights (h), without regard to sign, and dividing by the total number of measurements (n)

$$\text{AA Average} = \frac{h_1 + h_2 + h_3 + h_4 + \text{---} + h_n}{n}$$

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[1] Refer to ANSI B46.1-1978, *Surface Texture*, New York: The American Society of Mechanical Engineers.

The root mean square (RMS) is derived as follows:

$$\text{RMS Average} = \sqrt{\frac{(h_1)^2 + (h_2)^2 + (h_3)^2 + \text{---} + (h_n)^2}{n}}$$

RMS values are approximately 11% higher than AA values. This is because the large numbers are exaggerated when the heights (h) are squared.

The current trend is to adopt the American National Standard, in which surface roughness is specified in arithmetical average (AA) deviation values.

## 3.4 Abrasive Grit Blasting

Abrasive grit blasting is the most commonly used roughening technique. The surface to be coated is disturbed by the impingement of abrasive particles.

**3.4.1 Factors Influencing Grit Selection.** Care must be exercised in grit selection. Factors that must be considered include the following:

(1) part material and hardness
(2) part construction and thickness in the area being grit blasted
(3) part size
(4) type of coating and roughness requirement for good adhesion
(5) service requirements
(6) production rate requirement
(7) grit particle size
(8) blast pressure
(9) blast nozzle size
(10) life cycle

**3.4.2 Type and Size of Abrasives.** The effects of grit blasting depend on the type and size of abrasive. Sharp, hard, angular particles provide the best results. Spherical or rounded particles should not be used. All abrasives must be clean, dry, and free of oil, feldspar, or other contaminants.

**Abrasive Grit Types.** Several types of commercial abrasive grit are tabulated in Tables 3.4.2A and 3.4.2B. The most commonly used types are

(1) aluminum oxide
(2) chilled iron
(3) angular steel
(4) silicon carbide
(5) garnet

Proper selection of the blasting medium depends on the substrate hardness.

Refractory oxides with sharp cutting edges may embed in soft substrates, such as aluminum. Chilled iron grit, which dulls rather than fractures on impact, is better for cleaning most substrates with hardnesses of less than 40-45 Rockwell C. Chilled iron grit generally creates greater stresses in the substrate than aluminum oxide. For this reason, it should not be used on thin substrates which may be warped by blasting.

**Table 3.4.2A**
**Characteristics of abrasives commonly used for grit blasting prior to thermal spraying**

| Abrasive | Natural or mft'd | Major chemical component | Shape | Bulk density 100 g/cc | Breakdown* % of sample | Rc hardness |
|---|---|---|---|---|---|---|
| Chilled steel grit | Mft'd | Iron | Angular | 765 | 0 | 100 |
| Chilled iron grit | Mft'd | Iron | Angular | 740 | 8 | 97 |
| Virgin alum. oxide | Mft'd | Aluminum | Cubic | 380 | 24 | 76 |
| Reclaimed alum. oxide | Mft'd | Aluminum | Cubic | 376 | 34 | 66 |
| Garnet | Nat. | Iron silica | Cubic | 409 | 46 | 54 |
| Mineral slag | Mft'd | Silica alum. iron | Cubic | 279 | 61 | 39 |
| Flintbrasive | Nat. | Silica | Very angular | 261 | 67 | 33 |
| Silica sand | Nat. | Silica | Cubic | 261 | 77 | 23 |
| Silica sand | Nat. | Silica | Angular | 263 | 90 | 10 |
| Silicon carbide | Mft'd | Silicon carbide | Blocky | 381 | 57 | 43 |
| Standard sand | Nat. | Silica | Angular | 262 | 84 | 16 |

* Amount of sample reduced to unacceptable size in standard blast test.

## Table 3.4.2B
## Recommended abrasives as used in abrasive blast cleaning applications

| Recommended service[1,2] | Aluminum | Silica abrasives | Slag sand | Slag shot | Flint abrasives | Natural mineral abrasives | Synthetic abrasives | Special abrasives | Vegetable abrasives | Glass abrasives | Chilled iron grit | Chilled iron shot | Annealed abrasives | Steel grit |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| General blast cleaning where abrasives can be recycled and reused economically | C | C | C | C | C | C | P |  | C |  | P | C | C |  |
| General blast cleaning where abrasives cannot be economically reclaimed |  | P | C | C | C |  |  |  |  |  |  |  |  |  |
| Pre-thermal spray blasting | P | C | C |  | P | C | C |  |  |  | P |  | C | C |
| Blasting where metal tolerances cannot be changed |  |  |  |  |  |  |  | C | P |  |  |  |  |  |
| Blasting in rooms and cabinets | P | C | C | C | C | C | P | C | C | C | P | C | C |  |
| Blasting where the elimination of food contamination or nonmagnetic abrasives are required |  |  |  |  |  |  |  |  | P |  |  |  |  |  |
| Blasting to obtain a high luster on aluminum, brass, etc. |  |  |  |  |  |  |  | C | C | P |  |  |  |  |
| Liquid hone, hydro hone, wet hone blasting |  | C |  |  |  | C | P | P | P | P |  |  |  |  |
| Centrifugal wheel blasting | C |  |  |  |  |  |  |  |  |  |  |  | C | P |

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1. C=commonly used abrasives; P=preferred for thermal spraying applications.

2. Federal and State safety regulations governing the use of silica and mineral type abrasives for abrasive blasting are revised occasionally. The user of a recommended abrasive should be certain of compliance with the latest regulations.

Aluminum oxide may be used on hard substrates such as martensitic steel. When used on soft substrates, subsequent air blasting may help to remove any embedded particles.

Silicon carbide has a much greater tendency to embed, and breaks down more rapidly than aluminum oxide.

**Abrasive Grit Sizes.** Since the roughness of the finish depends on the size of the grit, abrasives are furnished in different grades. Smaller sized particles will allow for the preparation of more area per hour. Larger abrasive particles result in more rapid removal of material from the substrate, and produce rougher finishes. Table 3.4.2C shows the particle size distribution for a given grit mesh size, and Table 3.4.2D shows sieve standards. It is recommended that the particle size should be 16 to 60 grit for metal substrates, and 60 to 100 grit for most plastics.

For thin coatings, particularly when used on thin substrates, fine grit (25 to 120) should be used. Coarser grits (18 to 25) that produce rougher finishes are used for thick coatings [greater than 0.010 in. (0.25 mm)], and best coating adherence.

**3.4.3 Blasted Surface Roughness.** The National Association of Corrosion Engineers (NACE) Technical Committee T-60 has conducted research and development to set standards for surface preparation. The following information and additional data may be obtained from the *Surface Preparation Handbook.*

There are four grades of blast cleaning presented on two Visual Standards (order #TM-01-70) which have been prepared to conform to the four surface conditions defined by NACE. These are recommended for use in describing or specifying degrees of surface preparation on steel by abrasive blasting. The most preferred grade for thermal spraying is NACE No. 1 (Table 3.4.3).

## Table 3.4.2C
## Particle size distribution vs. grit sizes

Grit sizes

| Sieve No. | 6 | 8 | 10 | 12 | 14 | 16 | 20 | 22 | 24 | 30 | 36 | 40 | 46 | 54 | 60 | 70 | 80 | 90 | 100 | 120 | 150 | 180 | 220 | 240 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4 | 0 | | | | | | | | | | | | | | | | | | | | | | | |
| 5 | 15 | | | | | | | | | PARTICLE SIZE DISTRIBUTION STANDARD MESH RANGES | | | | | | | | | | | | | | |
| 6 | 45 | 0 | | | | | | | | | | | | | | | | | | | | | | |
| 7 | 25 | 15 | 0 | | | | | | | | | | | | | | | | | | | | | |
| 8 | 12 | 45 | 15 | 0 | | | | | | | Grading Standards Department of Commerce Abrasive Grain Association | | | | | | | | | | | | | |
| 10 | 3 | 30 | 45 | 15 | 0 | | | | | | | | | | | | | | | | | | | |
| 12 | | 7 | 30 | 45 | 15 | 0 | | | | | | | | | | | | | | | | | | |
| 14 | | 3 | 7 | 30 | 45 | 15 | 0 | 0 | | | | | | | | | | | | | | | | |
| 16 | | | 3 | 7 | 30 | 45 | 15 | | 0 | | | | | | | | | | | | | | | |
| 18 | | | | 3 | 7 | 30 | 45 | 20 | | 0 | | | | | | | | | | | | | | |
| 20 | | | | | 3 | 7 | 30 | 45 | 25 | | 0 | | | | | | | | | | | | | |
| 25 | | | | | | 3 | 7 | 25 | 45 | 25 | | 0 | | | | | | | | | | | | |
| 30 | | | | | | | 3 | 7 | 25 | 45 | 25 | | 0 | | | | | | | | | | | |
| 35 | | | | | | | | 3 | 2 | 25 | 45 | 25 | | 0 | | | | | | | | | | |
| 40 | | | | | | | | | 3 | 2 | 25 | 45 | 30 | | 0 | | | | | | | | | |
| 45 | FIVE SIEVE TEST<br>U. S. STANDARD SIEVES<br>PERCENTAGES SHOW<br>0 ON 100% THRU SIEVE,<br>MAXIMUM PERMITTED ON<br>CONTROL SIEVE, MINIMUM ON<br>NUMBER OR GRIT SIZE SIEVE,<br>MINIMUM TOTAL REQUIRED ON<br>CUMULATIVE SIEVES (IN BLOCK)<br>AND MAXIMUM PERMITTED<br>THRU FINE CONTROL SIEVE.<br>MAXIMUM VARIATION PERMITTED<br>ON CONTROL SIEVE 20 POINTS. | | | | | | | | | 3 | 2 | 25 | 40 | 30 | | 0 | | | | | | | | |
| 50 | | | | | | | | | | | 3 | 2 | 25 | 40 | 30 | | 0 | | | | | | | |
| 60 | | | | | | | | | | | | 3 | 2 | 25 | 40 | 15 | | 0 | | | | | | |
| 70 | | | | | | | | | | | | | 3 | 2 | 25 | 45 | 25 | | 0 | | | | | |
| 80 | | | | | | | | | | | | | | 3 | 2 | 25 | 40 | 15 | | 0 | | | | |
| 100 | | | | | | | | | | | | | | | 3 | 12 | 25 | 40 | 15 | | 0 | | | |
| 120 | | | | | | | | | | | | | | | | 3 | 7 | 30 | 45 | 15 | | 0 | | |
| 140 | | | | | | | | | | | | | | | | | 3 | 12 | 20 | 30 | 15 | | 0 | |
| 170 | | | | | | | | | | | | | | | | | | 3 | 10 | 30 | 20 | 15 | | 0 |
| 200 | | | | | | | | | | | | | | | | | | | 7 | 15 | 20 | 20 | 15 | 5 |
| 230 | | | | | | | | | | | | | | | | | | | 3 | 7 | 35 | 20 | 20 | |
| 270 | | | | | | | | | | | | | | | | | | | | 3 | 7 | 25 | 20 | 8 |
| 325 | | | | | | | | | | | | | | | | | | | | | 3 | 17 | 20 | 30 |
| −325 | | | | | | | | | | | | | | | | | | | | | | 3 | 25 | 57 |

Note: Procedures for determining the particle size distribution are described in the following standards:

ASTM C371-77, Standard Method for Wire-Cloth Sieve Analysis of Nonplastic Ceramic Powders.

ASTM B214-76, Standard Test Method for Sieve Analysis of Granular Metal Powders

## Table 3.4.2D

**Nominal Dimensions, Permissible Variations for Wire Cloth of Standard Test Sieves (U.S.A. Standard Series)**

| Sieve Designation | | | | | | |
|---|---|---|---|---|---|---|
| Standard[b] (1) | Alternative (2) | Nominal Sieve Opening, in.[c] (3) | Permissible Variation of Average Opening from the Standard Sieve Designation (4) | Maximum Opening Size for Not More than 5% of Openings (5) | Maximum Individual Opening (6) | Nominal Wire diameter, mm[a] (7) |
| 125 mm | 5 in. | 5 | ±3.7 mm | 130.0 mm | 130.9 mm | 8.0 |
| 106 mm | 4.24 in. | 4.24 | ±3.2 mm | 110.2 mm | 111.1 mm | 6.40 |
| 100 mm[d] | 4 in.[d] | 4 | ±3.0 mm | 104.0 mm | 104.8 mm | 6.30 |
| 90 mm | 3½ in. | 3.5 | ±2.7 mm | 93.6 mm | 94.4 mm | 6.08 |
| 75 mm | 3 in. | 3 | ±2.2 mm | 78.1 mm | 78.7 mm | 5.80 |
| 63 mm | 2½ in. | 2.5 | ±1.9 mm | 65.6 mm | 66.2 mm | 5.50 |
| 53 mm | 2.12 in. | 2.12 | ±1.6 mm | 55.2 mm | 55.7 mm | 5.15 |
| 50 mm[d] | 2 in.[d] | 2 | ±1.5 mm | 52.1 mm | 52.6 mm | 5.05 |
| 45 mm | 1¾ in. | 1.75 | ±1.4 mm | 46.9 mm | 47.4 mm | 4.85 |
| 37.5 mm | 1½ in. | 1.5 | ±1.1 mm | 39.1 mm | 39.5 mm | 4.59 |
| 31.5 mm | 1¼ in. | 1.25 | ±1.0 mm | 32.9 mm | 33.2 mm | 4.23 |
| 26.5 mm | 1.06 in. | 1.06 | ±0.8 mm | 27.7 mm | 28.0 mm | 3.90 |
| 25.0 mm[d] | 1 in.[d] | 1 | ±0.8 mm | 26.1 mm | 26.4 mm | 3.80 |
| 22.4 mm | ⅞ in. | 0.875 | ±0.7 mm | 23.4 mm | 23.7 mm | 3.50 |
| 19.0 mm | ¾ in. | 0.750 | ±0.6 mm | 19.9 mm | 20.1 mm | 3.30 |
| 16.0 mm | ⅝ in. | 0.625 | ±0.5 mm | 16.7 mm | 17.0 mm | 3.00 |
| 13.2 mm | 0.530 in. | 0.530 | ±0.41 mm | 13.83 mm | 14.05 mm | 2.75 |
| 12.5 mm[d] | ½ in.[d] | 0.500 | ±0.39 mm | 13.10 mm | 13.31 mm | 2.67 |
| 11.2 mm | 7/16 in. | 0.438 | ±0.35 mm | 11.75 mm | 11.94 mm | 2.45 |
| 9.5 mm | ⅜ in. | 0.375 | ±0.30 mm | 9.97 mm | 10.16 mm | 2.27 |
| 8.0 mm | 5/16 in. | 0.312 | ±0.25 mm | 8.41 mm | 8.58 mm | 2.07 |
| 6.7 mm | 0.265 in. | 0.265 | ±0.21 mm | 7.05 mm | 7.20 mm | 1.87 |
| 6.3 mm[d] | ¼ in.[a] | 0.250 | ±0.20 mm | 6.64 mm | 6.78 mm | 1.82 |
| 5.6 mm | No. 3½ | 0.223 | ±0.18 mm | 5.90 mm | 6.04 mm | 1.68 |
| 4.75 mm | No. 4 | 0.187 | ±0.15 mm | 5.02 mm | 5.14 mm | 1.54 |
| 4.00 mm | No. 5 | 0.157 | ±0.13 mm | 4.23 mm | 4.35 mm | 1.37 |
| 3.35 mm | No. 6 | 0.132 | ±0.11 mm | 3.55 mm | 3.66 mm | 1.23 |
| 2.80 mm | No. 7 | 0.111 | ±0.095mm | 2.975 mm | 3.070 mm | 1.10 |
| 2.36 mm | No. 8 | 0.0937 | ±0.080 mm | 2.515 mm | 2.600 mm | 1.00 |
| 2.00 mm | No. 10 | 0.0787 | ±0.070 mm | 2.135 mm | 2.215 mm | 0.900 |
| 1.70 mm | No. 12[e] | 0.0661 | ±0.060 mm | 1.820 mm | 1.890 mm | 0.810 |
| 1.40 mm | No. 14 | 0.0555 | ±0.050 mm | 1.505 mm | 1.565 mm | 0.725 |
| 1.18 mm | No. 16 | 0.0469 | ±0.045 mm | 1.270 mm | 1.330 mm | 0.650 |
| 1.00 mm | No. 18 | 0.0394 | ±0.040 mm | 1.080 mm | 1.135 mm | 0.580 |
| 850 μm[f] | No. 20 | 0.0331 | ±35 μm | 925 μm | 970 μm | 0.510 |
| 710 μm | No. 25 | 0.0278 | ±30 μm | 775 μm | 815 μm | 0.450 |
| 600 μm | No. 30 | 0.0234 | ±25 μm | 660 μm | 695 μm | 0.390 |
| 500 μm | No. 35 | 0.0197 | ±20 μm | 550 μm | 585 μm | 0.340 |
| 425 μm | No. 40 | 0.0165 | ±19 μm | 471 μm | 502 μm | 0.290 |
| 355 μm | No. 45 | 0.0139 | ±16 μm | 396 μm | 425 μm | 0.247 |
| 300 μm | No. 50 | 0.0117 | ±14 μm | 337 μm | 363 μm | 0.215 |
| 250 μm | No. 60 | 0.0098 | ±12 μm | 283 μm | 306 μm | 0.180 |
| 212 μm | No. 70 | 0.0083 | ±10 μm | 242 μm | 263 μm | 0.152 |
| 180 μm | No. 80 | 0.0070 | ±9 μm | 207 μm | 227 μm | 0.131 |
| 150 μm | No. 100 | 0.0059 | ±8 μm | 174 μm | 192 μm | 0.110 |
| 125 μm | No. 120 | 0.0049 | ±7 μm | 147 μm | 163 μm | 0.091 |
| 106 μm | No. 140 | 0.0041 | ±6 μm | 126 μm | 141 μm | 0.076 |
| 90 μm | No. 170 | 0.0035 | ±5 μm | 108 μm | 122 μm | 0.064 |
| 75 μm | No. 200 | 0.0029 | ±5 μm | 91 μm | 103 μm | 0.053 |

### Table 3.4.2D (continued)

| Sieve Designation |  | Nominal Sieve Opening, in.[c] | Permissible Variation of Average Opening from the Standard Sieve Designation | Maximum Opening Size for Not More than 5% of Openings | Maximum Individual Opening | Nominal Wire diameter, mm[a] |
|---|---|---|---|---|---|---|
| Standard[b] | Alternative |  |  |  |  |  |
| (1) | (2) | (3) | (4) | (5) | (6) | (7) |
| 63 μm | No. 230 | 0.0025 | ±4 μm | 77 μm | 89 μm | 0.044 |
| 53 μm | No. 270 | 0.0021 | ±4 μm | 66 μm | 76 μm | 0.037 |
| 45 μm | No. 325 | 0.0017 | ±3 μm | 57 μm | 66 μm | 0.030 |
| 38 μm | No. 400 | 0.0015 | ±3 μm | 48 μm | 57 μm | 0.025 |

[a] The average diameter of the warp and of the shoot wires, taken separately, of the cloth of any sieve shall not deviate from the nominal values by more than the following:

| | |
|---|---|
| Sieves coarser than 600 μm | 5% |
| Sieve 600 to 125 μm | 7½% |
| Sieves finer than 125 μm | 10% |

[b] These standard designations correspond to the values for test sieve apertures recommended by the International Standards Organization, Geneva, Switzerland.

[c] Only approximately equivalent to the metric values in Column 1.

[d] These sieves are not in the standard series, but they have been included because they are in common usage.

[e] These numbers (3½ to 400) are the approximate number of openings per linear inch, but it is preferred that the sieve be identified by the standard designation in millimeters or μm.

[f] 1000 μm=1 mm.

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### Table 3.4.3
### Guide to base metal gritblasting rates for NACE* No. 1, white metal finish

| Equipment | Rate, ft $^{2/h}$ minimum | - maximum |
|---|---|---|
| Syphon type | 10 | 20 |
| Pressure type | 20 | 40 |
| Manual abrasive return room | 30 | 60 |
| Automatic abrasive return room | 50 | 100 |
| Wheel type airless (per wheel) | 150 | 400 |

Notes:
The minimum rate indicates the output on small work heavily corroded requiring considerable handling.
The maximum rate is for large surfaces in semi-bright or lightly corroded conditions.
*National Association of Corrosion Engineers

NACE No. 1, White Metal Blast Cleaned Surface Finish is a surface with a gray white (uniform metallic) color that has been roughened to form a suitable anchor pattern for coatings. This surface is free of oil, grease, dirt, mill scale, rust, corrosion products, oxides, paint, and other foreign matter. (Comparable to *SSPC-SP 5-63, White Metal Blast Cleaning.*)

The surface roughness adequate for most spray coatings is 100μ in. (2.5 μm) to 500μ in. (13 μm) AA. For some critical applications, especially on thin metal parts, it may be necessary to use a roughness value of 50μ in. (1.3 μm) AA. For plastic parts coated with low melting point materials and alloys, such as zinc, the roughness should be 250μ in. (6 μm) AA, minimum.

Adhesion bond strength normally increases with surface roughness, although the rate of improvement decreases above 400μ in. (10 μm) AA. The best adhesion bond strength is associated with a roughness dimension comparable to three-fourths of the diameter of the particles sprayed.

**3.4.4 Blasting Procedures.** In addition to the abrasive grit type and size, other process variables of importance are air pressure, blast angle, distance, and time (Table 3.4.4).

## Table 3.4.4
## General conditions frequently used to produce the required roughness on steel substrates

| Grit size (mesh) | Grit material | Blast pressure psi | Blast pressure (kPa) | Nozzle bore dia. in. | Nozzle bore dia. (mm) | Machine type | Substrate | Roughness AA in. | Roughness AA (μm) |
|---|---|---|---|---|---|---|---|---|---|
| 24 | Aluminum oxide | 60 | (414) | 5/16 | (7.9) | Pressure | Steel | 500 | (13) |
| 60 | Silicon carbide or aluminum oxide | 60 | (414) | 5/16 | (7.9) | Suction | Stainless | 250 | (μ6) |
| 80 | Aluminum oxide | 60 | (414) | 5/16 | (7.9) | Pressure | Plastic | 250 | (μ6) |

All substrate areas that can be damaged by the blast operation, or are to be coated, must be protected by suitable masking. Dust or grit adhering to the substrate surface must be removed by air blast before starting a spraying operation.

Air pressures for blasting are in the range of 30 to 100 psi (34 to 88 kg/sq cm), depending on the substrate material; the required surface finish; the flow, weight, and size of abrasive particles; and the machine and nozzle type used.

Low blasting air pressures and soft or fine grit should be used for substrates, such as aluminum and copper alloys, bronzes, and plastics, to minimize the likelihood of embedding the grit. High air pressures, in addition to causing rapid breakdown of the grit, produce compressive stresses which can distort thin substrates.

With pressure type blasting equipment, the following pressures at the nozzle should be used:

(1) With aluminum oxide, silicon carbide, flint or slag - 50 psi (345 kPa) minimum and 60 psi (414 kPa) maximum

(2) With sand, garnet, or crushed chilled iron grit - 75 psi (517 kPa) minimum

These are not the pressures at the blast machine tank, but at the blast nozzle as measured with a needle probe gauge.

When syphon blasting (suction blasting), the maximum nozzle pressure should be

(1) With aluminum oxide, silicon carbide, flint or slag - 75 psi (517 kPa)

(2) With sand, garnet, or crushed chilled iron grit - 90 psi (621 kPa)

The abrasive stream should be directed onto the substrate surface at a spray angle of 75° to 90°, and moved from side to side.

Nozzle to substrate distance varies from 4 to 12 in. (102-304 mm), depending upon the size and type of abrasive used, nozzle opening size, and capacity of the blast machine.

Visual inspection for uniform coverage and surface texture determines the required time for producing a grit-blasted surface suitable for spraying (3.4.3, NACE No. 1). Excessive blasting time may result in an undesirable surface texture.

**3.4.5 Blasting Speeds and Costs.** Blasting speeds and costs depend on several factors including the type, size, and loading capacity of the blasting equipment as well as the substrate material. Table 3.4.3 shows the typical performance of various blasting devices.

Blast machine nozzles having large diameter orifices will cover more area per hour than nozzles having smaller orifices. However, the size of the nozzle orifice to be chosen is limited by the amount of compressed air available. Table 3.4.5 shows the square feet (square meters) of blast cleaned surface that can be obtained for various surface conditions with a given size nozzle, using a continuous pressure type blaster with an air pressure of 100 psi (0.03 kg/m$^2$).

The type and size of the abrasive also influences blasting rates. Generally, the larger the abrasive particle size, the slower the operation. Approximately 15 lb (6.8 kg) of aluminum oxide or 25 lb (11.3 kg) of chilled iron grit are required per square foot of blasted surface.

**3.4.6 Grit Recycling.** Abrasives used in shop or production applications may be recycled, cleaned, and screened so that they can be used again. Angular chilled iron grit and aluminum oxide are most commonly used in such operations. When an abrasive is reused, it should be cleaned of dust and resized, with a minimum of 80% conforming to the original size requirements. Con-

### Table 3.4.5
### Pressure blast cleaning rates on semi-bright or lightly corroded steel substrate using 925 iron grit

| Surface condition and type blasted | Nozzle size, in. (mm) ¼ (6.4) | ⁵⁄₁₆ (7.9) | ⅜ (9.5) |
|---|---|---|---|
| | Blasting rate, ft²/h (m²/h) | | |
| Surface condition No. 1 | | | |
| White | 75 (7.0) | 117 (10.9) | 168 (15.6) |
| Commercial | 112 (10.4) | 175 (16.3) | 252 (23.4) |
| Brush-off | 299 (27.8) | 467 (43.4) | 672 (62.4) |
| Surface condition No. 2 | | | |
| White | 96 (8.9) | 150 (13.9) | 216 (20.1) |
| Commercial | 144 (13.4) | 225 (20.9) | 321 (29.8) |
| Brush-off | 381 (35.4) | 600 (55.7) | 851 (79.1) |
| Surface condition No. 3 | | | |
| White | 85 (7.9) | 133 (12.4) | 192 (17.8) |
| Commercial | 128 (11.9) | 200 (18.6) | 288 (26.8) |
| Brush-off | 341 (31.7) | 533 (49.5) | 768 (71.4) |

taminated abrasive grains, or those of questionable quality, should not be reused. Failure to remove broken down grit (fines) from the abrasive can be detrimental to the proper bonding of a coating.

Table 3.4.6 shows frequently used materials evaluated under controlled conditions. There are many variables that can alter these data, but the table gives a relative idea of the number of times different types of material can be recycled through a blast machine.

### Table 3.4.6
### Abrasive life

| Material | No. of recycles |
|---|---|
| Aluminum oxide | 10 |
| Chilled iron | 15 |
| Steel | 100 |
| Garnet | 7 |

Single-use abrasives are employed in on-site or field applications, where it is usually not economical to reclaim and reuse abrasives.

**3.4.7 Compressed Air Supply.** The compressed air supply should be adequate to furnish the necessary pressure and volume to sustain the proper blast quality. The air should be free from oil, water, and other contaminates. In addition to clogging the system, oil or water in the compressed air can adversely affect surface preparation and subsequent bonding.

## 3.5 Macroroughening

Macroroughening is another surface preparation method usually accomplished by machining or grinding, and is performed in conjunction with grit blasting, the use of bond coatings, or both.

**3.5.1 Undercutting.** Undercutting is the operation of machining or grinding away surface to provide space for the thermal spray deposit. This is necessary on mechanical parts that are to be rebuilt.

Undercutting is also done to provide a uniform thickness of finished coating or to remove metal from a surface due to work hardening, chemical contamination, oxidation, or previously applied sprayed material. Since undercutting reduces the cross-sectional area of the components, it can adversely affect the tensile and fatigue strength of the part.

**Shoulders and Undercut Sections.** At each undercut section on a cylindrical part, the shoulders should be cut square or at a slight obtuse angle (15°). The use of acute angle dovetails is detrimental and not recommended. A radius of 0.015 to 0.020 in. (0.38 to 0.50 mm) should be made at each corner of the undercut. The undercut section should not extend to the end of a shaft. The proper and improper ways to terminate the thermal sprayed inlay at the end of a shaft are illustrated in Fig. 3.5.1. Leave a shoulder at end of the undercut section wherever possible.

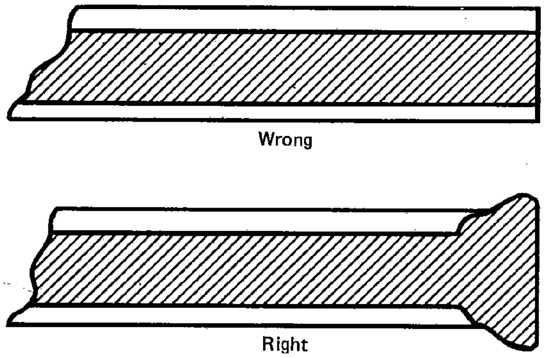


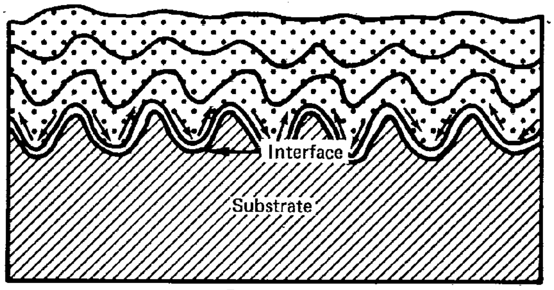
**Fig. 3.5.1—Shaft with proper and improper undercut section**

On cylindrical surfaces (such as pump plungers) where the coating is exposed to pressure from the end, it is recommended that a weld be deposited circumferentially around the pressure end. The welded bead should then be machined to a 1/8 in. (3.2 mm) minimum shoulder. The diameter of the shoulder should be greater than the final finish size of the shaft. The welded bead can withstand the pressure of operation better than an exposed thermal sprayed layer. It is important to note that welding can affect base metal properties; this must be considered in salvage or repair applications.

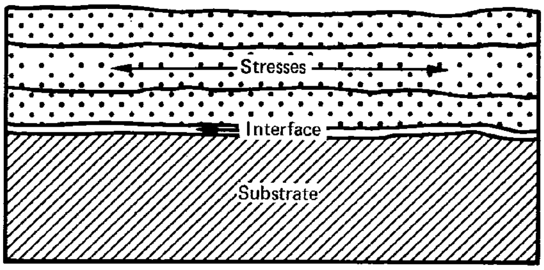
**3.5.2 Grooving.** Grooving pertains to the operation of cutting deep, closely spaced striations in the substrate. Grooving (or threading) is performed primarily for the following purposes:

(1) restrict the shrinkage stresses
(2) increase the bond surface area
(3) produce folds in the layers of the coating to limit internal stresses

Internal stresses from shrinkage develop in coatings, which can result in bond failure. The stresses increase with increased coating thickness, and are more severe in hard metals or ceramics. Grooving is a method of reducing the stresses by dividing the internal stresses into smaller components. Figure 3.5.2 shows sections of two shafts. One is undercut without threading, and the internal stresses are in a straight line across the full length of the undercut. In the threaded shaft, stresses have been broken into smaller components, along each side of each thread, and can cancel each other. All corners at the root of each thread should be radiused to reduce the notch effect. A second method is to use U-shaped grooves instead of conventional V-shaped threads which may act as points of stress concentration in heavily loaded machine parts.



Over grooves
Stresses (arrows) tend to cancel



On smooth surface
Stresses, parallel to substrate, tend to separate coating

**Fig. 3.5.2 — Sprayed metal**

Since thermal sprayed coatings consist of laminations or layers of flattened particles, much like a piece of straight grained wood, the strength of the coating is lower in the direction perpendicular to the layers than in the parallel direction. As the laminations are folded up and down over relatively large grooves, the coating strength is improved, and there is less tendency for layer separation to occur.

Grooving should be considered in the following situations:

(1) for all coatings over 0.050 in. (1.27 mm) thickness wherever there is an edge

(2) for high-shrink coatings over 0.030 in. (0.76 mm)

thickness wherever there is an edge

(3) for coatings that do not have edges, such as continuous coatings on cylindrical surfaces, when severe service conditions exist, or when there is danger of cracking due to thick buildups or high shrink materials

**3.5.3 Studs or Slots on Flat Surfaces.** Hard metallic coatings on flat surfaces present special problems. If the substrate is of a harder metal, the depth of the blast profile is reduced, and the adhesion of the thermal sprayed coating is decreased. In addition, hard metal coatings are usually applied thicker than soft coatings such as aluminum or zinc. Consequently, the total amount of coating shrinkage during cooling is much greater.

On such applications, it is often necessary to stud the surface. This consists of drilling and tapping holes at 1 in. (25 mm) intervals and inserting unplated flat-head screws which match the composition of the substrate. Screw diameters vary from 0.125 to 0.25 in. (3 to 6 mm). After attachment, the surfaces and screws are blasted.

**3.5.4 Coarse Grit Blasting.** For some types of work where grooving is not practical, but where macroroughening is desired, extremely coarse grit blasting can produce similar results (see 3.4). Coarse grit blasting is used in place of grooving methods for many applications to take advantage of lower costs and higher production. SAE[2] G-14 chilled iron grit will provide adequate roughness for a strong adhesive bond and cause sufficient folds in the laminations to effectively perform the function of fine grooves. This method may also be used for undercutting.

## 3.6 Roughening Applications

**3.6.1 Corrosion Resistant Coatings.** Where zinc coatings up to and including 0.009 in. (0.23 mm) thick or aluminum coatings up to and including 0.007 in. (0.18 mm) thick are to be applied, the following abrasive grits are recommended for use with pressure blast equipment to produce a 300μ in. (7.5 μm) AA anchor tooth pattern.

1. Aluminum oxide or silicon carbide
   mesh size: SAE G-25 to SAE G-40
2. Hardened steel grit
   mesh size: SAE G-25 to SAE G-40
3. Angular silica sand, garnet, flint, or crushed slag
   mesh size: SAE G-25 to SAE G-50

To prepare surfaces for zinc coatings greater than 0.010 in. (0.25 mm) thick or aluminum coatings in excess of 0.008 in. (0.20 mm), the following abrasives are recommended for use in pressure type blast machines to provide a 500μ in. (13 μm) AA anchor tooth pattern:

1. Aluminum oxide or silicon carbide
   mesh size: SAE G-18 to SAE G-25
2. Hardened steel grit
   mesh size: SAE G-18 to SAE G-25
3. Angular silica sand, garnet, flint, or crushed slag
   mesh size: SAE G-18 to SAE G-25

**3.6.2 Fused Coatings.** For the application of self-fluxing alloys, the surface preparation must be sufficient to hold the coating until the fusing operation is accomplished. Self-fluxing alloy applications receive the greatest stress during the fusing operation at temperatures of 1800 to 2100°F (982 to 1149°C).

When preparing the surfaces, SAE G-25 chilled iron grit is normally used. Grit size may vary according to substrate hardness, etc. However, grit such as aluminum oxide tends to embed in the surface and impair the coating adhesion.

On cylindrical surfaces that are to be precision finished, undercutting is necessary. The depth of the undercut is determined by service conditions. If the maximum allowable wear is 0.020 in. (0.5 mm), an undercut of an additional 0.015 in. (0.38 mm) minimum is recommended so that some coating will remain after maximum wear has taken place.

Shoulders at the end of the undercut section should be opened to about a 40° to 45° angle. For coatings, greater than 0.040 in. (1.0 mm) thick, threading the undercut surface is advisable prior to grit blasting.

**3.6.3 Stainless Steel Coatings.** For stainless steel coatings on hardened steel, an SAE G-20 aluminum oxide grit provides a surface roughness with a 500μ in. (13 μm) AA anchor tooth pattern. For stainless steel coatings on mild steel or cast iron, an SAE G-25 chilled iron grit is recommended.

**3.6.4 Plastic Substrates.** Soft substrates, such as plastics, require a finer mesh size and lower blasting pressure. Aluminum oxide, size SAE G-50 to SAE G-80, will provide a 250μ in. (6 μm) AA surface roughness.

## 3.7 Cleanliness After Roughening

When blast roughening is employed, the freshly exposed substrate is extremely susceptible to contamination. Hand contact should be avoided because deposited oil or finger

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[2] Refer to SAE J444, *Cast Shot and Grit Size Specifications for Peening and Cleaning*, Rev. A, Society of Automotive Engineers, November 1, 1976.

prints may adversely affect the coating bond. Spray coatings should be completed before oxidation occurs on the cleaned surface. Clean roughened surfaces are degraded by moisture or condensate; even slight corrosion is an indication of moisture. Where possible, humidity should be maintained at 60% or less in the spray and preparation area. In some instances, a mild preheat prior to blasting may be helpful.

**3.7.1 Coverings.** Freshly prepared surfaces, that are not to be coated immediately can be protected by covering them with clean plastic sheet. For extended periods, all prepared parts may be stored in a clean heated cabinet or oven, or a sealed bag with a dessicant. Heated storage can facilitate preheating for spraying.

**3.7.2 Handling.** Work pieces that have been prepared for spraying should be handled with clean, lint free gloves or the equivalent until the thermal sprayed coating is applied.

## 3.8 Bond Coatings

The use of bond coatings is another method of surface preparation. Certain materials adhere to clean, smooth surfaces forming strong coating-to-substrate bonds, over a wide range of conditions. A thin layer of bonding material serves as an anchoring subcoat for subsequently applied coating layers. For best results, the substrate should be grit blasted before applying the bond or intermediate coating. A top coat applied to a grit blasted, bond-coated surface normally will produce a higher bond strength than that obtained without a bond coating.

Bond coatings are particularly applicable for substrates that are too thin or too hard to be prepared by abrasive grit blasting or macroroughening. They are also applicable when size or configuration make blasting or roughening difficult. Frequently, bond coating is selected to provide protection to the substrate as well as to provide a good bond to it.

**3.8.1 General Considerations.** Certain general rules should be observed in using a bond coating. The decision to use a bond coating must take into account the conditions under which the coating will be used, particularly if the coating will be exposed to corrosive or oxidizing conditions. Molybdenum has poor oxidation resistance, and would not be suitable for use in air at temperatures above 600°F (316°C). Nickel-aluminum coatings are susceptible to corrosion in aqueous salt solutions. Where the coating will be exposed in electrolytic solution, the bond coating may be cathodic to the substrate material, resulting in increased rate of corrosion and delamination.

**3.8.2 Bond Coat Thickness.** The use of a bond coat sometimes limits the thickness of subsequently applied top coats. Unless the substrate has first been treated, the bond coat may not be able to absorb the shrinkage stresses produced by thick, hard metallic deposits. The bonding material should be applied sufficiently thick to cover the substrate, usually 0.003 to 0.007 in. (0.08 to 0.18 mm). There is no practical economic or engineering advantage in a thick bond coating, except when used as the entire coating.

**3.8.3 Bond Coat Materials.** Commercially available bonding materials include molybdenum and nickel-aluminum composites and alloys which produce some metallurgical interaction with the substrate during spraying. Table 3.8.3 lists common bond coating materials and their service temperatures. Nickel-aluminum is used for many applications because of its good high temperature properties and ease of application to various substrates. Materials such as aluminum, tin, and zinc aid the bonding of sprayed coatings to materials, such as plastics, that are resistant to low temperature.

Nickel-chromium alloys or other metal-chromium-aluminum alloy (MCrAlY) materials resist thermal shock better than other bonding materials. They are particularly suited for thermal barrier coatings in high temperature environments, 2300° to 2400°F (1260° to 1316°C).

**Table 3.8.3**
**Approximate maximum service temperature limits for bond coatings**

| Coating | °F | °C |
|---|---|---|
| Molybdenum | 600 | 315 |
| 80 Ni-20 Al | 1150 | 620 |
| 95 Ni- 5 Al | 1850 | 1010 |
| 80 Ni-20 Cr | 2300 | 1260 |
| 94 NiCr-6 Al | 1800 | 980 |

**3.8.4 Ceramic Top Coatings.** Surface preparations for ceramic coatings are the same as those used for metallic coatings. Bond coatings are used extensively, and vary with the composition and characteristics of the substrate. The environment in which the coating is to operate dictates the type of bond coating material.

Bond coatings of nickel, chromium, stainless steel, or other corrosion resistant alloys, such as MCrAlY, are often applied (80 nickel-20 chromium being especially good) in thicknesses of 0.002 to 0.013 in. (0.05 to 0.33 mm) or more. They provide flexible and adherent coatings for ceramic deposits. Ceramic coatings are often subject to thermal cycling, high temperatures, and chemical corrosion. Relatively thicker bond coatings promote longer life under these conditions.

### 3.8.5 Arc, Combustion, and Plasma

**Arc.** The inherently high adhesive bond strengths achieved with the electric arc process make it possible to eliminate surface roughening for certain applications by using a bond coating of nickel-aluminum alloy. This, however, should be the exception rather than the rule. Surface roughening as described previously is always recommended.

High bond strengths may be obtained with arc spray coatings applied to a prepared surface by making the first pass as hot as possible to produce large particles [low air pressure and a 2 in. (50 mm) spray distance.] This establishes conditions for the superheated spray particles to adhere tightly. Three materials, 9 aluminum-91 copper alloy (aluminum-bronze), 80 nickel-20 chromium alloy, and 95 nickel-5 aluminum alloy, have excellent bonding properties. The adhesion and the ability to produce a rough profile with the first pass makes these materials ideally suited for subsequent coating buildup.

**Combustion** (Wire and Powder Flame Spraying). With flame spraying (see 1.4.3), grit blasting and bond coatings are usually required for most applications because of the low heat of combustion and low particle velocities.

**Plasma.** The surface preparation and bond coatings required for subsequent plasma sprayed deposits are as outlined in this chapter.

# Chapter 4

# Coating Characteristics

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# Chapter 4

# Coating Characteristics

## 4.1 Introduction

To understand the characteristics of the sprayed deposit, knowledge of the various deposition processes and the associated fuels, raw materials, and kinetics is important.

In addition to the operating conditions associated with the thermal spray process, raw material characteristics must also be considered. This is especially true of powdered materials. Particle shape, size, density, oxide content, all contribute to the quality of the end product. The melting and vaporization temperatures of the coating material are important because they restrict the use of a material and dictate the spraying conditions. For example, the liquid-vapor temperature range for pure alumina is narrow, and vaporization may occur under conditions of superheating, and produce a sponge-like coating structure.

The basic criterion is that the particles should melt completely without excessive vaporization, and remain molten until they impinge onto the substrate. Although smaller particle size will ensure more complete melting, there are usually serious difficulties in proper injection of fine particles [<200μ in. (5 μm)] into the heat system. In the case of oxyfuel flame spraying, consideration should be given to the dust content in the powder. The use of powders containing sizeable quantities of fines (dust) will lead to excessive coating oxidation and voids.

In externally fed plasma spraying systems, the velocity gradient of the high energy plasma stream restricts entry of fine particles into the hot zone. Therefore, some of the particles are transported on the periphery of the stream and do not melt sufficiently prior to impact. Further, fine particles cool more rapidly and, therefore, can partially solidify before impact. Only properly aligned particles melt completely by absorption of radiation from the surrounding hot gases.

Some simplified models have been proposed to describe the melting of solid particles in a heated gas effluent. Material related variables, such as the heat transfer coefficient, conductivity, and melting temperature, have been combined in equations for gas flow dynamics and heat conduction yielding the following equation:

$$\underset{\text{effluent}}{\frac{S(K\,\Delta\,T)^2}{V\mu}} \geqq \underset{\text{particle}}{\frac{L^2D^2}{16p}} \qquad \text{(Eq 1)}$$

where:

S = particle travel distance (spray distance)
K = mean boundary layer thermal conductivity
ΔT = mean boundary layer temperature gradient
V = mean effluent velocity
μ = mean effluent viscosity
L = particle heat content per unit volume at melting temperature
D = mean particle diameter
p = particle density

According to equation (1), there is a critical particle residence time and a critical particle size for which complete melting is achieved. The residence time is determined mainly by gas velocity, energy, and spray distance. The physical attributes of the particle, which are given by the term on the right of equation (1), depend on the material under consideration.

To measure particle temperature, T, a model was suggested by Plunkett which assumes that the surface temperature of a particle with a radius, R, is instantaneously brought to a constant temperature, $T_s$, while the interior temperature is raised by conduction during the dwell time, such that

$$\frac{T}{T_S} = \left\{ 1 = \frac{2R}{\pi R}\ \Sigma\ \frac{(-1)^n}{n}\ \mathrm{Sin}\ \frac{n\pi r}{R} \bullet \frac{(\propto n\pi)^2 t}{R} \right\} \qquad \text{(Eq 2)}$$

where:

n = 1
T = Particle temperature
$T_S$ = Constant temperature
R = Radius of particle (particle size in microns)

$\Sigma$ =Symbol for summation of all terms, in brackets
$r$ =Distance from particle center to R
$t$ =Residence time for particle
$\alpha$ =Thermal diffusivity

Wire and rod feedstock vary in size from 20 gauge (0.88 mm) to 1/4 in. (6.35 mm). Powdered spray materials have a size range of 5 to 45 microns for refractory oxides and 45 to 106 microns (−140 to 325 mesh) for metallic powders with melting ranges lower than 3500°F (1927°C).

## 4.2 Formation and Structure of Coatings

**4.2.1 Form of the Spray.** Observation of the coating material exiting a thermal spray gun will reveal a conical shape, with the spray concentrated in the central zone and more sparse in the outer portions. The central zone is comparatively narrow and the material content highly concentrated. This may be demonstrated by spraying a single pass and then examining under a microscope a transverse section of the structure at 90 degrees to the direction of application. Figure 4.2.1A shows such a section in sequence A-B, B-C, C-D where A was at periphery of the deposit and D at the center.

The particles in the outer periphery (A) of the deposit, are widely spaced and poorly adhered to the substrate. The spray deposit density ratio is largely dependent on the particles within the peripheral zone.

Figure 4.2.1B schematically illustrates the actual spray form shape. A circular or oval central zone, within which the densest and thickest coating is deposited, is between C and C. Between B and C, the spray stream is luminous, and coating deposition of a marginal nature occurs, (point B). The deposited coating in the zone identified as AB is extremely porous.

The final sprayed coating contains a mixture of material from each zone, because the gun and the substrate are moved relative to each other during coating application.

**4.2.2 Particle Deposition.** During the spraying process, particles are superheated and impinge on the substrate with varying velocities. The porous "pancake" morphology generally produced by spraying results from the rapid flattening of superheated liquid particles impinging, essentially independently, on the substrate of previously deposited layers. This is referred to as *splat-cooling*.

It is important to accurately represent the rate of cooling in a typical spray process. Some of the factors which must be taken into consideration are the size variation of the particles, their location within the heat zone, and, in the case of metal particles, the formation of an oxide film.

Ballard and Gerdeman/Hecht (see Bibliography) have studied the splash effects of molten droplets onto glass. In these experiments, glass slides were passed under the spray stream. The molten particles impinged on the glass, solidified, and were studied with a microscope. While somewhat idealized, the investigations indicated the ef-

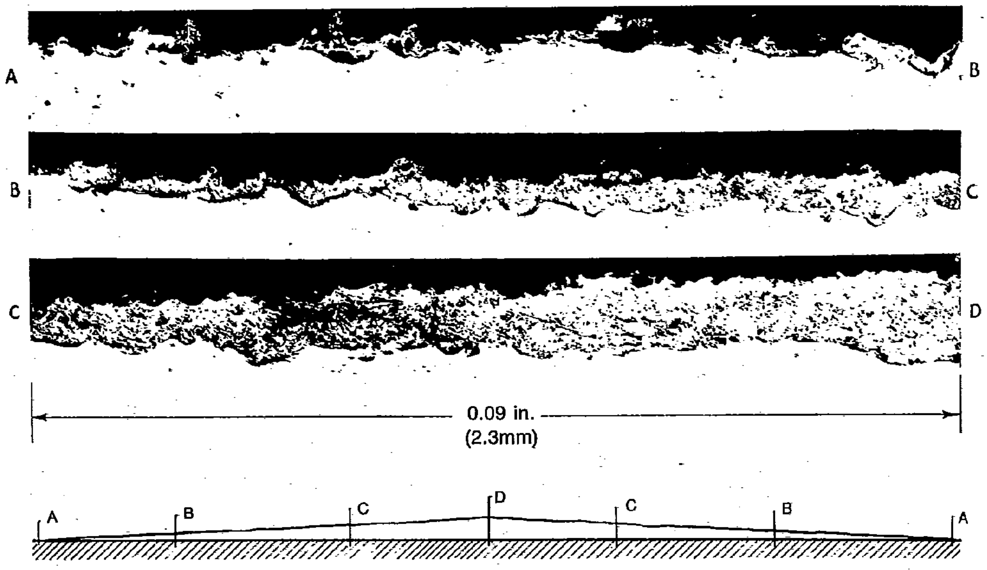


Fig. 4.2.1A — Typical transverse section of spray deposit from one pass of the thermal spray gun

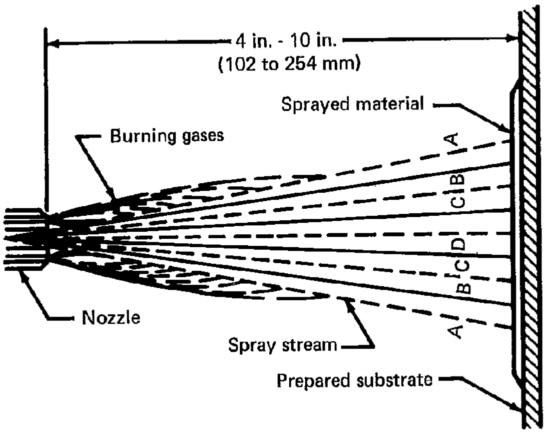


**Fig. 4.2.1B—Development of spray pattern**

fects of operating conditions upon final splat configuration.

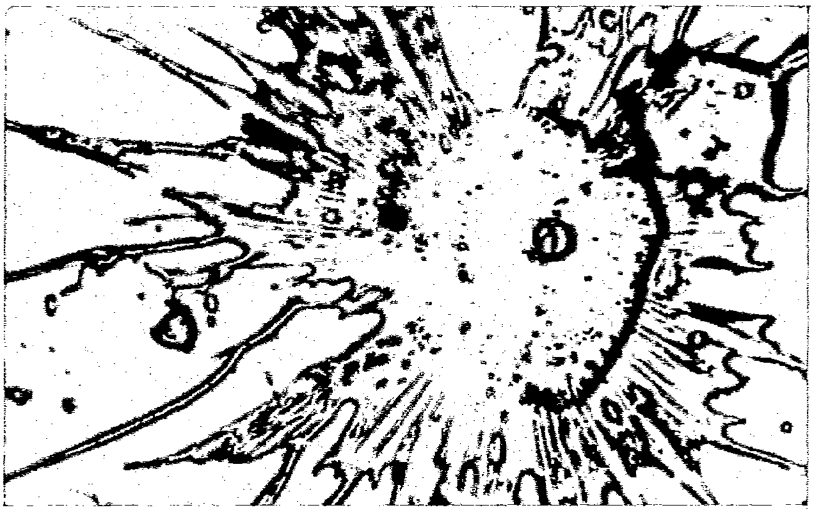
Gerdeman and Hecht considered the technique useful for rapidly determining optimum standoff distance. Figure 4.2.2A illustrates properly melted ceramic particles. The particle splash, or wetting, resulting from improper standoff distances are shown in Fig. 4.2.2B as being too close and in Fig. 4.2.2C as being too far.

In Figure 4.2.2B, where gun-to-work standoff distance was too close, the particle has not become completely molten, and the solid center core has rebounded away from the glass surface, resulting in a void.

Figure 4.2.2D shows two particles which began to solidify while in transit.

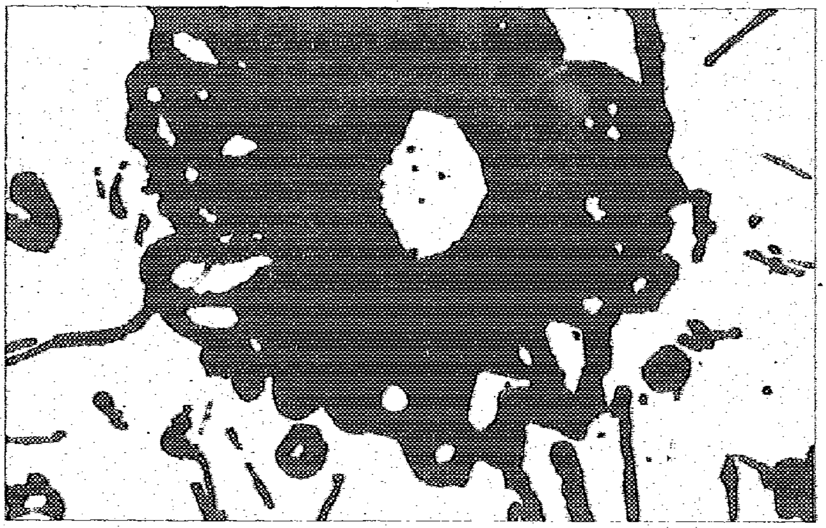
A molten drop, arriving at the surface which it does not wet, will first spread out in a thin layer and will, if surface tension does not operate, continue to spread until the layer becomes of unimolecular thickness or until it solidifies. The spreading is helped if the drop arrives at high velocity, but after a short interval, surface tension restrains this spreading. The edge of the drop becomes thickened, and tends to break and form a ring of small spherical drops, leaving a spherical drop in the center, smaller than the original. This action of retraction also causes a number of radial splashes, as shown in Fig. 4.2.2E.

In the case of the sprayed drop, solidification may take place at any instant in the cycle of events. It is apparent, therefore, that in considering the formation of sprayed coatings, retraction of individual drops, or aggregates of drops as a result of surface tension, must be taken into account. Oxide films on the splats or aggregates also cause modifications to the splash effect, as they tend to interfere with the distribution of surface energy. In some metals, most of the splats become frozen in the first stages of spreading and retraction, and they then appear roughly circular in shape, with serrated edges. This general effect is shown by cadmium, lead, tin, and zinc, which have



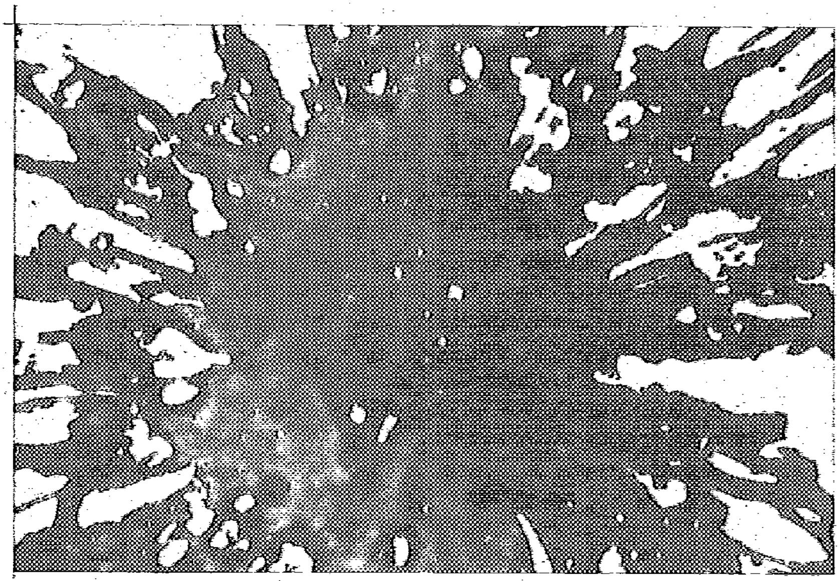
**correct standoff distance**

**Fig. 4.2.2A — Fully melted cermaic particle (2000 x)**



close standoff distance

**Fig. 4.2.2B — Partially melted metallic particle (2000 x)**



far standoff distance

**Fig. 4.2.2C — Fully melted metallic particle (2000 x)**

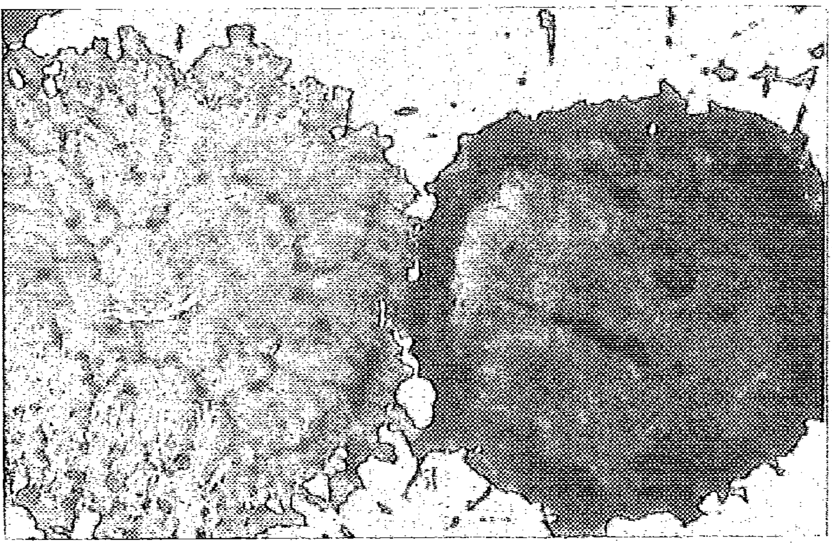


**Fig. 4.2.2D — Recooled metallic particles (2000 x)**

a comparatively low heat content. Conversely, aluminum, iron, nickel, and copper have high heat content, and show more variation in the pattern of splats.

One aspect of this difference may be illustrated. Consider the case when all particles are molten on impact. Droplets of metals with high heat content will have pronounced splash effect, and the patterns will be broken up. Surface tension will have produced many small spheres, not connected if the layer is one particle in thickness. If the metal has low heat content, the drops will have frozen when the surface tension was at its maximum value, considering the flattened splat as a whole.

Sprayed coatings are generally examined metallographically in transverse or longitudinal sections through the thickness of the coating. In these sections, the most characteristic features of the deposit is the lamellae — the undulating contours of the individual sprayed particles. These particles, at the moment of impact, flatten out into elongated lenticular splats. Typical coatings applied in an air environment are a heterogenous mixture of sprayed material, oxide inclusions, and porosity (Fig. 4.2.2F). The deposit is bonded to the substrate by adhesive forces and to itself by cohesion.

A face view or the front of a sample taken parallel to the surface shows the structure to be an emulsification of oxides and round metallic flakes grouped in irregular superposition (Fig. 4.2.2G).

As-sprayed self-fluxing alloy coatings exhibit microstructure and properties similar to any typical thermally sprayed coating. It is only after heating to 1900° to 2200°F (1040° to 1200°C), that they assume their characteristic fused, homogenous appearance (Fig. 4.2.2H).

Generally, the grain orientation in as-sprayed deposits is determined by the heat flow pattern within the individual particles. Microstructural examination of thick, sprayed deposits reveals directionally oriented, columnar grains near the interface where rapid cooling occurs through the substrate.

Examination by scanning electron microscopy (SEM) has verified the light microscopy observations (Fig. 4.2.2I).

The columnar orientation gradually decreases as the thickness of the sprayed coating increases. The change from columnar to random grain morphology is believed to be produced by the effective lowering of the cooling rate, because of the evolved heat of fusion, which gives the grains time to reform and change shape.

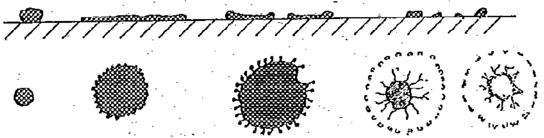


**Fig. 4.2.2E—Splash forms of mercury on glass**

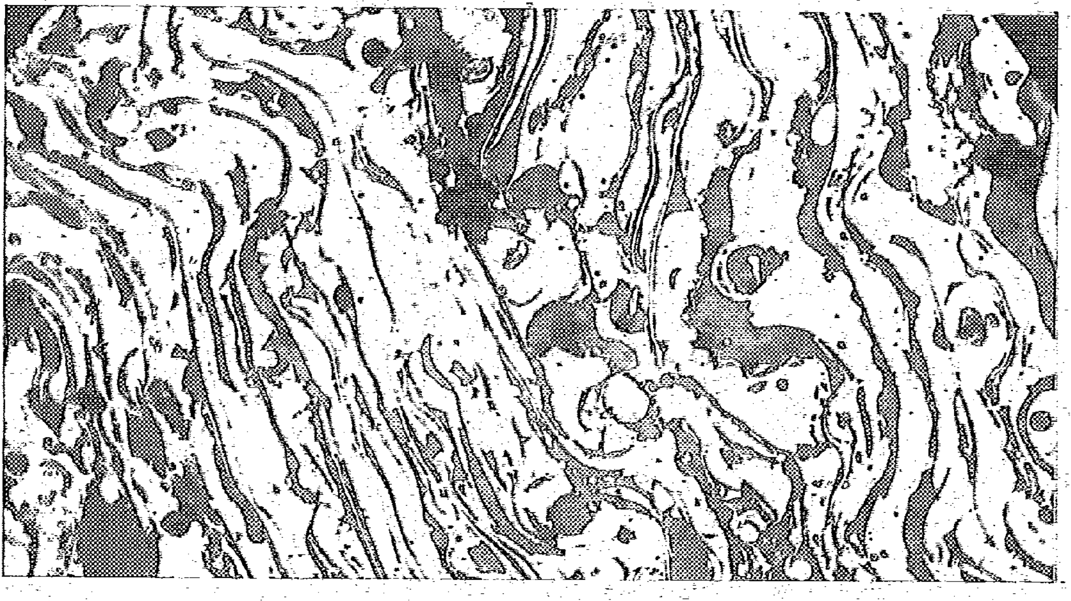


**Fig. 4.2.2F — Transverse section through 0.8C (carbon) steel wire flame sprayed coating (250 x)**

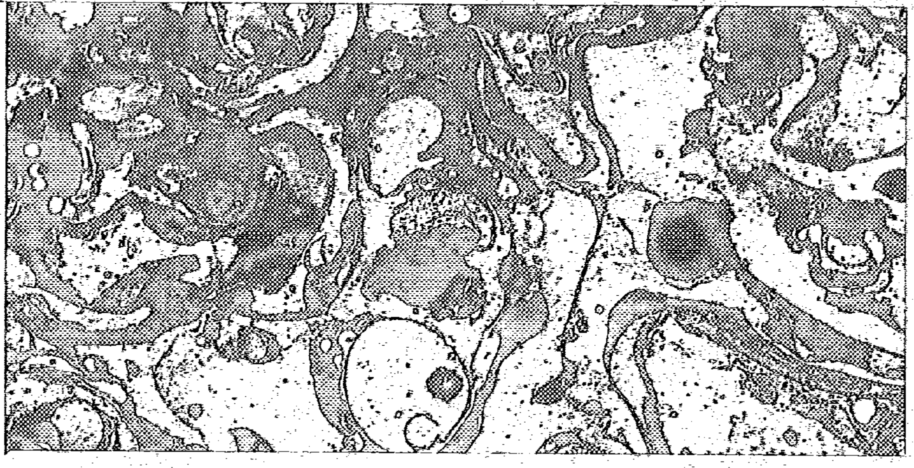


**Fig. 4.2.2G Frontal section of 0.8C steel wire sprayed coating. Light areas are steel, gray areas are iron oxide, and black areas are voids (250 x)**

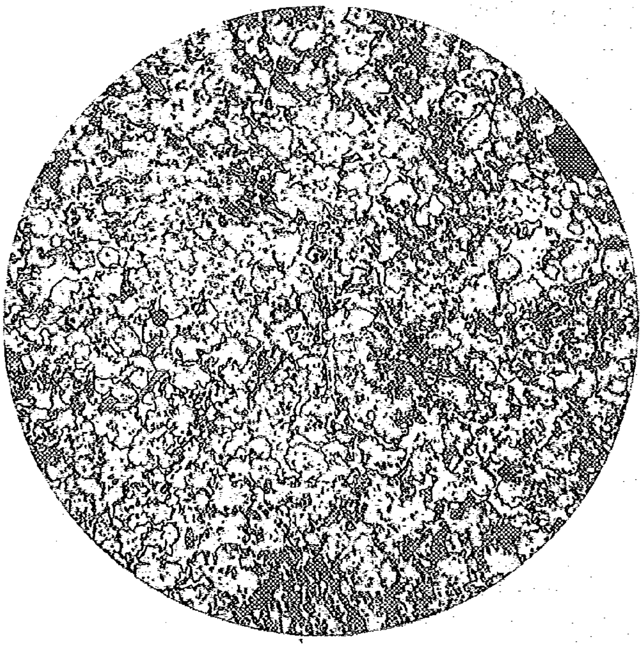
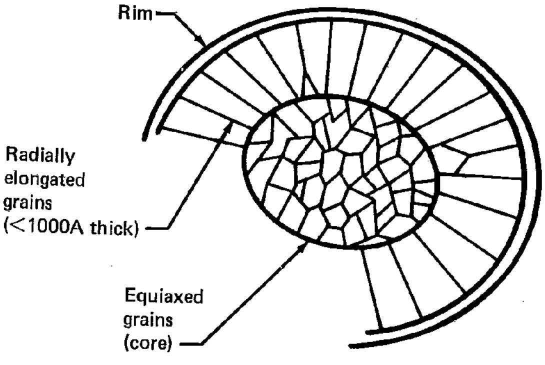


Fig.4.2.2H — Fused NiCrBSi brazing alloy (250 x)
(Aerospace Materials Specification 4775)

Fig. 4.2.2I — Scanning electron micrograph of an alumina plasma sprayed coating showing the columnar structure

**4.2.3 Substrate Surface Influence on the Molten Particle.** The substrate surface influences the formation of metastable phases in the fluid particle, resulting from rapid solidification of the molten particles. This will, to some extent, depend on substrate surface topography and on the influence of the surface on particle spreading at impact (i.e., wetting).

Transmission electron microscopy (TEM) has been utilized to determine the solidification morphology of particles as affected by the surface topography of the substrate. Because of the high kinetic energy of the molten particles, considerable liquid flow and radial sliding occur upon particle impact. Two different grain morphologies were observed. Figure 4.2.3 shows a schematic of the plannar morphology of a solidified particle.



Top view

**Fig. 4.2.3 — Plannar morphology of a solidified particle**

In the central core region, where the particle first comes into contact with the surface, heat is extracted through the substrate, and the solid-liquid interface moves away from the substrate. This area is generally too thick to be examined by TEM in the as-sprayed condition. However, in the peripheral areas, heat is not extracted through the substrate but rather back through the core region. This is indicated by the radially elongated grains which propagate from the core and terminate at the rim. Furthermore, the virtually defect free and regularly patterned grains suggest that these thin regions are not in full contact with the substrate. Similar arguments have been given for the splat quenching of metal alloys.

The assumption of one dimensional heat flow perpendicular to the substrate was shown to be unreasonable. TEM observations of plasma sprayed aluminum particles strongly support experimental results regarding heat flow parallel to the substrate in thin regions of the liquid-quenched particles.

This solidification process for the individual droplets appears common to virtually all observed microstructures in sprayed metals. Columnar grains can be found in regions far from the substrate. Due to the limited liquid flow on the rough surfaces of the previously deposited layers, radially elongated grains are rarely observed in thick coatings. This is due to the high thermal conductivity of metals. In addition, thin regions under the impact of the subsequently arriving molten droplets probably recrystallize into randomly oriented grains.

The gradual transformation of the grains from highly oriented to larger, randomly shaped structures in metal coatings is attributed to several factors. Although these metals have very high thermal conductivity, they can resolidify and undergo rapid grain growth at relatively low temperatures. Therefore, substrate temperature and cooling rate are of great importance and should be controlled in order to deposit a more homogeneous metal coating.

Another feature of the rapid solidification in thermal spraying is the formation of structural defects, especially with copper, where significant twinning occurs. With liquid quenched aluminum, defects such as vacancy coagulation and dislocations are observed. However, the structure depends heavily on quench rate. Aluminum samples quenched from high temperatures, do not exhibit dislocation loops, clusters, or concentrations of dislocation and subgrain boundaries. This is important in TEM studies. Even when spray conditions are selected so that most particles are heated to barely above the melting point, some particles may be superheated to very high temperatures, >2200°F (1200°C).

In summary, a number of microstructural similarities are found between the liquid quenched metals formed by conventional techniques and those prepared by thermal spraying. For thin layers, or the first few layers of the thick deposits, the grain structure reveals rapid cooling rates essentially identical with those observed for amorphous cooling techniques. However, hot particles impinging onto the surface can result in annealing and recrystallization of the lamellae during spray deposition. For pure metals, such as aluminum and copper, annealing is rather extensive. Defect annihilation and grain reorientation, especially in thick layers, readily occur.

## 4.3 Coating Properties

The chief advantage of thermal spraying is the ability to tailor coating properties to suit the application. A particular material may be sprayed to form a hard or soft, porous or dense coating. This versatility presents difficulties when attempts are made to compare reported properties of coatings. These effects are compounded when different testing techniques are employed. The values presented in this section and Tables 4.3A, 4.3B, 4.3C, 4.3D, 4.3E, and 4.3F should, therefore, be regarded only as general information.

## Table 4.3A
## Physical properties of ceramic rod coatings

| Type of coating | Crystal form | Average bulk density (gm/cc) | Knoop microhardness | Porosity, percent |
|---|---|---|---|---|
| Aluminum oxide | Gamma type | 3.3 | 2000 | 8 (7% open) |
| Barium zirconate | Cubic | 5.25 | -- | 10.0 (5.1% open) |
| Calcium zirconate | Cubic | 4.414 | -- | 5.7 (4.5% open) |
| Chrome oxide | Hexagonal | 4.6 | 1900 | 4 (2% open) |
| Magnesium aluminate | Cubic | 3.3 | -- | 6 (4% open) |
| Magnesium zirconate | Cubic | 4.52 | -- | 4.8 (4.5% open) |
| Strontium zirconate | Orthorhombic | 4.71 | -- | 9.8 (7.8% open) |
| Zirconium oxide | Cubic | 5.2 | 1000 | 8 (7% open) |
| Zirconium silicate | Cubic $ZrO_2$ in siliceous glass | 3.8 | 1000 | 8 (4% open) |

## Table 4.3B
## Electrical properties of ceramic rod coatings

| Type of coating | Electrical resistivity (Ohm-inch) | Dielectric strength, ac volts per 0.001 in. | Dielectric constant at 0°-600°F | Dissipation factor at 0°-600°F | Loss factor |
|---|---|---|---|---|---|
| Aluminum oxide | $4.5 \times 10^6$ @ 500°F<br>$1.2 \times 10^5$ @ 800°F | 0.005 in. thk-160<br>0.010 in. thk-120<br>0.020 in. thk- 65<br>0.030 in. thk- 48+ | 10 | .05 | 0.5 |
| Barium zirconate | — | 140 | — | — | — |
| Calcium zirconate | — | 70 | — | — | — |
| Magnesium zirconate | — | 150 | — | — | — |
| Strontium zirconate | — | 130 | — | — | — |
| Zirconium oxide | $2.7 \times 10^4$ @ 500°F<br>$2.1 \times 10^2$ @ 800°F | — | 35 | 0.15 | 5.25 |
| Zirconium silicate | $1.1 \times 10^6$ @ 500°F<br>$4 \times 10^2$ @ 800°F | — | 15 | 0.08 | 1.20 |

## S.I. Soft Conversion

## Table 4.3B
## Electrical properties of ceramic rod coatings

| Type of coating | Electrical resistivity (Ohm-meter) | Dielectric strength ac volts V/0.025 mm | Dielectric constant at −18° to 315°C | Dissipation factor at −18° to 315°C | Loss factor |
|---|---|---|---|---|---|
| Aluminum oxide | $1.14 \times 10^5$ @ 260°C<br>$3.0 \times 10^3$ @ 427°C | 160 @ 0.13 mm thk<br>120 @ 0.25 mm thk<br>65 @ 0.51 mm thk<br>48 + @ 0.76 mm thk | 10 | 0.05 | 0.5 |
| Barium zirconate | — | 140 | — | — | — |
| Calcium zirconate | — | 70 | — | — | — |
| Magnesium zirconate | — | 150 | — | — | — |
| Strontium zirconate | — | 130 | — | — | — |
| Zirconium oxide | $6.9 \times 10^3$ @ 260°C<br>$5.3 \times 10^2$ @ 427°C | — | 35 | 0.15 | 5.25 |
| Zirconium silicate | $2.8 \times 10^4$ @ 260°C<br>10 @ 427°C | — | 15 | 0.08 | 1.20 |

### Table 4.3C
### Thermal and chemical properties of ceramic rod coatings

| Type of coating | Melt temp. °F | Mean specific heat Btu/lb/°F | Coefficient of expansion, in./in./°F | Conductivity, Btu/hr/ft$^2$ in./°F (coating only) | Total emittance | Thermal shock resistance | Chemical composition, percent | Resistance to acids | Resistance to alkalis |
|---|---|---|---|---|---|---|---|---|---|
| Aluminum oxide | 3600 | .28<br>(90-3100°F) | $4.1.10^{-6}$<br>(70-2250°F) | 19<br>(1000-2000°F) | 0.8-0.4<br>(200-1000°C) | Good | Pure aluminum oxide<br>98.6 $Al_20_3$ | Good | — |
| Barium zirconate | 4870 | — | $3.5.10^{-6}$<br>(70-2012°F) | — | — | — | — | — | Good<br>(except hot) |
| Calcium zirconate | 4245 | — | $4.6.10^{-6}$<br>(70-2012°F) | — | — | — | — | — | — |
| Chrome oxide | 3000 | .2<br>(60-2700°F) | $5.0.10^{-6}$<br>(70-2000°F) | 18 (est)<br>(1000-2000°F) | 0.8-0.9<br>(100-1200°C) | Moderate | 85 $Cr_20_3$ | Good<br>(except HF) | Good<br>(except hot) |
| Magnesium aluminum | 3500 | .25<br>(70-1832°F) | $4.5.10^{-6}$<br>(70-2000°F) | 18 | 0.7-0.3<br>(100-1200°C) | Good | 98<br>$Mg0\text{-}Al_20_3$ | Good<br>(except HF) | Good<br>(except hot) |
| Magnesium zirconate | 3880 | — | $4.0.10^{-6}$<br>(70-2012°F) | — | — | — | — | — | — |
| Strontium zirconate | 5070 | — | $4.7.10^{-6}$<br>(70-2012°F) | — | — | — | — | — | — |
| Zirconium oxide | 4500 | .175<br>(80-2550°F) | $5.4.10^{-6}$<br>(70-2250°F) | 8<br>(1000-2000°F) | 0.7-0.3<br>(200-1000°C) | Very good | $Zr0_2$<br>+2% $Hf0_2$<br>+3.5-5% Ca0 | Good<br>(except HF) | Good |
| Zirconium silicate | 3000 | .15 est. | $4.2.10^{-6}$<br>(70-1100°F) | 15<br>(1000-2000°F) | 0.7-0.3<br>(200-1000°C) | Good | 65 $Zr0_2$<br>34 $S10_2$ | Fair<br>(except HF) | Good<br>(except hot) |

## S. I. Soft Conversion

### Table 4.3C
### Thermal and chemical properties of ceramic rod coatings

| Type of coating | Melt temp. °C | Mean specific heat J/(kg.K) | Coefficient of expansion, m/m °C | Conductivity, coating only W/(m.K) | Total emittance | Thermal shock resistance | Chemical composition, percent | Resistance to acids | Resistance to alkalis |
|---|---|---|---|---|---|---|---|---|---|
| Aluminum oxide | 1982 | 0.067<br>(32-1700°C) | $2.3.10^{-6}$<br>(21-1230°C) | 2.7<br>(540-1090°C) | 0.8-0.4<br>(200-1000°C) | Good | Pure aluminum oxide<br>98.6 $Al_2O_3$ | Good | — |
| Barium zirconate | 2688 | — | $1.9.10^{-6}$<br>(21-1100°C) | — | — | — | — | — | Good<br>(except hot) |
| Calcium zirconate | 2340 | — | $2.6.10^{-6}$<br>(21-1100°C) | — | — | — | — | — | — |
| Chrome oxide | 1649 | 0.048<br>(16-1480°C) | $2.8.10^{-6}$<br>(21-1090°C) | 2.6<br>(540-1090°C) | 0.8-0.9<br>(100-1200°C) | Moderate | 85 $Cr_2O_3$ | Good<br>(except HF) | Good<br>(except hot) |
| Magnesium aluminum | 1927 | 0.06<br>(21-1000°C) | $2.5.10^{-6}$<br>(21-1090°C) | 2.6 | 0.7-0.3<br>(100-1200°C) | Good | 98<br>$MgO-Al_2O_3$ | Good<br>(except HF) | Good<br>(except hot) |
| Magnesium zirconate | 2138 | — | $2.2.10^{-6}$<br>(21-1100°C) | — | — | — | — | — | — |
| Strontium zirconate | 2799 | — | $2.6.10^{-6}$<br>(21-1100°C) | — | — | — | — | — | — |
| Zirconium oxide | 2482 | 0.042<br>(27-1400°C) | $2.7.10^{-6}$<br>(21-1230°C) | 1.15<br>(540-1090°C) | 0.7-0.3<br>(200-1000°C) | Very good | $ZrO_2$<br>+2% $HfO_2$<br>+3.5-5% CaO | Good | Good |
| Zirconium silicate | 1648 | 0.04 est. | $2.3.10^{-6}$<br>(21-590°C) | 2.2<br>(540-1090°C) | 0.7-0.3<br>(200-1000°C) | Good | 65 $ZrO_2$<br>34 $SiO_2$ | Fair<br>(except HF) | Good<br>(except hot) |

## Table 4.3D
## Mechanical properties of ceramic rod coatings

| Type of coating | Compressive strength at ambient temperature ksi | (MPa) | Adherence to steel (approx.) psi | (MPa) | Minimum profilometer surface finish AA range | Coefficient of friction | Strain % elongation per unit of lgth. (0.020 in. thk. coat) |
|---|---|---|---|---|---|---|---|
| Aluminum oxide | 37 | (255) | 1000 | (6.89) | **** | 0.10** | 0.7 |
| Barium zirconate | — | — | 1153 | (9.5) | — | — | — |
| Calcium zirconate | — | — | 1125 | (7.76) | — | — | — |
| Chrome oxide | 105 | (724) | — | — | **** | 0.11*** | 1.3 |
| Magnesium aluminate | — | — | — | — | **** | — | — |
| Magnesium zirconate | — | — | 1000 | (6.89) | — | — | — |
| Strontium zirconate | — | — | 1129 | (7.78) | — | — | — |
| Zirconium oxide | 21 | (145) | 1000* | (6.89) | **** | 0.10** | 1.4 |
| Zirconium silicate | — | — | 1000* | (6.89) | **** | 0.10** | 0.7 |

Notes:
* Nonferrous substrate 600 psi (4KPa)
** Against 440 stainless steel
*** Against brass
**** As coated 200-300μ in. (5.1-7.6 nm)
As ground 50- 60μ in. (760-1270 μm)
As lapped 25- 45μ in. (435-1143 μm)

## Table 4.3E
## Specific gravity of flame sprayed wire coatings

| Metal | Specific gravity weight relative to water |
|---|---|
| Aluminum | 2.35 |
| Aluminum 12% silicon | 2.32 |
| Aluminum 5% magnesium | 2.32 |
| Copper | 7.56 |
| Copper 10 aluminum | 6.92 |
| Copper 10 zinc | 7.57 |
| Copper 40 zinc | 7.38 |
| Copper 42 zinc | 7.41 |
| Copper 30 zinc | 7.45 |
| Copper 5 tin | 7.65 |
| Iron | 6.50 |
| Lead | 10.00 |
| Magnesium | 1.52 |
| Molybdenum | 9.05 |
| Nickel | 7.58 |
| Nickel 20 chromium | 7.28 |
| Silver | 9.10 |
| Steel 0.1 chromium or carbon | 6.67 |
| Steel 0.25 carbon | 6.77 |
| Steel 0.40 carbon | 6.94 |
| Steel 0.80 carbon | 6.35 |
| Steel 1.20 carbon | 6.74 |
| Steel 18 Nickel 8 chromium | 6.98 |
| Tin | 6.83 |
| Zinc | 6.35 |

**4.3.1 Visual.** As-sprayed coatings present a dull matte finish. In some instances, the surfaces are rougher than the original grit blasted surface. Profilometer measurements taken on these surfaces range from less than 100 to greater than 1500μ in. (2.5 to 38 μm). High energy plasma and detonation sprayed coatings will average 60 to 90μ in. (1.5 to 2.2 μm) AA; standard plasma coatings range from 100 to 500μ in. (2.5 to 12.5 μm) AA. This is dependent on the size of the powder, in that fine powder yields a smoother coating than one produced from coarse powder. Wire and rod coatings are coarser, with typical values of 300 to 1000μ in. (7.5 to 25 μm) AA. Coatings applied by powder flame spraying, especially those applied for gas path seals, have been measured in excess of 1000μ in. (25 μm) AA with some readings exceeding 1500μ in. (38 μm) AA. This roughness is typical of a porous and loose structure. The arc gun, when operated at low atomizing pressures, can produce coating roughness profiles as great as 1/8 in. (3.2 mm).

**4.3.2 Tensile Strength.** The tensile strength of a thermal sprayed deposit consists of the bond between the deposit and the substrate (adhesion) and interparticle attraction (cohesion).

The adhesion of the coating to the substrate is the relationship of particle to surface interactions. The bonding mechanisms fall into three categories: mechanical, metallurgical-chemical, and physical. The adhesion is a combination of all three mechanisms. A molten particle

## Table 4.3F
## Typical mechanical properties of plasma sprayed coatings*

| Material | Bond tensile strength | Hardness macro/micro | Density | |
|---|---|---|---|---|
| | psi (MPa)* | Rockwell | lb/ft$^3$ | (g/cc) |
| **Pure metals** | | | | |
| Aluminum | 1200 ( 8.3) | $R_H$ 45/58 | 155 | (2.48) |
| Copper | 3100 (21.4) | $R_B$ 65/142 | 449 | (7.20) |
| Molybdenum (fine) | 8300 (57.2) | $R_{15N}$ 70/1450 | 618 | (9.90) |
| Molybdenum (coarse) | 8000 (55.2) | $R_A$ 65/1448 | 559 | (8.96) |
| Nickel (fine) | 3400 (23.4) | $R_{15T}$ 84/-- | 496 | (7.95) |
| Nickel (coarse) | 4800 (33.1) | $R_{15T}$ 81/-- | 467 | (7.48) |
| Niobium | 7900 (54.5) | $R_c$ 61/1344 | 441 | (7.06) |
| Tantalum | 6800 (46.9) | $R_A$ 65/1585 | 883 | (14.15) |
| Titanium | 6000 (41.4) | $R_{15N}$ 78/ | 260 | (4.17) |
| Tungsten | 5800 (40.0) | $R_A$ 50/500 | 1055 | (16.90) |
| **Alloy metals** | | | | |
| 304 Stainless | 2550 (17.6) | $R_{15T}$ 88/-- | 451 | (7.22) |
| 316 Stainless | 3400 (23.4) | $R_{30T}$ 70/-- | 425 | (6.80) |
| 431 Stainless | 4500 (31.0) | $R_C$ 35/-- | 390 | (6.25) |
| 80Ni 20Cr (fine) | 4500 (31.0) | $R_{15}$ 90/-- | 467 | (7.48) |
| 80Ni 20Cr (coarse) | 4200 (29.0) | $R_{15T}$ 90/-- | 449 | (7.19) |
| 40Ni 60Cu | 3500 (24.1) | $R_B$ 72/-- | 493 | (7.89) |
| 35Ni 5In 60Cu | 3500 (24.1) | $R_{15T}$ 83/-- | 496 | (7.94) |
| 10A1 90Cu (fine) | 4100 (28.3) | $R_{15T}$ 88/-- | 418 | (6.73) |
| 10A1 90Cu (coarse) | 3200 (22.1) | $R_{15T}$ 81/-- | 393 | (6.30) |
| Hastelloy 31 (fine) | 6000 (41.4) | $R_{15T}$ 79/-- | 478 | (7.65) |
| Hastelloy 31 (coarse) | 3400 (23.4) | $R_{15T}$ 79/-- | 489 | (7.83) |
| 5A1 95Ni | 9900 (68.3) | $R_B$ 80/490 | 469 | (7.51) |
| 20A1 80Ni | 6900 (47.6) | $R_B$ 80/510 | 432 | (6.92) |
| 6A1 19Cr 75Ni | 7200 (49.6) | $R_B$ 90/250 | 469 | (7.51) |
| 12Si 88A1 | 2400 (16.5) | $R_{15T}$ 78/60 | 155 | (2.49) |
| 5A1 5Mo 90Ni | 5500 (37.9) | $R_B$ 80/200 | 464 | (7.43) |
| Hastelloy X | 6200 (42.7) | $R_{15T}$ 89/-- | 478 | (7.65) |
| Hastelloy C | 6100 (42.1) | $R_{15T}$ 90/-- | 515 | (8.25) |
| 420 Stainless | 3200 (22.1) | $R_{15N}$ 70/-- | 443 | (7.10) |
| 0.9C Steel | 4900 (33.8) | $R_C$ 35/-- | 440 | (7.05) |
| Cast Iron | 5200 (35.9) | $R_C$ 28/-- | 437 | (7.00) |
| Ti 6A1 4V | 4800 (33.1) | $R_C$ 35/-- | 268 | (4.30) |
| Monel | 6500 (44.8) | $R_{15N}$ 35/-- | 531 | (8.50) |
| 0.2 C Steel | 3200 (22.1) | $R_B$ 95/-- | 431 | (6.90) |
| **Metal composites** | | | | |
| 95Ni 5A1 | 4900 (33.8) | $R_{15T}$ 80/500 | 461 | (7.39) |
| 80Ni 20A1 | 4700 (32.4) | $R_{15T}$ 86/500 | 438 | (7.02) |
| 65Ni 35Ti | 4650 (32.1) | $R_{15N}$ 72/660 | 413 | (6.62) |
| 75Ni 19Cr 6A1 | 6200 (42.7) | $R_{15T}$ 92/250 | 481 | (7.71) |
| 75Ni 9Cr 7A1 5Mo 5Fe | 4000 (27.6) | $R_B$ 80/250 | 431 | (6.90) |
| 90Ni 5A1 5Mo | 7000 (48.3) | $R_B$ 80/200 | 462 | (7.40) |
| **Carbide powders & blends** | | | | |
| 88WC 12Co (cast, fine) | 6500 (44.8) | $R_{15N}$ 88/-- | 858 | (13.75) |
| 88WC 12Co (cast, coarse) | 6500 (44.8) | $R_{15N}$ 81/-- | 775 | (12.41) |
| 88WC 12Co (sintered) | 8000 (55.2) | $R_{15N}$ 85/-- | 908 | (14.55) |
| 83WC 17Co | 10000 (68.9) | $R_{15N}$ 85/950 | 693 | (11.10) |
| $75Cr_3C_2$ 25NiCr (fine) | 6000 (41.4) | $R_{15N}$ 84/950 | 400 | (6.41) |
| $75Cr_3C_2$ 25NiCr (coarse) | 5000 (34.5) | $R_{15N}$ 80/1850 | 389 | (6.23) |
| $75Cr_3C_2$ 25NiCr (composite) | — | $R_{15N}$ --/1850 | — | — |
| $85Cr_3C_2$ 15NiCr | — | $R_{15N}$ 80/1850 | 362 | (5.80) |

**(Continued)**

## Table 4.3F (continued)

| Material | Bond tensile strength | Hardness macro/micro | Density | |
|---|---|---|---|---|
| | psi (MPa)* | Rockwell | lb/ft$^3$ | (g/cc) |
| **Ceramic oxides** | | | | |
| Zirconia (calcinated) | 6500 (44.8) | $R_{15N}$ 70/-- | 331 | (5.30) |
| Chromium Oxide | 6500 (44.8) | $R_{15N}$ 90/-- | 300 | (4.80) |
| 80 Zirconia 20 Yttria | 2200 (15.2) | $R_{15N}$ 80/-- | 312 | (5.00) |
| Titanium Oxide | — | $R_{15N}$ 87/-- | 256 | (4.10) |
| Aluminum Oxide (white) | 6500 (44.8) | — | — | — |
| 87 Alumina 13 Titania | 2250 (15.5) | $R_{15N}$ 90/-- | 218 | (3.50) |
| 60 Alumina 40 Titania | 4000 (27.6) | $R_{15N}$ 90/850 | 218 | (3.50) |
| 50 Alumina 50 Titania | — | $R_{15N}$ 85/-- | 250 | (4.0 ) |
| Alumina-Grey (fine) | 1000 ( 6.9) | $R_{15N}$ 87/-- | 187 | (3.30) |
| Alumina-Grey (coarse) | — | $R_{15N}$ 85/-- | 187 | (3.30) |
| Magnesium Zirconate | 2500 (17.2) | $R_{15N}$ 75/-- | 262 | (4.20) |

Note:
*Over a grit blasted surface roughened to 100 to 160μ in. (2.5 to 4.1 μm) AA.

impinging on a suitably prepared surface will flatten and conform to the undulating surface, and mechanically key itself to the asperities thereon. When diffusion or alloying occurs, including the formation of intermetallic compounds and solid solutions, the adhesion mechanism is metallurgical-chemical. The particle adhesion to the substrate by van der Waals forces or secondary valence bonds is physical bonding.

Particle to substrate adhesion is generally mechanical and emphasizes the importance of proper surface preparation to achieve bonding.

Self-bonding materials (molybdenum, columbium, tantalum, nickel-aluminum alloys, and nickel aluminum composites) exhibit bond strengths in excess of 2500 psi (17.2 MPa). For this reason, they are used as bond coats for subsequent coatings. The overall adhesion of the system is improved. The adhesion of self-bonding materials occurs as localized fusion and alloying with the substrate. The heat of reaction comes from the striking molten particle. The degree of fusion-diffusion is governed by the particle quench rate.

Zones of interaction are located primarily at the center of the particle or that portion containing the greatest mass.

Cohesive bonding, that is particle to particle bonding, operates on the same principles governing particle to substrate adhesion. For adhesive bonding, the mating relies on particle characteristics such as mass, quench rate, and heat content.

### 4.3.3 Residual Stress.

**4.3.3 Residual Stress.** As in other types of deposits, thermal sprayed coatings contain residual stresses that result from contraction during cooling and solidification. They can cause cracking and spalling (separation).

Residual stresses are stresses existing within a body not resulting from external forces. They exist either as micro forces acting within the structural elements ("textural" stresses) or as forces affecting the mass ("body" stresses). Both forms are often interrelated, although from a practical standpoint, only mass effects are of direct interest to the user. The magnitude of the stresses depends upon the coefficient of thermal expansion of the coating material. Thin coatings seldom cause residual stress problems, but thick deposits having coatings with high coefficients of expansion may cause problems.

Methods which reduce residual tensile stress in the coating, and hence reduce shear stress on the bond are

(1) expanding the substrate before spraying, by preheating
(2) selecting a coating material with low shrinkage properties
(3) macroroughening (3.5) to limit the magnitude of stresses
(4) building up part way with a low shrinkage material

When a sprayed coating is applied to only one side of a thin plate, the tensile forces in the deposit produce compressive forces in the underlying metal near the interface. These forces cause concave deformation of the plate. To some extent, this relieves the tensile stresses in the deposit, but the remaining stresses are still predominantly tensile. Greater distortion occurs in deposits which have been separated from their supporting plates, since the deposit is then free from restraint at the interface. Deformation of the mass occurs until finally the tensile stresses developed in the inner layers are equal to those in the outer layers.

Coating tensile stresses occur through the contraction of individual particles as they solidify on the substrate. Momentarily, the molten particles are in intimate contact with cooled solid particles. They all contract in the same proportion, but in the time pause between depositions, an accumulation of tensile forces arises. In a bimetallic strip, longitudinal compressive and tensile forces are in equilibrium so long as the strip is free to deflect. In sprayed coatings, however, the deposit is entirely under tensile stress.

Contraction stresses due to thermal variations result in dimensional changes and are largely responsible for residual stresses set up in casting and fusion welds. Thermal spraying is a related process, and its products are similarly affected.

The interface is subject to shearing stresses. For a given adhesion strength, only a tensile force up to the bond strength can be tolerated in the coating; otherwise, failure of the bond results. This limits the maximum thickness of any deposit, since the tensile force is proportional to the deposit thickness.

**4.3.4 Hardness.** Thermal spray coatings possess a heterogenous structure consisting of the coating material, oxides and voids. As a result, the macrohardness values are less than those of equivalent material in either a cast or a wrought form.

The hardness of sprayed deposits are determined by macro or micro hardness tests. Macrohardness is a measurement of the resistance of the total deposit to penetration, and is measured with either the Brinell or the Rockwell hardness test. The hardness of individual particles is measured by a microhardness test. Under light loads of 50 to 100 grams, a Knoop hardness impression may be confined to a single particle, as shown in Fig. 4.3.4. Values are reported as KHN.

A standard diamond pyramid (Vickers) is also frequently used for microhardness determination, especially for tungsten carbide coatings, with a 300 gram load. The values are expressed as $DPH_{300}$.

Macrohardness values are not a true indication of the coating hardness but are a general indication of coating quality for a given material. The hardest coating in a trial spray run often indicates application by optimum conditions. However, in the case of metal coatings, high hardness may indicate a very oxidized coating.

In addition to indentation hardness tests, scratch hardness testing of sprayed coatings is also utilized. Scratch hardness testing of abradable clearance control coatings is a measure of their resistance to rubbing. The wider and deeper a scratch, the more abradable is a deposit.

**4.3.5 Compression.** Thermal sprayed coatings possess compressive strengths greater than their tensile strengths, often from three to four times greater than the ultimate cohesive tensile strengths. Compressive strength is an important property when considering bearing loads on shafts, flanges, and rabbet diameters. The compressive strengths of several ceramic materials are listed in Table 4.3D. Operating environments, especially temperatures, should

**Fig. 4.3.4 — Rhomboidal Knoop indentation (arrow) in electric arc sprayed $Ni_5Al$**

always be considered. High temperature usage coupled with load will cause plastic flow and consequently dimensional loss.

Thin coatings are better suited to transmit compressive loads than thick deposits. Spray coatings do not fracture when suddenly subjected to compression loading.

**4.3.6 Wear Resistance.** Thermal spray coatings are used to increase the wear resistance of soft or worn substrates. Types of wear, the deterioration of a surface through use, include (1) erosion through gas flow or solid particle impingement, (2) non-intended motion or fretting wear, (3) sliding wear, (4) combined impact-sliding wear, (5) cavitation, and (6) galling.

There are many tests for evaluating wear including Alpha LFW-1, Falex, Tabor, (Reference[1] ASTM Sections 5 and 15) simulated service tests, and others. The test results are useful as a guide in coating selection, since various factors have to be individually selected and evaluated. Simulated service results are limited in practical application, because there may be other critical factors in actual service. In defining the wear characteristics of thermal sprayed deposits, it is necessary to define the service environment.

Sprayed coatings are generally more wear resistant than the parent material in wrought or cast form. This is attributed to particle quench rate, resulting structure, porosity, and in the case of metallic coatings, oxide content. Porosity in a coating enables it to maintain a film of lubricant. An advantage of porosity is to contain debris generated during wearing, thus exposing clean contact surfaces.

**4.3.7 Fatigue.** Limited specific data exist concerning the endurance limits of sprayed coatings. Sprayed coatings should not be used under tensile loading or under bending flexing motion. The laminar structure of the product and its inherent propensity is sensitive to crack propagation when exposed to these conditions.

Substrate preparation for a thermal spray deposit affects the fatigue properties of the coating. Grit blasting or intentional roughening of a smoothly machined surface will lower the endurance limit of aluminum, iron, nickel, cobalt and nickel alloys in low cycle fatigue (LCF) and high cycle fatigue (HCF). The loss will depend upon the degree and severity of roughening. However, the effects of roughening can be offset by shot peening prior to blasting.

All self bonding materials, such as molybdenum, tantalum, columbium, nickel-aluminum alloys, and composites, significantly reduce both the low and high cycle fatigue life of high strength alloys. Similar reductions in endurance limit may be expected with carbide coatings produced by the detonation or high energy plasma processes. Loss in fatigue properties is attributed to fusion or diffusion of the coating particles with the substrate. Each point of attachment is a minute notch from which cracking can propagate. The substrate surface is blanketed with notches, any of which may initiate a crack under the proper conditions. Finish grinding of the spray coating does not significantly improve fatigue life of as-sprayed coatings.

**4.3.8 Ductility.** The ductility of metallic thermal spray coatings is slightly better than cast iron, but less than most cast metal structures. This is related to the mechanical bond of each sprayed and unfused layer and to the cohesion strength between particles. Once the cohesive bond between particles is broken, the coating will disintegrate and fail. The ductility of sprayed coatings rarely exceeds 2%.

**4.3.9 Corrosion Resistance.** Corrosion protection of iron and steel is an important use of thermal spray coatings. There are guidelines which the trained, knowledgeable applicator follows. These are based upon experience, asking the right questions, and a familiarity with the theories of chemistry and electro- chemistry. Section 5.7.3 and AWS publication C2.14-74, *Corrosion Tests of Flame-Sprayed Coated Steel, 19-year Report,* contains additional information.

## 4.4 Coatings Produced Under Controlled Atmospheres

Arc or plasma generators may be operated with an inert gas shroud or in an inert gas chamber.

Shielding of the spray cone by an inert gas shroud significantly decreases oxygen, nitrogen, or hydrogen contamination while providing higher particle temperatures and velocities for better bond strengths. Microscopic examination reveals shrouded coatings strongly resemble those applied in the air; there is an accumulation of residual stresses.

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[1] Standard tests for wear and wear life may be found in the *Annual Book of ASTM Standards,* Section 5 and 15, published by the American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103.

For a controlled spray environment, atmospheric chambers are utilized. The chambers are evacuated to a pressure of less than 20 Torr (2.7 kPa) and then back-filled with an inert gas to a specific pressure under which the spraying is to be done. After the chamber has been evacuated and back-filled with inert gas, the only gases entering the system are the plasma and the atomizing gases that are usually inert. The workpiece can be heated without dangers of oxidation, and the substrate surface will not be contaminated. The resulting nascent surface substantially enhances coating adherence (Fig. 4.4A).

Lack of intersplat oxides improves particle-to-particle cohesion and overall coating density. Porosity in as-sprayed metallic overlays is usually less than 1%. This is true even in coatings that are applied at impingement angles of 45 degrees or less.

The operation of a plasma or arc gun in a low pressure environment permits attainment of higher temperatures at the workpiece, without detrimental oxidation. The lengthened effluent produces longer residence times for the spray particles. A greater percentage of particles are plasticized and deposited onto the substrate surface. Elevated substrate preheat temperatures reduce particle rebounding, and promote wetting by the impinging powdered materials.

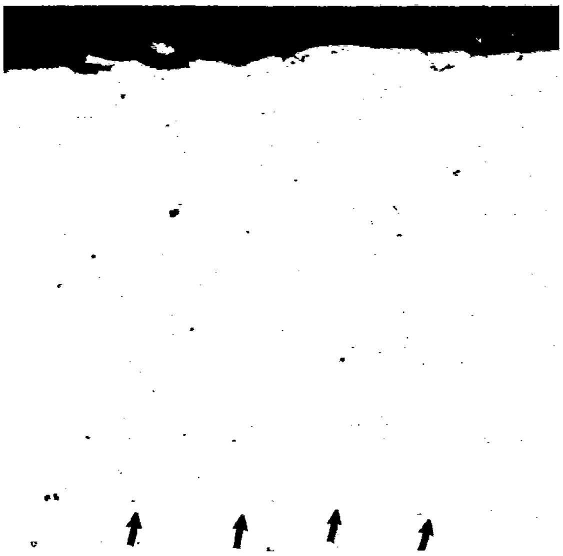


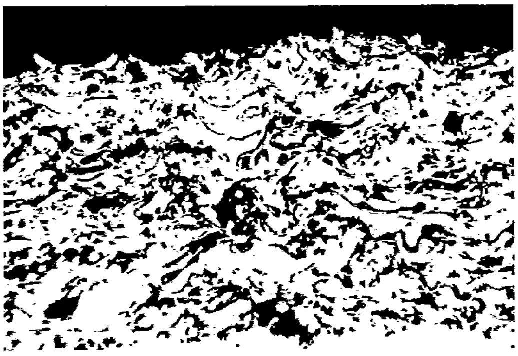
**Fig. 4.4A — Metallic coating as applied utilizing the low pressure plasma coating process. Note intimate coating to substrate interface (arrows) (500 x)**

The effluent velocities are much greater in vacuum than in an air environment or one atmosphere inert gas environment. Since the gas stream is moving at high speeds, exceeding 3000 fps (900m/s), it may be concluded that the entrained particles will travel at rates greater than during atmospheric pressure spraying. Oxide-free splats, deposited at high velocities, wet and flatten to a higher degree than those applied at atmospheric pressure. This also increases process density.

The low pressure spraying process deposits coatings with low stress levels. It also permits the fabrication of free standing structures suitable for engineering components, such as those used in gas turbines.

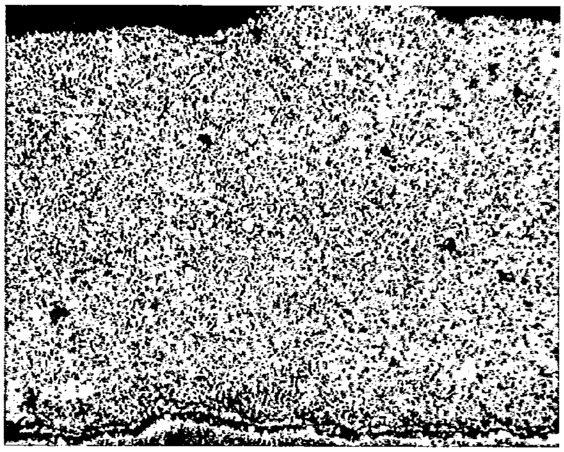
The chemical integrity of coatings applied under partial pressures has been found to be equal to the input material. Elemental losses were not readily evident, nor was the formation of oxides, nitrides or hydrides. Metallographic examination of these metallic coatings reveals a homogeneous, relatively pore free and oxide free, coalescent structure (Fig. 4.4B).

The intersplat oxide lattice normally obtained in the lamellar structure, typical of air or gas shrouded deposits, is absent. The interface is clean and void of oxides or residual surface preparation media. This is akin to evaporative Physical Vapor Deposited (PVD) coatings, but without the columnar structure and leaders often observed in those overlays (Fig. 4.4C). Similar coatings have been obtained utilizing the arc spray process operating in a controlled argon atmosphere.



**Cobalt, chromium, aluminum, yttrium deposit plasma sprayed in air**

**Fig. 4.4B — Plasma Sprayed Deposit**



Same material applied under partial pressure conditions. Note absence of oxide stringers and overall coating homogeneity

Fig. 4.4B (continued)—Plasma Sprayed Deposit

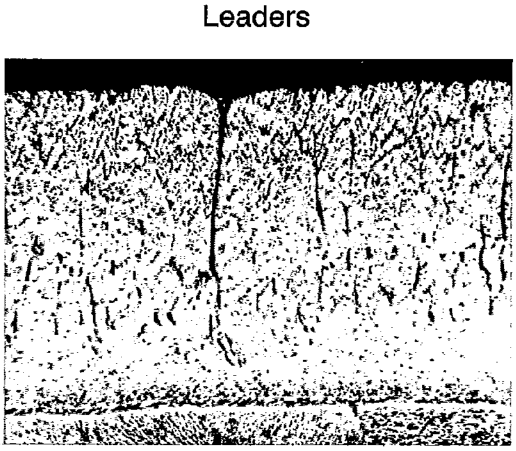


Fig. 4.4C — Typical metallic coating material as applied by the EB vacuum evaporative (PVD) process. Note numerous, deep leaders

# Chapter 5

# Coating Selection and Application

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# Chapter 5

# Coating Selection and Application

## 5.1 Introduction

The selection of a proper coating material involves more than choosing the desired properties of a deposit. It should be approached as an engineering problem by considering items such as coating function and service environment, in addition to the physical and chemical properties of both the coating and the substrate. Choosing a thermal spray material for an application is more complex than selecting a wrought or cast material for the same application. The properties of conventional materials are well understood, and their service performance is predictable. This is not true of thermal spray coatings. The mechanical and corrosion resistant properties of sprayed materials differ from solid or powder metal parts of the same chemistry (see Chapter 4).

The total operational environment should be evaluated prior to choosing a candidate material. Although the primary function of a coating may be wear protection, the operating temperature, and service environment — such as corrosive media — should all be taken into account. Coating material selection should be based on properties and related to end use and service environment, plus factors involving its compatibility with the substrate.

It is not difficult to select the proper coating for a given function after all the pertinent factors are taken into consideration.

Information is presented in two forms: (1) the broad function of coatings, and (2) a study of applications. Bond coat materials and applications are discussed according to their basic function (mechanism). This is followed by an extensive listing of materials (powders, wires, and rods) classified according to well known metallurgical definitions and modified by thermal spray industry requirements. Each material is coded for cross referencing to a listing of applications. Applications (case histories) are treated primarily by function and, where appropriate, by industry. For each application, the working thermal spray coating is called out by code number and a generic description.

## 5.2 Bonding (see 3.8)

Predominantly successful bonding agents are refractory metals such as molybdenum, columbium, tantalum, nickel-aluminum composites, and nickel-aluminum, nickel-chromium, and aluminum-bronze alloys (see Table 5.2). Bond coats are thin [.003 to .007 in. (.08 to .18 mm)], with the overlay coating material comprising the bulk of the deposit. They have the ability to adhere to smooth substrates by metallurgical and mechanical interaction. This is called *self-bonding*, and grit blasting is not required for adhesion. However, industry practice is to grit blast or otherwise roughen the substrate, where practical, for good bond strength and integrity.

**Table 5.2**
**Commonly used bonding materials and method of application**

| Bond coating | Powder flame spray | Powder plasma spray | Wire arc | Wire flame spray |
|---|---|---|---|---|
| Molybdenum | | X | | X |
| Columbium | | X | | |
| Tantalum | | X | | |
| 80/20 Nickel/Aluminum | X | X | X | X |
| 83/17 Nickel/Aluminum | X | | X | X |
| 95/5 Nickel/Aluminum | X | X | X | X |
| Nickel Chromium Aluminum | | X | X | X |
| 80/20 Nickel Chromium | | | X | X |
| Aluminum Bronze | X | X | X | |
| 90/5/5 Ni/Al/Mo | X | X | | |

## 5.3 Electrical Applications

Thermal spray deposits are used extensively in the electrical industry for a number of applications including electrically conductive coatings and resistance type heating circuits.

**5.3.1 Condensers, Resistors, and Brushes.** One application is the production of electrolytic condensers. Automatic wire flame spray equipment is used to apply aluminum onto a gauze-like fabric. Special air caps are employed to provide uniform spray patterns at high velocities.

Carbon and ceramic resistors and carbon brushes are sprayed with a thin film of copper to provide an electrical connection of high conductivity. Pigtails may be soldered to the copper layers on the carbon brushes. Ceramic resistors are also coated. Surface preparation is unnecessary, because the copper particles readily adhere to the relatively porous surface of the carbon or ceramic parts.

**5.3.2 Circuits, Panels, and Switches.** Thermal spraying is a useful method of producing thick film electrical circuits. These circuits can carry higher currents than the printed type, yet are more flexible than stampings. Circuits are produced by spraying the metal onto a nonconductive substrate — usually plastic, ceramic, or glass. The bond to plastics is obtained by grit blasting the surface. Unglazed ceramics are sprayed without surface preparation. The circuit patterns are produced by spraying through masks and etching away unwanted material afterward, or by molding the patterns into the plastic. After the entire surface has been coated, the molded circuits are revealed by grinding away the excess coating to the plastic substrate.

The most commonly used metals for thick film applications are copper, aluminum, zinc, and silver. Materials which may make thermal spraying even more attractive to the electrical industry are being developed for stable resistors, capacitors, and inductors. Heater panels have been produced by spraying onto thermally treated glass. Aluminum is the preferred metal for use on glass. Silver is used in the contact areas of large knife switches to provide good electrical contact.

**5.3.3 Shielding.** Shielding material is used to eliminate electromagnetic and radio frequency interference (EMI/RFI) and to dissipate static discharge sparks. Applications include computer terminals, electronic office equipment, medical monitoring devices, and sensitive electronic equipment. Housings constructed of temperature sensitive plastics do not offer shielding. Zinc coatings provide protection, are inexpensive, and easily applied. Adhesion is excellent, as is electrical conductivity, which provides high levels of attenuation in the range of 60-120 dB.

**5.3.4 Electronics.** In electronic applications that require wear resistance with a high dielectric factor, pure aluminum oxide is applied by wire flame spraying.

## 5.4 Antifretting and Wear

Wear may be caused by fretting, sliding, impact, abrasion, erosion, and other service conditions. Consequently, wear resistant coatings are generally hard and exhibit resistance to heat and chemical attack. The self-fluxing alloys of iron, nickel, or cobalt, discussed in other sections of this manual, offer such properties. When the substrate cannot tolerate high fusing temperatures, carbides, ceramics, and Laves phase alloys (cobalt and molybdenum based) offer excellent protection.

Laves phase is a "size factor compound" where one atom is 20 to 30% smaller than the other, enabling them to pack together in crystal structures more efficiently than if they were the same size.

Tungsten carbides are best used at temperatures less than 900°F (480°C). Between 900°F (480°C) and 1200°F (650°C), titanium carbide and chromium carbide are preferred. Above 1200°F (650°C), chromium carbide or ceramics are best. Laves phase alloys may be used to resist both fretting and sliding wear at temperatures to 1800°F (980°C). Highly lubricious materials, such as aluminum bronze, copper-nickel-indium, and even polyesters, afford resistance to fretting type wear. High carbon steels, cast iron, martensitic stainless steels, molybdenum, nickel chromium alloys, and other materials have been utilized to protect against sliding wear. In any situation where protection is required, it is best to select a material and evaluate it under actual service conditions prior to committing a large quantity of parts. See the applications chart for case histories and coating recommendations in this chapter.

## 5.5 Reclamation

Thermal spraying is a cost effective means for dimensional restoration. Whether the component is undersize due to service induced wear or manufacturing errors, new surfaces may be provided without the distortion of welding or the expense of special plating techniques. Furthermore, the new surface may be constructed from wear or corrosion resistant materials, or even the same material as the base metal.

**5.5.1 Applications.** Typical applications include machine shafts and spindles, rotating and reciprocating shafts, automotive and machine crankshafts, roller faces and journals, hydraulic rams, dryer drums for paper making, pump plungers, sleeves, and impeller blades and housings for chemical and petrochemical industries.

**5.5.2 Wear.** The coatings required to combat wear or corrosion, or both, will include carbon steel, stainless steel, nickel-chromium steels, low alloy steels, nickel, bronze, and other alloys. The mating diameters of components such as bores for roller races and fly wheels, which require shrink or interference fits, may be sprayed with steel, nickel-aluminum, or molybdenum.

While molybdenum coatings are not recommended for use with the arc spray process, most other iron and nickel based wire arc coatings are suitable for machine element reclamation, when chosen for the excellent adhesion and high cohesive strength of the coating.

The carbon steel tubes that form a wall in coal fired power plant boilers are subject to fireside corrosion, sometimes coupled with abrasion or erosion, or both. Thermal spray coatings applied to a nominal thickness of 0.030 in. (0.75 mm) are considered to be effective in protecting water walls, slope tubes, economizers, superheaters, and cyclones from fireside wastage. Coatings selected for use in coal fired boilers should combine self bonding, high density, high bond strength, technique independence, and the ability to apply a new coating over an old one.

Spray coatings allow restoration of worn, steam heated drums used in the drying of paper. Before the original wall thickness is reduced to where lower steam pressure is necessary, restoration can be performed. Coatings of 400 series stainless steel have successfully provided bond strength and wear resistance, with moderate loss in thermal conductivity. Pulp and paper mills have achieved improvements in both production and quality through use of such coatings.

## 5.6 Clearance Control Coatings

**5.6.1 Abradables.** Abradable coatings wear preferentially when contact is made with the mating part. This makes it possible for the mating elements to establish the necessary clearances automatically, providing optimum seals. Abradable or sacrificial materials have been successfully employed to reduce the rotor to shroud clearance for aircraft engine applications. The coating is sacrificial in the event of an incursion by an opposing member, and the abradable material will be rubbed away. A series of sprayed abradable coatings have been developed for sealing the gas path areas of jet engines. Significant improvements in efficiency have been achieved when these materials are applied to the outer air seal locations, between compressor or turbine blade tips and the metallic superstructure or shrouds. Sacrificial materials are also used in the labyrinth seal locations, where they are used to channel cooling air, to minimize loss of pressurized air from the engine, and to maintain a pressure balance on the rotor shaft.

Pure aluminum flame spray coatings were initially used for clearance control applications in the high pressure compressor. Today, high technology abradable coatings consist of two powders blended or agglomerated and applied using the combustion or plasma spray processes. A common abradable coating consists of a metal matrix and a nonmetallic filler such as graphite, polyester, polymide, boron nitride, or a friable mineral. The filler serves to weaken the integrity of the matrix and thereby enhance abradability.

Plasma and flame sprayed abradables are applied directly onto aircraft engine hardware. By eliminating the need for a secondary brazing operation, the sprayed abradables are economical in both initial engine manufacture and overhaul.

**5.6.2 Abrasives.** Gas path seals of the type used in aircraft engines are meant to be sacrificial when rubbed by rotating components such as compressor and turbine blades or labyrinth seal teeth. In areas of high erosion, potential clearance control coatings of high integrity are required. These erosion-resistant coatings often result in rotor wear. To solve this problem, abrasive, wear resistant coatings are applied to blade tips and labyrinth seal teeth. Coatings recommended for this application include alumina, alumina titania, nickel-aluminum cermet, and an 80% nickel 20% chromium alloy blended with chromium carbide.

## 5.7 Environment

**5.7.1 Thermal Barrier Coatings.** Thermal barrier coatings (TBC), which are usually used on diesel engine pistons, gas turbine combustion chambers, vanes, and flame holders, are generally two component systems consisting of a metallic layer overcoated with a ceramic material or mixture. These coatings protect base metals from high operating temperatures, thus allowing more efficient operation of the machinery. They lower the operating temperature of the base metal from 50° to 150°F (10° to 65°C).

Typically, thermal barrier coatings are duplex or triplex layered. Duplex coatings consist of a metallic bond coat overlayed with a ceramic. Triplex coatings include a transitional cermet layer or layers between the bond and ceramic layers. The metallic component may be a cobalt or nickel plus chromium-aluminum-yttrium material, but nickel-aluminum and nickel-chromium-aluminum alloys have also been utilized. Zirconia, stabilized with either yttria or magnesia, is preferred as the ceramic constituent.

Thermal barrier coatings may be used to protect dies and mandrels used in the fabrication of high temperature extrusions. A hardened tool steel die or mandrel is coated with calcia-stabilized zirconium oxide over an 80% nickel-20% chromium undercoat. The advantage of this system for extruding refractory materials, such as molybdenum, tungsten, and tantalum, is that the mandrel or die can be recoated after multiple extrusions.

Other applications involving the use of zirconium oxide as a thermal barrier include protection against hot gases in exhaust systems, thus increasing the efficiency of pistons. There are many applications in the fabrication of steel equipment, including transfer rolls and oxygen lances. Magnesium zirconate is used as a nonwetting thermal barrier. Its principle applications are in vessels and handling equipment for molten material.

**5.7.2 High Temperature and Oxidation Resistant Coatings.** Aluminum coatings are suitable for the protection of iron and steel against corrosion or oxidation, or both, at temperatures between 250°F (120°C) and 1600°F (870°C), and for short term protection to 2100°F (1150°C). For working temperatures up to 1000°F (535°C), sealing with a suitable silicone type sealer is the only additional treatment required.

For higher working temperatures, combustion sprayed aluminum coatings should be covered with a bituminous or other carbonaceous sealer. The treated component is then heated to some temperature above the melting point of aluminum. During the heating cycle, compounds of iron and aluminum are formed on the substrate surfaces. These provide excellent resistance to high temperature attack under service conditions. Arc sprayed aluminum coatings do not require a special thermal treatment, because they form compounds by diffusion during elevated temperature service.

**5.7.3 Corrosion Protection.** Thermal spray coatings are used for protection of iron and steel in a range of corrosive environments. Long term effectiveness (over 20 years) in both industrial and marine locations has been documented.

Austenitic stainless steels, aluminum bronze, and cobalt and nickel base alloys, when sealed, offer varying degrees of atmospheric protection. The particular environment will dictate the appropriate alloy selection.

Zinc and aluminum provide the broadest atmospheric protection, and the choice in their use is often based on the relative ease of application and comparative costs for the specific case. They are more corrosion resistant than steel, and hence form an effective atmospheric barrier. Zinc and aluminum are anodic to steel. They also protect the ferrous substrate in electrolytic solutions. The coating serves as a sacrificial anode and is consumed in time. This reserve cathodic protection acts to prevent corrosion of the substrate even when the coating coverage is incomplete or suffers mechanical damage. Aluminum corrodes less rapidly than zinc in highly acidic conditions, while zinc performs better than aluminum in alkaline conditions.

For the protection of steel in gas and chemical plants, or for other applications where the temperature is in excess of 390°F (200°C), aluminum is used. Spraying of aluminum coatings should be avoided whenever there is a fire or explosion hazard, as in the case of mines or oil rigs, because of the possibility of impact sparking. Consequently, sprayed zinc is always used in coal mines. Zinc is the preferred metal for the protection of steel in fresh cold waters, while above 150°F (65°C), aluminum is used.

Where zinc is alloyed with aluminum, the zinc-rich spray material forms a highly effective corrosion-resistant coating, having the attributes of both elemental components. The zinc affords sufficient electrochemical activity, enabling it to protect cathodically; the aluminum strengthens the coating, providing abrasion and erosion resistance.

Flame and arc spraying give rapid, uniform coverage at economical spray rates, and are replacing painting for reasons of effectiveness and economics. Coatings have a predictable life, require but a single application, need no drying time, protect damaged areas cathodically, and have good abrasion resistance. Thermal spraying complements hot-dip galvanizing, and should be considered for coating existing structures when the fabrications are excessively large or otherwise cannot be hot-dip galvanized.

The size or shape of the structure to be protected is not a limiting factor. Components may be sprayed either in plant or on site. Automation is practical for long runs of repetitive work. The coating thickness can be controlled according to the degree of protection required. The life of a metal coating is proportional to the coating weight per unit area. For very long service life or in highly corrosive conditions, it is possible to increase the thickness to obtain enhanced corrosion protection. Zinc coatings can be applied in thicknesses from 0.002 in. (0.05 mm) to over 0.020 in. (0.50 mm); sprayed aluminum coatings range from 0.004 in. (0.10 mm) to 0.010 in. (0.25 mm) thick.

Surfaces which are not to be coated are masked before spraying. Areas of discontinuity or of insufficient thickness can be rectified by additional spraying. Aluminum and zinc coatings both have good adhesion to grit-blasted steel. Because spraying does not cause excessive heating of the substrate, there is no effect on the mechanical properties.

Porosity is an inherent feature of thermal sprayed coatings. In the case of active metal coatings, porosity is not detrimental, since porous passages through the thickness will not give rise to substrate attack because of the galvanic protection. The natural surface texture provides an excellent base for sealers or paint top coats.

There is a history of corrosion protection by metal spraying for structural steel work. Included are buildings, bridges, towers, radio and TV antenna masts, steel gantry structures, high power search radar aerials, overhead walkways, railroad overhead line support columns, electrification masts, tower cranes, traffic island posts, and street and bridge railings. On a smaller scale, zinc spraying has been used successfully to protect outdoor wrought iron furniture in corrosive environments.

The sulphurous and oxidizing atmospheres of chemical industries provide many applications, including storage tanks for fuels, alcohol, acetate, toluene, glycerine, molasses, and pump sleeves, mechanical seals, and impellers. Parts subjected to severe chemically corrosive environments require testing and evaluation of the coating before being placed in service.

Wellhead assemblies, for offshore use, have been coated for salt atmosphere corrosion protection since the 1950's. The process has been used for flare stacks, refinery columns, and for external protection of oil and propane gas storage tanks.

The interiors of fluid cargo railcars are thermal sprayed to control fluid purity and guard against iron contamination. The coating also aids in avoiding the discoloration of the cargo. Steel railroad cars are zinc sprayed for corrosion protection. These coatings should last the lifetime of the cars, thus eliminating the need of removal from service for painting (approximately every five years).

Spraying has been used to protect pipelines against many other environments. Lengths up to 40 feet (12 m) have been successfully coated internally. Pipe couplings, manhole covers, and other small industrial items are coated. Zinc spraying can restore corrosion protection to areas of products where galvanizing is inadvertently removed during fabrication. This can occur on the threaded ends of electrical conduit, or along the welded seams inside galvanized barrels and drums. Here, spraying is particularly advantageous because it ensures uniformity and reproducibility of coating thickness.

Sprayed zinc coatings have protected fresh water pipelines, the interiors of water towers, and sluice and canal lock gates in irrigation systems. These coated components have required virtually no maintenance for decades.

Sealed zinc coatings improve the resistance to corrosion of steel bridgework and railings from de-icing salts. Furthermore, the rebars in reinforced concrete can be zinc sprayed to retard corrosion. Reinforced concrete bridges and highways, especially in marine environments, commonly suffer damage caused by road salting (de-icing). There is evidence that the rate of corrosion of the reinforcing steel is substantially reduced if the steel is coated with zinc prior to embedding in the concrete.

In marine applications, hulls, deck sections, and concrete portions of barge, scow, tug, and fishing vessel superstructures have been sprayed with excellent long term results. Lifeboats and floating caissons have also been coated, as well as smaller items such as ship rudders and the axles of boat trailers. A common usage of metal spray is on piers, pilings, and ferry berths.

The U. S. Navy, in a major effort to combat shipboard corrosion, has developed a comprehensive program of thermal spray metallization. A number of above deck and steam room ferrous metal components have been sprayed with aluminum and subsequently sealed. Tests to date are encouraging and have led the Navy to introduce specifications for a wide range of thermal spray applications.

## 5.8 Decorative Coatings

Thermal spraying has not been widely adapted for decorative coatings. The most common and notable decorative effect occurs when bridges, water towers, masts, chimneys, above ground pipes, and other large structures are sprayed with aluminum or zinc for corrosion protection. Such structures are left unsealed or are clear sealed without further surface treatment. Zinc and aluminum are used for corrosion protection, but they also provide a cosmetic, improved appearance.

Plain and colored sealers, available for corrosion protection, add an aesthetically pleasing appearance to coated structures. For these applications, a choice is made based on economical and practical values. It must be decided whether to apply thin coatings of painting or sealing, or to apply a thick unpainted coating. An example would be: a fresh water tank sprayed internally with a 0.010 in. (0.25 mm) coating of zinc with no subsequent treatment; the exterior sprayed with a 0.004 in. (0.10 mm) coating of zinc that is sealed with aluminum vinyl.

Some work has been done in thermal spraying concrete brick and block products with glazing materials for decorative value. In many applications, thermal spraying has replaced hard or industrial type chromium plating. However, it cannot compete with decorative chromium plating whose primary function is aesthetic appeal.

## 5.9 Materials Classification

### 5.9.1 Oxide Ceramics[a]

| | | Available form | | | |
|---|---|---|---|---|---|
| | | Powder | | Wire, rod, cord | |
| Code | Composition weight — percent | Type | Particle size | Diameter in. (mm) | Comments |
| 1[a] | $A1_20_3$ 94.0, $Ti0_2$ 2.5, $Si0_2$ 2.0, $Fe0_3$ 1.0, other oxides bal. | Compound | −2100+590μ in. (−53+15 μm) | 3/16 (4.8) cord<br>1/8 (3.2) rod | |
| 2[a] | $Ti0_2$ 99.0+ | Neat* | −2100+400μ in. (−53+10 μm) | 3/16 (4.8) cord | |
| 3[a] | $A1_20_3$ 98.0, $Si0_2$ 0.5, other oxides bal. | Neat | −2100+400μ in. (−53+10 μm) | 3/16 (4.8) cord<br>1/8 (3.2) rod | |
| 4[a] | $Cr_2\ 0_3$ 98.0 | Neat | −3500+590μ in. (−90+15 μm) | 1/8 (3.2) cord<br>1/8 (3.2) rod | |
| 5[a] | $A1_20_3$ 50.0, $Ti0_2$ 50.0 | Blend | −2100+400μ in. (−53+10 μm) | — | |
| 6[a] | $Ti0_2$ 55.0, $Cr_20_3$ 45.0 | Blend | −4200+400μ in. (−106+10 μm) | — | |
| 7[a] | $A1_20_3$ 87.0, $Ti0_2$ 13.0 | Composite | −1200+200μ in. (−30+5 μm)<br>−2100+400μ in. (−53+10 μm) | — | Composite of $Ti0_2$ plus $A1_20_3$ |
| 8[a] | $A1_20_3$ 60.0, $Ti0_2$ 40.0 | Composite | −1800+200μ in. (−45+5 μm) | — | Composite of $Ti0_2$ plus $A1_2$ plus $A1_20_3$ |
| 9[a] | $Si0_2$ 5-9, others 3-5, $Cr_20_3$ bal. | Composite | −2100+590μ in. (−53+15 μm) | — | $Si0_2$ clad $Cr_20_3$ composite |
| 10[a] | $Zr0_2$ 93.0, Ca0 1-5, $A1_20_3$ 0.5, $Si0_2$ 0.4 | Composite | −2100+400μ in. (−53+10 μm)<br>−2100+400μ in. (−53+10 μm) | 1/8 (3.2) rod<br>1/8 (3.2) and<br>3/16 (4.8) cord | Calcia stabilized zirconia |

*Neat means unadulterated

## 5.9 Materials Classification (Continued)

### 5.9.1 Oxide Ceramics[a]

| | | Available form | | | |
|---|---|---|---|---|---|
| | | Powder | | Wire, rod, cord | |
| Code | Composition weight — percent | Type | Particle size | Diameter in. (mm) | Comments |
| 11[a] | $Zr0_2$ 80.0, $Y_20_3$ 20.0 | Composite or compound | −3500+400μ in.<br>(−90+10 μm) | — | Composite or fused yttria stabilized zirconia |
| 12[a] | $Mg0$ 24, $Zr0_2$ bal. | Compound | −2100+400μ in.<br>(−53+10 μm) | — | Magnesia stabilized zirconia |
| 13[a] | $Ca0$ 31.0, $Zr0_2$ bal. | Blend | −2100+400μ in.<br>(−53+10 μm) | — | |
| 14[a] | $Zr0_2$ 88, $Y_20_3$ 12 | Compound | −2100+400μ in.<br>(−53+10 μm) | — | Yttria stabilized zirconia |
| 15[a] | $Zr0_2$ $Y_20_3$ 6-8 | Compound | −2100+400μ in.<br>(−53+10 μm)<br>−2800+1700μ in.<br>(−70+44 μm) | — | Yttria stabilized zirconia |
| 16[a] | $Cr_20_3$ 40-50, $Mg0$ 1-10, $Fe_20_3$ 2-10, $Ti0_2$ 1-10, $A1_20_3$ 5-40, $Si0_2$ 0-8 | Compound | −1800+200μ in.<br>(−44+5 μm) | — | |
| 17[a] | $Cu_20_3$ 82-85, $Si0_2$ 7-9, $Ti0_2$ 3-4, $A1_20_3$ 3-5, $Mg0$ 2-3, $Cu0$ 0.2-0.5 | Compound | −1800+200μ in.<br>(−44+5 μm) | — | |
| 18[a] | $Cr_20_3$ 95, $Ti0_2$ 5 | Compound | −1800+590μ in.<br>(−44+15 μm) | — | |
| 19[a] | $A1_20_3$ 91.0, $Fe_20_3$ 6, $Ti0_2$ 3 | Compound | −2100+400μ in.<br>(−53+10 μm) | — | |

## 5.9 Materials Classification (Continued)

### 5.9.2 Iron Based Alloys[b]

| | | Available form | | | |
|---|---|---|---|---|---|
| | | Powder | | Wire, rod, cord | |
| Code | Composition weight — percent | Type | Particle size | Diameter gage, in. (mm) | Comments |
| 1[b] | Mn .5, C.10, Fe bal. | Alloy | −4200+1800μ in.<br>(−106+45 μm) | 11 (3.05)<br>1/8 (3.2)<br>3/16 (4.8) | Low carbon steel |
| 2[b] | Al 10.0, Mo 1.0, C .2, Fe bal. | Composite | −4900+1800μ in.<br>(−125+45 μm) | — | Low carbon "steel" composite |
| 3[b] | Al 3.0, Mo 3.0, C 3.0, Fe bal. | Composite | −4900+1800μ in.<br>(−125+45 μm) | — | High carbon iron "steel" composite |
| 4[b] | C .35, P .02, S .02, Mn .5, Cr 13.0, Si .5, Fe bal. | Alloy | −2900+1700μ in.<br>(−74+44 μm) | 14 (2.03)<br>11 (3.05)<br>1/8 (3.2)<br>3/16 (4.8) | Type 420 stainless steel |
| 5[b] | C .15, P .06, S .03, Mn 8.5, Ni 5.10, Cr 18.0, Si 1.0, Fe bal. | Alloy | — | 14 (2.03)<br>11 (3.05)<br>1/8 (3.2)<br>3/16 (4.8) | Type 202 stainless steel |
| 6[b] | C .80, P .04, S .04, Mn .7, Fe bal. | Alloy | — | 14 (2.03)<br>11 (3.05)<br>1/8 (3.2)<br>3/16 (4.8) | High carbon steel |
| 7[b] | C .04, P .03, S .03, Mn 2.0, Ni 4.0, Cr 1.5, Mo 1.5, Fe bal. | Alloy | — | 14 (2.03)<br>11 (3.05)<br>1/8 (3.2)<br>3/16 (4.8) | |
| 8[b] | Cr 17.0, Ni 12.0, Mo 2.5, Si 1.0, C .1, Fe bal. | Alloy | −2100+400μ in.<br>(−53+10 μm) | — | Type 316 stainless steel |

## 5.9 Materials Classification (Continued)

### 5.9.2 Iron Based Alloys[b]

| | | Available form | | | |
|---|---|---|---|---|---|
| | | Powder | | Wire, rod, cord | |
| Code | Composition weight — percent | Type | Particle size | Diameter gage, in. (mm) | Comments |
| 9[b] | Cr 16.0, Ni 2.0, C .2, Fe bal. | Alloy | −4200+1800μ in.<br>(−106+45 μm) | 14 (2.03) | Type 431 stainless steel |
| 10[b] | Mo 15.0, C 3.0, Mn .25, Fe bal. | Composite | −3500+400μ in.<br>(−90+10 μm) | — | High carbon molybdenum composite |
| 11[b] | C 3.50, Mn .35, Fe bal. | Alloy | −2100+400μ in.<br>(−53+10 μm) | 14 (2.03)<br>11 (3.05)<br>1/8 (3.2)<br>3/16 (4.8) | High carbon iron |
| 12[b] | Cr 19.0, Ni 9.5, Mn 2.0, Si 1.0, Fe bal. | Alloy | −3500+400μ in.<br>(−90+10 μm) | — | Type 304 stainless steel |

## 5.9 Materials Classification (Continued)

### 5.9.3 Nickel Based Materials and Cobalt[c]

| | | Available form | | | |
|---|---|---|---|---|---|
| | | Powder | | Wire, rod, cord | |
| Code | Composition weight — percent | Type | Particle size | Diameter gage, in. (mm) | Comments |
| 1[c] | Ni 99.5 | Element | −3000+1800μ in.<br>(−75+45 μm) | 15 (1.83) wire<br>1/8 (3.2) wire<br>3/16 (4.8) wire | Nickel |
| 2[c] | Al 20, Ni bal. | Composite | −3500+2100μ in.<br>(−90+53 μm) | — | "Nickel clad" aluminum |
| 3[c] | Cr 8.5, Al 7.5, Mo 5.0, Si 2.0, Fe 2.0, B 2.0, Ni bal. | Composite | −4900+1800μ in.<br>(−125+45 μm) | — | Stainless composite for bonding |
| 4[c] | Al 6.0, NiCr bal. | Composite | −4700+1800μ in.<br>(−120+45 μm) | — | Nickel chromium/ Al composite |
| 5[c] | Cr 9.0, Al 7.0, Mo 5.5, Fe 5.0, Ni bal. | Composite | −4900+1800μ in.<br>(−125+45 μm) | — | Self-bonding composite |
| 6[c] | Ni 60.0, Cr 16.0, Si 1.15, Fe bal. | Alloy | −4700+1800μ in.<br>(−120+45 μm) | 14 (2.03) wire<br>1/8 (3.2) wire<br>3/16 (4.8) wire | |
| 7[c] | Al 4.5, Ni bal. | Composite<br>Alloy | −3500+1800μ in.<br>(−90+45 μm) | 14 (2.03) wire<br>1/8 (3.2) wire | Aluminum/nickel for bonding |
| 8[c] | Cr 9.5, Si 2.5, B 1.5, Al .5, Ni bal. | Blend | −4200+1800μ in.<br>(−106+45 μm) | — | Nickel/chromium aluminum |
| 9[c] | Ni 80.0, Al 20.0 | — | — | 1/8 (3.2) wire | Composite nickel/ aluminum wire bond coat |

## 5.9 Materials Classification (Continued)

### 5.9.3 Nickel Based Materials and Cobalt[c]

| | | Available form | | | |
|---|---|---|---|---|---|
| | | Powder | | Wire, rod, cord | |
| Code | Composition weight — percent | Type | Particle size | Diameter gage, in. (mm) | Comments |
| 10[c] | Ni 80.0, Cr 20.0 | Alloy | −4200+1800μ in.<br>(−106+45 μm) | 14 (2.03) wire | |
| 11[c] | Ni 67.0, C.15, Fe 1.5, Mn 1.0, Si .1, Al .1, Cu bal. | Alloy | −2900+1700μ in.<br>(−74+44 μm) | 14 (2.03) wire<br>1/8 (3.2) wire<br>3/16 (4.8) wire | |
| 12[c] | Cr 25.5, Ni 10.5, W 7.5, CO 0.5, Co bal. | Alloy | −1800+200μ in.<br>(−45+5 μm) | — | |
| 13[c] | Ni 95, Al 5 | Alloy | −3500+1500μ in.<br>(−88+37 μm) | — | — |
| 14[c] | Cr 9.0, Al 7.0, Mo 5.5, Fe 5.0, Ni bal. | Alloy | −3500+1500μ in.<br>(−88+37 μm) | — | — |
| 15[c] | Cr 22.0, Al 10.0, Y 1.0, Ni bal. | Alloy | −1800+200μ in.<br>(−45+5 μm) | — | Ni, Cr, Al, Y |
| 16[c] | Mo 28, Cr 8.0, Si 2.5, Fe 1.0, Co bal. | Alloy | −1800+790μ in.<br>(−45+20 μm) | — | — |
| 17[c] | 60 Ni, 40 Ti | Alloy | −1800+790μ in.<br>(−45+20 μm) | — | — |
| 18[c] | Ni 32.0, Cr 21.0, Al 8.0, Y 0.5, Co bal. | Alloy | −1800+200μ in.<br>(−45+5 μm) | — | Ni, Co, Cr, Al, Y |

## 5.9 Materials Classification (Continued)

### 5.9.4 Nonferrous Materials[d]

| | | Available form | | | |
|---|---|---|---|---|---|
| | | Powder | | Wire, rod, cord | |
| Code | Composition weight — percent | Type | Particle size | Diameter gage, in. (mm) | Comments |
| $1^d$ | Al 9.5, Fe 1.0, Cu bal. | Alloy | −4900+1800$\mu$ in.<br>(−125+45 $\mu$m) | 14 (2.03) wire<br>11 (3.05) wire<br>1/8 (3.2) wire<br>3/16 (4.8) wire | Aluminum bronze |
| $2^d$ | Si 12.0, Al bal. | Alloy | −4200+1800$\mu$ in.<br>(−106+45 $\mu$m) | 14 (2.03) wire<br>11 (3.05) wire<br>1/8 (3.2) wire<br>3/16 (4.8) wire | Silicon aluminum alloy |
| $3^d$ | Al 99.0+ | Element | −3500+1800$\mu$ in.<br>(−90+45 $\mu$m) | 14 (2.03) wire<br>11 (3.05) wire<br>1/8 (3.2) wire<br>3/16 (4.8) wire | Aluminum |
| $4^d$ | Cu 99.0+ | Element | −3500+1800$\mu$ in.<br>(−90+45 $\mu$m) | 14 (2.03) wire<br>11 (3.05) wire<br>1/8 (3.2) wire<br>3/16 (4.8) wire | Copper |
| $5^d$ | Ni 38.0, Cu bal. | Alloy | −3000+1800$\mu$ in.<br>(−75+45 $\mu$m) | 14 (2.03) wire | Copper-nickel alloy |
| $6^d$ | Ni 36.5, In 5.0, Cu bal. | Alloy | −3000+1800$\mu$ in.<br>(−75+45 $\mu$m) | — | Copper-nickel indium alloy |
| $7^d$ | Zn 99.9+ | Element | — | 14 (2.03) wire<br>11 (3.05) wire<br>1/8 (3.2) wire<br>3/16 (4.8) wire | Zinc |
| $8^d$ | Cu 66, Zn 34 | Alloy | — | 14 (2.03) wire<br>11 (3.05) wire<br>1/8 (3.2) wire<br>3/16 (4.8) wire | Brass |

## 5.9 Materials Classification (Continued)

### 5.9.4 Nonferrous Materials[d]

| | | Available form | | | |
|---|---|---|---|---|---|
| | | Powder | | Wire, rod, cord | |
| Code | Composition weight — percent | Type | Particle size | Diameter gage. in. (mm) | Comments |
| 9[d] | Cu 90, Zn 10 | Alloy | — | 15 (1.83) wire<br>14 (2.03) wire<br>1/8 (3.2) wire<br>3/16 (4.8) wire | Brass |
| 10[d] | Cu 95, Sn 5 | Alloy | — | 1/8 (3.2) wire<br>3/16 (4.8) wire | Brass |
| 11[d] | Cu 58.2, Sn .8, Fe .75, Mn .25, Zn bal. | Alloy | — | 1/8 (3.2) wire<br>3/16 (4.8) wire | — |
| 12[d] | Cu/SiC | Composite | — | 1/8 (3.2) wire | Cu tubing with SiC composite filler |
| 13[d] | Zn 80, Tin 20 | Alloy | — | 14 (2.03) wire<br>11 (3.05) wire<br>1/8 (3.2) wire | — |
| 14[d] | 90 Tin, 7 Antimony, 3 Copper | Alloy | — | 11 (3.05) wire<br>1/8 (3.2) wire | Babbitt |
| 15[d] | 85 Zn, 15 Al | Alloy | — | 14 (2.03) wire<br>11 (3.05) wire<br>1/8 (3.2) wire | — |
| 16[d] | Tin | Element | — | 11 (3.05) wire<br>1/8 (3.2) wire | — |
| 17[d] | Lead | Element | — | 11 (3.05) wire<br>1/8 (3.2) wire | Caution: lead is hazardous. See Chapter 11 |
| 18[d] | 85 Pb Sn | Alloy | — | 11 (3.05) wire<br>1/8 (3.2) wire | Caution: see above SAE 6A solder |

## 5.9 Materials Classification (Continued)

### 5.9.5 Other Carbides[e]

| | | Available form | | | |
|---|---|---|---|---|---|
| | | Powder | | Wire, rod, cord | |
| Code | Composition weight — percent | Type | Particle size | Diameter gage, in. (mm) | Comments |
| 1[e] | $Cr_3C_2$ 99.0 | Compound | $-5500+1200\mu$ in.<br>($-140+30$ $\mu$m) | — | AMS 7875 |
| 2[e] | $Cr_3C_2$ 75, Ni 20, Cr 5 | Blend | $-1800+200\mu$ in.<br>($-45+5$ $\mu$m) | — | Chromium carbide + Ni chromium alloy blend |
| 3[e] | $Cr_3C_2$ 85, Ni 12, Cr 3 | Blend | $-5500+400\mu$ in.<br>($-140+10\mu$ m) | — | Chromium carbide + Ni chromium alloy blend |
| 4[e] | Cr 48, Ni 28, C 6, Al 2, Mo 2, B 1, Si 1, Co bal. | Blend | $-3000+400\mu$ in.<br>($-75+10$ $\mu$m) | — | Chromium carbide "Ni aluminide" blend |
| 5[e] | TiC 55, Co 45 | Composite | $-1700+400\mu$ in.<br>($-44+10$ $\mu$m) | — | Fine TiC particles clad with Co |
| 6[e] | TiC 55, Ni 45 | Composite | $-1700+400\mu$ in.<br>($-44+10$ $\mu$m) | — | Fine TiC particles clad with Ni |
| 7[e] | WC 67, NiCrB33 | Composite + Blend | $-1700+400\mu$ in.<br>($-44+10$ $\mu$m) | — | Fine WC particles clad with Co and blended with Ni |

## 5.9 Materials Classification (Continued)

### 5.9.6 Refractory Metals and Alloys[f]

|  |  | Available form |  |  |  |
|---|---|---|---|---|---|
|  |  | Powder |  | Wire, rod, cord |  |
| Code | Composition weight — percent | Type | Particle size | Diameter gage, in. (mm) | Comments |
| 1[f] | W 99.5 | Element | $-7900+1200\mu$ in.<br>$(-200+30\ \mu m)$ | — | — |
| 2[f] | Ta 99.5 | Element | $-3500+1700\mu$ in.<br>$(-90+44\mu\ m)$ | — | — |
| 3[f] | Mo 99 | Element | $-7900+1200\mu$ in.<br>$(-200+30\ \mu m)$ | 15 (1.83) wire<br>1/8 (3.2) wire<br>3/16 (4.8) wire | — |
| 4[f] | Mo 99.5 | Element | $-3500+1700\mu$ in.<br>$(-90+44\ \mu m)$ | 15 (1.83) wire<br>1/8 (3.2) wire<br>3/16 (4.8) wire | — |
| 5[f] | Mo 75.0, Cr 4.25, B 0.8, Si 1.0, Fe 1.0, C 0.2, Ni bal. | Blend | $-3500+590\mu$ in.<br>$(-90+15\ \mu m)$ | — | Self-fluxing alloy plus molybdenum blend |

## 5.9 Materials Classification (Continued)

### 5.9.7 Self-Fluxing Alloys$^g$

| | | Available form | | | |
|---|---|---|---|---|---|
| | | Powder | | Wire, rod, cord | |
| Code | Composition weight — percent | Type | Particle size | Diameter gage, in. (mm) | Comments |
| $1^g$ | Cr 10.0, B 2.5, Fe 2.5, Si 2.5, C .15, Ni bal. | Alloy blend | −4900+1800μ in. (−125+45 μm) | 1/8 (3.2) cord | — |
| $2^g$ | Cr 17.0, Fe 4.0, Si 4.0, B 3.5, C 1.0, Ni bal. | Alloy | −4200+1800μ in. (−106+45 μm)<br>−2100+590μ in. (−53+15 μm) | 1/8 (3.2) cord | — |
| $3^g$ | Co 40.0, Cr 18.0, Mo 6.0, Si 3.5, B 3.0, Fe 2.5, C 0.2, Ni bal. | Alloy | −4900+2100μ in. (−125+53 μm) | — | — |
| $4^g$ | Cr 16.0, Si 4.0, B 4.0, Fe 4.0, Cu 2.4, Mo 2.4, W 2.4, Co 0.5, Ni bal. | Alloy | −4200+1800μ in. (−106+45 μm) | — | — |
| $5^g$ | Ni 46.0, WC/Co 35.0, Cr 11.0, Fe 2.5, Si 2.5, B 2.5, C 0.5 | Blend | −4900+1800μ in. (−125+45 μm) blend | — | Blend of WC/Co powder plus self-fluxing alloy |
| $6^g$ | WC/Co 80.0, Ni 14.0, Cr 3.5, B 0.8, Fe 0.8, Si 0.8, C 0.1 | Blend | −4900+1800μ in. (−125+45 μm) blend | — | Blend of WC/Co powder plus self-fluxing alloy |
| $7^g$ | WC/Co 50.0, Ni 33.0, Cr 9.0, Fe 3.5, Si 2.0, B 2.0, C 0.5 | Blend | −2100+590μ in. (−53+15 μm) | — | Blend of WC/Co powder plus self-fluxing alloy |

## 5.9 Materials Classification (Continued)

### 5.9.7 Self-Fluxing Alloys[g]

| | | Available form | | | |
|---|---|---|---|---|---|
| | | Powder | | Wire, rod, cord | |
| **Code** | **Composition weight — percent** | **Type** | **Particle size** | **Diameter gage, in. (mm)** | **Comments** |
| 8[g] | WC/Co 3.0, Co 28.0, Ni 19.0, Cr 12.5, Mo 4.2, Si 2.5, B 2.0, Fe 1.9, C 0.1 | Blend | $-4900+1800\mu$ in. ($-125+45$ $\mu$m) | — | Blend of WC/Co powder plus self-fluxing alloy |
| 9[g] | Wc/C 35, Cr 11.0, B 2.5, Fe 2.5, Si 2.5, C 0.5, Ni bal. | Blend | $-5900+1800\mu$ in. ($-150+45$ $\mu$m) | — | Blend of WC/Co powder plus self-fluxing alloy |
| 10[g] | Si 1.6, B 2.4, Cr 19, Co .06, Ni 2.7, W 4.5, Co bal. | — | — | 3/16 (4.8) cord | — |

## 5.9 Materials Classification (Continued)

### 5.9.8 Tungsten Carbides[h]

| | | Available form | | | |
|---|---|---|---|---|---|
| | | Powder | | Wire, rod, cord | |
| Code | Composition weight — percent | Type | Particle size | Diameter gage, in. (mm) | Comments |
| 1[h] | Co 12, C 4, Fe 1, WC bal. | Composite | −1800+200μ in.<br>(−45+5 μm) | — | Full sintered and crushed powder meets AMS 7879 |
| 2[h] | Co 12, WC bal. | Composite | −1800+590μ in.<br>(−45+15 μm) | — | Partial sintered and crushed powder meets AMS 7880 |
| 3[h] | Co 17, WC bal. | Composite | −2100+400μ in.<br>(−53+10 m) | — | Composited plus sintered powder |
| 4[h] | Co 12, WC bal. | Composite | −1200+200μ in.<br>(−30+5 μm) | — | Composited plus without sinter |
| 5[h] | C 0.5, Si 1.5, Cr 6.0, B 1.0, Fe 1.5, Al 0.7, WC 12, Co 50, Ni bal. | Blend | −6700+590μ in.<br>(−170+15 μm) | — | Blend of WC/Co (Code 120) plus nickel-aluminum |
| 6[h] | WC 12, Co 75.0, Cr 3.0, Al 1.5, Fe 0.8, Si 0.8, B 0.5, C 0.15, Ni bal. | Blend | −3500+550μ in.<br>(−90+14 μm) | — | Blend of WC/Co (Code 120) plus nickel-aluminum |
| 7[h] | Co 20, WC 80 | Composite | −1700+400μ in.<br>(−44+10 μm) | — | Fine WC particles clad with Co |
| 8[h] | Co 12, WC 88 | Composite | −1700+400μ in.<br>(−44+10 m) | — | Fine WC particles clad with Co |

## 5.9 Materials Classification (Continued)

### 5.9.9 Abradable Coatings[i]

| | | Available form | | | |
|---|---|---|---|---|---|
| | | Powder | | Wire, rod, cord | |
| Code | Composition weight — percent | Type | Particle size | Diameter gage, in. (mm) | Comments |
| 1[i] | BN 5.5, Al 3.5, Fe 8, Cr 14, Ni bal. | Composite | −4900+1800μ in.<br>(−125+45 μm) | — | Boron nitride plus Ni alloy composite |
| 2[i] | Ni 75, C 25 | Composite | −3500+1200μ in.<br>(−90+30 μm) | — | Nickel plus graphite composites |
| 3[i] | Ni 85, C 15 | Composite | −3500+1200μ in.<br>(−90+30 μm) | — | Nickel plus graphite composites |
| 4[i] | Al 57, C 35, Si 8 | Composite | −4900+590μ in.<br>(−125+15 μm) | — | Silicon aluminum graphite composite |
| 5[i] | Al Si 55, C 45 | Composite | −4900+590μ in.<br>(−125+15 μm) | — | Silicon aluminum plus graphite composite |
| 6[i] | Al (12 Si) 60 polyester bal. | Blend | −5500+400μ in.<br>(−140+10 μm) | — | Aluminum plus polyester blend |
| 7[i] | Al Si 60, PI 40 | Composite | −5500+400μ in.<br>(−140+10 μm) | — | Silicon aluminum polyimide composite |
| 8[i] | Cu 9.5 Al, 1.0 Fe, BN 7 | Composite | −3000+400μ in.<br>(−75+10 μm) | — | Aluminum bronze plus boron nitride cermet powder |
| 9[i] | Ni 80, C 20 | Composite | −3500+1200μ in.<br>(−90+30 μm) | — | Nickel plus graphite composite |

## 5.10 Applications

### 5.10.1 Machine Element — Salvage and Restoration of Dimension

| Part by name | Material code no. | Thermal spray system | Comments |
|---|---|---|---|
| Heavy duty bearing surfaces, where corrosion is not critical:<br>Rolls surfaces<br>Journals<br>Crankshafts<br>Papermill dryer drums | 4b, 10b, 11b, 6b | Wire, combustion, or arc<br>Powder, combustion, or plasma | Finished by grinding |
| Heavy duty bearing surfaces, good corrosion resistance is required:<br>Pump plungers<br>Hydraulic rams<br>Impellers<br>Shafts | 4b, 3c, 8c | Wire, combustion, or arc<br>Powder, combustion, or plasma | Finished by grinding |
| Load bearing applications, under marine or caustic environments | 11c | Wire, combustion, or arc<br>Powder, combustion, or plasma | —— |
| Repair:<br>Printing roller surfaces,<br>Electric grounding conductors,<br>Railway carriage axles, conductor rolls in electric plating plants | 4d | Wire, combustion, or arc<br>Powder, combustion, or plasma | For electrical conductivity |

## 5.10 Applications (Continued)

### 5.10.2 Antifretting and Wear

| Part by name | Material code no. | Thermal spray system | Comments |
|---|---|---|---|
| Fan blade interlocks | 1h, 2h, 3h | Detonation, plasma | Wear and impact resistance |
| Compressor blade interlocks | 1h, 2h, 3h | Detonation, plasma | Wear and impact resistance |
| Exhaust nozzle flaps | 16c, 2e, 3e, 3h | Plasma | Rub and wear resistance |
| Exhaust nozzle seal | 16c, 2e, 2h | Plasma | Fretting resistance |
| Miscellaneous brackets | 5d, 6d, 2h, 7h, 8h | Plasma | Fretting resistance |
| Miscellaneous clips | 5d, 6d, 2h, 3h, 7h, 8h | Plasma | Fretting resistance |
| Landing gear struts | 2d | Plasma wire-arc | Rebuild struts |
| Helicopter pulleys | 6b | Wire combustion | Rebuild pulleys |
| LPTV interlocks | 16c, 2e | Plasma detonation | High temperature resistance to fretting |
| Exhaust nozzle | 16c, 2e | Plasma | |
| Stator seal | 2e | Plasma | High temperature resistance to fretting |
| Nozzle diaphragm | 16c, 2e, 2g | Plasma | |
| Seal mate faces | 16c, 5d | Plasma | Fretting wear |
| Compressor vane dovetail | 16c, 5d, 6d | Plasma detonation | Fretting wear |
| Fan disc pressure faces | 5d, 6d | Plasma | Soft antifretting |
| Fan blade dovetails | 16c, 5d, 6d | Plasma | —— |
| Blade retainer rings | 16c, 5d | Plasma | —— |
| Bearing housing | 3f | Plasma | —— |
| Tail engine adaptors | 2h | Plasma | Fretting wear |
| Cam and cam followers | 16c, 2h | Plasma | Sliding wear |
| Wire drawing capstans | 4a, 17a, 18a, 19a | Plasma | Sliding wear |
| Wire drawing pullies | 4a, 18a, 19a | Plasma | Sliding wear |
| Oil flangers | 4a, 11b | Plasma | —— |
| Seals | 16a, 17a, 5d, 6d | Plasma | Sliding wear |

## 5.10 Applications (Continued)

### 5.10.3 Clearance Control

| Part by name | Material code no. | Thermal spray system | Comments |
|---|---|---|---|
| Fan tip seals | 2d, 6i | Wire arc<br>Wire combustion<br>Plasma | |
| Low pressure compressor (inner and outer seals) | 2d, 2i,<br>3i, 6i | Wire combustion<br>Wire arc<br>Powder combustion<br>Plasma | |
| Intermediate compressor case (Rolls Royce) | 6i | Plasma | |
| High pressure compressor (inner and outer seals) | 2d<br>1i, 2i,<br>3i, 6i | Wire combustion<br>Wire arc<br>Powder combustion<br>Plasma | |
| Centripetal compressors (small engines) | 6i | Plasma | |
| Low pressure turbine shrouds [below 1500°F (815°C)] | 7c, 1i,<br>8i | Wire arc<br>Powder combustion | Open structure |
| High pressure turbine shrouds* | 11a | Plasma | Intermediate cermet is required |
| Fuel nozzle valve seal | 1i | Powder combustion | |
| Low pressure turbine nozzle | 8i | Powder combustion | |
| Labyrinth seals (including oil seals) | 1i, 2i,<br>3i, 4i,<br>NiA1+Ag<br>6i<br>NiA1-1 | Powder combustion<br>Plasma | |

* Bond coat code — 1007

## 5.10 Applications (Continued)

### 5.10.4 Petrochemical and Paper

| Part by name | Material code no. | Thermal spray system | Comments |
|---|---|---|---|
| Yankee dryer rolls | 4b | Wire combustion<br>Wire arc<br>Plasma | Paper industry |
| Corrugated rolls —<br>Sleeve<br>Journal fits | 4b | Wire combustion<br>Wire arc<br>Plasma | Paper industry |
| Pressure rolls —<br>Sleeve<br>Journal fits | 4b | Wire combustion<br>Wire arc<br>Plasma | Paper industry |
| Compressor cylinders<br>Hydraulic and power | 4b | Wire combustion<br>Wire arc<br>Plasma | Oil industry |
| Swivel joints for underwater securing | 11c | Wire combustion<br>Wire arc<br>Plasma | Oil industry |
| Compressor pistons — all types | 4b, 1d, 11d, 12d | Wire combustion<br>Powder combustion | Oil industry |
| Compressor piston rods | 7a, 4b, 3h | Wire combustion<br>Plasma | Oil industry |
| Turbine runners | 4b | Wire combustion | Oil industry |
| Turbine runners —<br>Bearing seal and carbon areas | 4b | Wire combustion | Oil industry |
| Burner nozzle | 10a, 12a, 15a | Plasma<br>Flame (rod) | Thermal barrier coating |
| Rotary valve | 1a | Flame (rod) | Resist wear by particle erosion |
| Boiler tubes | 4b, 5c, 14c, 3d | Wire arc plasma | Resist corrosion |
| Packing journals —<br>Sleeves | 7a, 14a, 15a, 16a | Plasma | Slurry pumps — paper industry |
| Pump housings | 14a, 15a, 16a, 17a | Plasma | Resist wear by particle erosion |
| Extrusion screws | 16a, 17a | Plasma | Resist wear by particle erosion |

## 5.10 Applications (Continued)

### 5.10.5 Atmosphere and Sea Corrosion

| Part by name | Material code no. | Thermal spray system | Comments |
|---|---|---|---|
| Winches | 3d, 7d | Wire, arc, or combustion | Coatings should be primed, and sealed for maximum life |
| Booms | 3d, 7d | Wire, arc, or combustion | Coatings should be primed, and sealed for maximum life |
| Piping | 3d, 7d | Wire, arc, or combustion | Coatings should be primed, and sealed for maximum life |
| Stanchions | 3d, 7d | Wire, arc, or combustion | Coatings should be primed, and sealed for maximum life |
| Tie downs | 3d, 7d | Wire, arc, or combustion | Coatings should be primed, and sealed for maximum life |
| Steam riser valves | 3d, 7d | Wire, arc, or combustion | Coatings should be primed, and sealed for maximum life |
| Exhaust stacks | 3d, 7d | Wire, arc, or combustion | Coatings should be primed, and sealed for maximum life |
| Bridges | 3d, 7d | Wire, arc, or combustion | Coatings should be primed, and sealed for maximum life |

## 5.10 Applications (Continued)

### 5.10.6 Electrical

| Part by name | Material code no. | Thermal spray system | Comments |
|---|---|---|---|
| Capacitors | 13d, 4d,<br>16d, 7d, 3d | Wire combustion<br>Wire arc | — |
| Ceramic resistors | 3d, 4d, 7d | Wire combustion<br>Wire arc | — |
| Graphite electrodes | 3d, 4d | Wire combustion<br>Wire arc | — |
| Varistors | 3d, 7d | Wire combustion<br>Wire arc | — |
| Oxides (special) | 3d, 7d | Wire combustion<br>Wire arc | — |
| Glass | 3d, 4d | Wire combustion<br>Wire arc | — |
| Shielding | 3d, 7d | Wire combustion<br>Wire arc | — |

# Chapter 6

# Training, Testing, and Quality Control

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# Chapter 6

# Training, Testing, and Quality Control

## 6.1 Introduction

W. E. Ballard has written, "When applying coatings, the pistol is used as a hand tool, and the ultimate behavior of the deposit will therefore depend to some extent on the operator. One of the standard criticisms of the metal spraying process is its dependability on the human element, and it is therefore necessary to consider how best to avoid unsatisfactory work." Meters and controllers have been added since 1926, when the author first made this observation, but the operator is still relied upon to produce a quality product. This applies not only to the deposition process but also to the preparatory processes, and ultimately, the end product. Controls must be applied to all phases of the operation to assure a consistently dependable end product. This chapter identifies existing controls and alerts readers to measures they may want to take.

## 6.2 Operator

**6.2.1 Certification.** The United States Navy has issued an Operator Certification Requirement in DOD-STD-2138, *Metal Spray Coatings for Corrosion Control on Naval Ships,* and certain other industries also require certification acknowledging proficiency with the degree of compliance determined by the user.

**6.2.2 Training.** Before operators handle or use any thermal spray equipment, they should be trained in basic safety, equipment and tool handling, and have a good familiarity with manuals and instructions. These include, but are not limited to

**Safety Tools***
- Safety glasses, clear
- Safety glasses, number 3, 4, and 5 lens
- Welder's helmet, number 9 lens
- Work gloves
- Aluminized gloves
- Aluminized bib or apron
- Hearing protection
- Breathing respirator

* Consult Chapter 11 Safety for proper usage.

**Publications** - (see Bibliography)
- AWS C2.1-73, *Recommended Safety Practices for Thermal Spraying*
- AWS A3.0, *Welding Terms and Definitions*
- Background information on various spray processes and practices
- Equipment manufacturers recommendations

**Instruction**
- Presentation of safety precautions and process procedures that yield acceptable quality deposits
- Equipment/process description including discussion and demonstrations by qualified personnel
- Trainee self-study period on previously supplied manuals and processing instructions
- Supervised process operation on-the-job training with qualified personnel
- Maintenance/repair of equipment
- Solo process operation with frequent performance review by qualified personnel
- Performance evaluation

Generally, a **THOROUGH** training period, encompassing all processes, may require as much as ten to twelve weeks, with the final week devoted to solo on-the-job operation and testing. The training period should be divided into segments; for example:

**Safety**
- Demonstration of safety devices
- Demonstration of operating equipment
- Self-study (reading)
- Testing (written/oral/performance)

**Surface Preparation**
- Process description
- Demonstration of safety practices
- Demonstration of operating equipment
- Solo
- Testing (performance)

**Wire Flame and Arc Spraying**
- Process description

- Demonstration of safety practices
- Demonstration of operating and control equipment
- Self-study (reading/hands-on)
- Equipment construction and assembly
- Trouble shooting
- Testing (written/oral/performance)

**Powder Flame Spraying**

- Process description
- Demonstration of safety practices
- Demonstration of gun and control equipment
- Self-study (reading/hands-on)
- Equipment construction and assembly
- Trouble shooting
- Testing (written/oral/performance)

**Plasma Spraying**

- Process description
- Demonstration of safety practices
- Demonstration of gun and control equipment
- Self-study (reading/hands-on)
- The feed system
- Equipment construction and assembly
- Trouble shooting
- Testing (written/oral/performance)

**6.2.3 Testing.** Upon completion of the required training, the proficiency of the candidate for thermal spray operator should be evaluated. Testing may be either written or oral, and a hands-on demonstration of skills. A combination of these is preferred. The written or oral test should contain questions directly related to the text or subject material. True-or-false or multiple choice are best. Plans for retesting and additional training should be established. The actual tests should be direct and to the point. Individual tests should be provided for each subject; i. e., Safety, Surface Preparation, Plasma Spraying, Wire and Powder Flame Spraying, Wire Arc Spraying, and Detonation. It would be inappropriate to test candidates for proficiencies in areas of expertise that they would never be expected to perform. A typical written/oral test on two subjects is presented in Exhibit 6.2.3 (A & B). Such tests should be prepared for each process. Spray tests should be on a pre-established schedule and should be conducted on actual or simulated hardware. Each may be accompanied by companion panels suitable for physical testing. These tests may include hardness, tensile strength, and microstructure. The purpose of the spray test is to enable the candidate to demonstrate required skills as a craftsman. Hence, the coating visual appearance, thickness control, temperature during application, and amount of overspray all should be evaluated.

## Exhibit 6.2.3
## Thermal Spray Operators Test

This example could be used to certify trainees as they complete the program as well as for operator recertification.

| **A. Plasma Spraying** | **True** | **False** |
|---|---|---|
| 1. Spraying should follow grit blasting after four hours exposure. | X | |
| 2. All parts need not be cleaned and grit blasted before spraying. | | X |
| 3. Dry powder should be poured directly from the can to the hopper "as is." | | X |
| 4. Spilled powder should be replaced in the can immediately. | | X |
| 5. Dirt in small amounts in the powder is not critical since it will be consumed in the arc. | | X |
| 6. If there is any doubt as to the dryness of the powder, it should be dried in an oven before use. | X | |
| 7. Nitrogen and hydrogen are used as carrier gases. | | X |
| 8. The exhaust system should always be turned on before entering the spray booth. | X | |
| 9. If the gas or cooling water pressure fails, the system shuts down automatically. | X | |
| 10. To rid the gun body of water the "Purge" button should be pushed as long as necessary. | X | |
| 11. Internal gun and control valve units can be cleaned with ordinary compressed air. | | X |
| 12. Powder feed unit "O" rings should be changed daily. | | X |
| 13. "O" rings should be lubricated before assembly into the gun. | X | |
| 14. A green color in the plasma stream indicates trouble. | X | |
| 15. The gap between the nozzle and the electrode should be kept completely dry. | X | |
| 16. The electrode nozzle arc should always be adjusted with the special tool provided. | | X |

### A. Plasma Spraying (cont'd.)

| | True | False |
|---|---|---|
| 17. A welding helmet is sufficient eye protection. | | X |
| 18. Gloves, ear plugs or muffs, or both, and long sleeves need only be worn when spraying certain materials. | | X |
| 19. Respiratory equipment should be worn when spraying toxic materials, but need not be worn otherwise unless felt necessary by the operator. | | X |
| 20. No spraying should be performed without a procedure. | X | |
| 21. Part temperature can be controlled by reducing amperage. | | X |
| 22. The secondary gas should be turned off when the ammeter drops to 250-300 amps. | | X |
| 23. The "Run-Off" button should be pushed when the ammeter shows about 100 amps. | X | |
| 24. It is necessary to check the electrode for replacement whenever replacing the nozzle. | X | |

### B. Powder and Wire Combustion Spraying

| | True | False |
|---|---|---|
| 1. Structure of sprayed steel is different from cast, rolled, or drawn steel. | X | |
| 2. A coating sprayed at 45° to the surface is just as good as one sprayed at 90°. | | X |
| 3. When heating I.D.'s to improve bond, 600° F (315° C) is an approximate temperature to use. | | X |
| 4. If small light blue streamers appear in the flame, the oxygen pressure is too high. | X | |
| 5. The melting end of all wires should always be even with the front of the air cap. | | X |
| 6. When spraying dual coatings, the thickness of the first coat is not critical. | | X |
| 7. When spraying molybdenum for a bond coat, the initial passes are put on at 6-8 in. (152-203 mm), after which the gun is moved into 2-3 in. (51-76 mm). | | X |
| 8. As a general rule of thumb, the travel speed of the work piece in surface feet per minute should be fifty or higher. | | X |
| 9. Maintenance of the guns is not so important as spray technique. | | X |
| 10. A small flame or noise at the nozzle after the gun has been shut off shows a leak in the gas valve. | X | |
| 11. Wire gun valves should be lubricated after every 500 hours of use. | X | |
| 12. Oil in small amounts on the wire is not critical since it will be consumed in the flame. | | X |
| 13. Kinky wire will cause sticking in the gun. | X | |
| 14. Low spraying speeds increase the oxide content in the deposit. | X | |
| 15. Cracking can be minimized on heavy coatings by interrupted spraying. | X | |
| 16. After grit blasting, the area to be sprayed must not be touched or contaminated. | X | |
| 17. No wire should be in the gun when adjusting the settings. | | X |
| 18. Molybdenum is a stainless steel wire. | | X |
| 19. If something happens to sprayed coatings during the process, the defect can be covered over with added spray. | | X |
| 20. Ceramic rods can be sprayed using the same gun as that for wire coatings. | | X |
| 21. Poorly bonded coatings can usually be traced to contaminated gases. | | X |
| 22. Thick coatings can be deposited faster by increasing wire feed speed. | | X |
| 23. A "flashback" will result when wire feed is too fast. | | X |
| 24. Compressed air should be turned on after the wire gun is ignited. | | X |

## 6.3 Consumables

### 6.3.1 Spray Materials

**Metal Wires and Rods.** The wire and rods used in spraying should always be certified for coating applications. Some of the requirements are

Chemical composition
Physical dimensions
Surface appearance
Physical condition/strength
Camber or cast

Though not covered by universal industry standards, the chemical composition of metallic wires and rods is determined by utilizing standard procedures. Chemical limits for most of these products are listed in military specification MIL-W-6712, Rev. B, *Metallizing Wire.* Materials for spraying should meet this or other industrial specifications.

| | |
|---|---|
| ASTM | - American Society for Testing and Materials - *Annual Book of ASTM Standards* covers the general requirements for conventional wire types under Section 1 and 2, in the appropriate volume for the metal involved. |
| AWS | - American Welding Society - *Filler Metals Specifications,* A5 series, give such data as classifications, composition, details of manufacture, certification, test methods, marking, and packaging. |
| SAE | - Society of Automotive Engineers - *Aerospace Materials Specifications* covers metals according to product form and temper.<br>SAE also publishes a reference guide with a cross index of chemically similar specifications - *Metals and Alloys in the Unified Numbering System.* |

The roundness and diameter of wires has a direct effect on sprayability and feed. Oversized wires may not feed. Oval shaped or loose fitting wires permit combustion gases to flow backwards, behind the nozzle, into the drive rolls. This could result in a fire, explosion, or both. Wire or rod should be +0 - 0.004 in. (+0 mm - 0.10 mm) of the indicated nozzle bore diameter.

Wrought spray stock should be clean, have a smooth surface, be free of shavings, nicks, or kinks which may cause binding within the nozzle. The material should not be oxidized, corroded, or contain sulfides and other contamination which may affect the quality of the spray deposit. This includes drawing/extruding lubricants such as grease, oils, or graphite.

Wires are provided in coils or on spools. Wire/rod sized 1/8 to 3/16 in. (3.2 to 4.8 mm) is used for combustion spraying. Material of 6 to 13 gauge (4.1 to 1.8 mm) is used for arc spraying. The wire should not overlap itself, so it can be freely fed to the gun without knotting. The cast or curvature of the wire should not be tight. Wire with a tight cast, if not properly straightened, may cause binding within the spray head or wandering of the electric arc. The wire should possess sufficient ductility and strength that, on bending or pulling, it does not break. Materials, such as tin and zinc, should be sufficiently hard to resist flattening or gouging by drive rolls. Wire should be properly packaged, some with dessicants, for protection during storage and shipping.

**Powders.** Wires are wrought products, produced by either drawing or extruding, and providing a consistent, homogenous product. In contrast, powders, while consistent in method of manufacture, are different from lot to lot. These differences are in particle configuration and size distribution.

The quality of powders for thermal spray coatings depends upon several basics. Many methods can be employed to manufacture powders, but only two have any commercial significance:

Mechanical processing of solid materials
Atomization of liquid materials

Mechanical processing of solids involves pulverizing and milling. Liquid metal may be atomized by techniques using gas, water, centrifugal force, or mechanical means. Particle sizes and shapes may vary both within and between methods of manufacture. All powder particles of similar chemical composition may not behave in the thermal spray gun in a manner identical to differently sized particles. It is necessary to characterize each powder in detail for successful reproduction. Materials should be spray tested using the thermal spray devices intended for their deposition.

**Particle Size Distribution.** Powders are a specific blend of various, predetermined sizes. The greater the sieve number the smaller the openings in the screen. A 20 mesh sieve has a standard opening of 850 microns, (22 $\mu$m), a 400 sieve is 38 microns (1.1 $\mu$m).

Consider a powder designated $-140 + 325$ mesh; that is, containing particles within the range of 106 microns (2.7 $\mu$m) to 45 microns (1.1 $\mu$m). A powder this broadly classified should be more fully characterized in terms of the several intermediate screens. Between the 140 and 325 screens are four others: 170, 200, 230 and 270. Particle sizes may have to be tailored to improve coating properties or deposit efficiency.

Standard methods exist for evaluating powders, such as ASTM specifications B214, *Sieve Analysis of Granular Metal Powders* and E11, *Wire-cloth Sieves for Testing Purposes.*

For powders finer than 50 microns (1.25 μm), a variety of procedures is available. Many are time consuming if absolute values are required. Approximate or empirical methods which give changes or trends are usually adequate.

Test methods which can be employed to test fine particle sizes are

(1) Direct measurement and counting, using an optical or electron microscope

(2) Automatic counting, using a "flying spot" microscope

(3) Methods based on settling or transport rates in still or moving currents of liquids or gases

(4) Methods dependent upon permeability to gases or to air

(5) Methods of measurement of specific surface, as for example by absorption of gases, liquids, or dyes

(6) Methods based upon centrifugal forces

(7) X-ray line-broadening techniques

In these methods of measurement, reproducible results are preferred even when they do not represent absolute values. Reference ASTM standard methods include B293, *Subsieve Analysis of Granular Metal Powders by Air Classification,* B212, *Apparent Density of Free-Flowing Metal Powders, and Special Technical Publications* No. 140 and No. 234 on Particle Size Measurement.

**Apparent Density.** Apparent powder density is an indication of particle size distribution and shape. Determinations are made by weighing the powder that occupies a specified volume either after it has fallen from a specified height from an orifice, or after being subjected to a specified method of tapping, shaking, or vibration. ASTM B212 covers the subject in detail. Although laboratory determination of apparent density provides essential information, it does not necessarily indicate powder flowability from a hopper through a feed tube to the spray nozzle.

**Rate of Flow.** Powder flow rates can be determined in the laboratory by measuring the rate at which a specific weight or volume of powder flows through a small orifice at the base of a funnel. Most instruments of this type are based upon the Hall flowmeter, and are specified in ASTM B213, *Flow Rate of Metal Powders.*

In determining powder flow properties, the equipment should be free of magnetic or static electrical fields which may influence the powder or the instrument.

When evaluating powders, it is imperative that they be dry. Drying may be accomplished using heat or dessicants. Whichever method is used, care should be exercised to avoid damaging the powder.

**Sprayability.** Testing of thermal spray materials includes determining the chemical and physical properties of each material and its behavior in the thermal spray gun. This sprayability testing includes feed and deposition characteristics, plus an evaluation of the deposited product.

Powders should be free flowing to prevent clogging of powder feeders, injectors, gun nozzles, or feed lines. Feed rate or spray rate is the measure of flowability. This is expressed as pounds per hour (lbs/hr) or grams per minute (g/min). When determining spray rate, equipment configuration and gas pressures and flows should be specified, as they would for the actual spray operation. To begin a deposit efficiency test, powder flow should first be started, and the powder feeder should reach full speed (rpm), achieving a smooth flow rate. Conditions should stabilize within ten to twenty seconds; powder then is collected in a clean container for a prescribed period, such as one or two minutes.

Efficiency may vary with target configuration, size, and amount of overspray. Deposition efficiency is the ratio of sprayed material adhering on a large flat surface compared to the amount of material sprayed. Material counted is confined within the borders of that surface. Deposit efficiency, expressed as a percentage, is the ratio of coating weight to the weight of powder sprayed.

**Example:**

A coated panel, minus the weight of that panel, weighs 1.4 ounces (40 grams). The time duration for deposition was two minutes; spray rate was 0.88 ounces (25 grams) per minute. Deposit efficiency is 80 percent, computed as follows:

$$\frac{1.4 \text{ oz. X } 100}{0.88 \text{ oz./min X } 2 \text{ min}} \text{ or } \frac{40\text{g X } 100}{25\text{g/min X } 2 \text{ min}} = 80\%$$

Ceramic rods are inspected for characteristics similar to wires; i.e., size, surface condition, roundness, and chemical integrity. Rods that are curved can break in the drive rolls causing binding or damage to the spray gun.

Rods are usually 3/16 or 1/4 in. (4.8 or 6.4 mm) in diameter, and are generally supplied in lengths from 18 to 24 in. (460 to 610 mm). Color varies with composition, as follows:

| Refractory | Color |
|---|---|
| Aluminum Oxide | White |
| Magnesium Aluminate | White |
| Zirconium Oxide | Tan |
| Zirconium Silicate | Tan |
| Chromium Oxide | Dark Green/Black |

Contaminated rods, especially when short or curved, should not be used since defective coatings or lowered productivity, or both, may result.

### 6.3.2 Gases

**Compressed Air.** Compressed air is the single most widely used gas in thermal spray coating applications. The compressed air utilized should be of proper quality to assure a reliable end product.

The Compressed Gas Association (CGA) *Commodity Specification for Air* (CGA No. G-7.1) presents limits on the impurities for atmospheric air (see Table 6.3.2A), and for air synthesized by blending oxygen and nitrogen. Atmospheric air contains a wide variety of trace contaminants such as water and oil.

Typical operating systems include in-line water and oil filters located between the compressor and the spray device. These should be inspected and cleaned periodically to assure uncontaminated dry air. This should be an established in-house **STANDARD PRACTICE.** Where greater control is required, techniques and instruments are available to determine dewpoint.

**Oxygen.** Four grades of gaseous oxygen, E through H, Table 6.3.2B, are satisfactory for flame spray applications. These tables are a digest of Compressed Gas Association (CGA) data as it applies to thermal spraying. Water content and dewpoint both affect coating quality. The user should establish in-house standard practices to maintain oxygen quality. Water content is determined as outlined under compressed air, Table 6.3.2A - Note 2, and by using a dewpoint analyzer, in which the temperature of a viewed surface is measured at the time frost first begins to form.

**Fuel Gases.** Refers to combustible gases used in the gas flame spray process. The more common gases are acetylene, hydrogen, propane, and methylacetylene propadiene. These gases should have a minimum purity of 99.6%. Acetylene should not have an excess of acetone vapors, because they lower the flame temperature and propagation rate. Acetylene should not be drawn off at a rate greater than 1.5% of the total gas available in the cylinder or at pressures greater than 15 psi (103 kPa).

**Plasma Gases.** Plasma forming gases include argon (A), nitrogen ($N_2$), and hydrogen ($H_2$). These gases are described in CGA specifications G-11.1 Commodity Specification for Argon, G-10.1 Commodity Specification for Nitrogen, and G-5.3 Commodity Specification for Hydrogen.

**Argon.** Table 6.3.2C lists the various commercial grades of argon, Grades D through H which are suitable for plasma spray applications. Gas constituents most often scrutinized are water content, dewpoint, and oxygen/nitrogen level.

**Table 6.3.2A**
**Grades of compressed air for thermal spray use**

| Limiting characteristics | Type I (Gaseous) Grade A | Grade B | Grade C | Grade D | Grade F |
|---|---|---|---|---|---|
| Contamination limits (Note 1) | atm | atm | atm/<br>19-23 | atm/<br>19-23 | atm/<br>19-23 |
| Water vapor | | none condensed | (Note 2) | (Note 2) | (Note 2) |
| Hydrocarbons (condensed) in mg/m$^3$ of gas at Ntp (Note 3) ppm | | none | 5 | 5 | 5 |
| Carbon monoxide ppm | | | 50 | 20 | 10 |
| Carbon dioxide ppm | | | | 1000 | 500 |

**Note 1.** The term "atm" (atmospheric) denotes the oxygen content (21%) normally present in atmospheric air. The numerical values denote oxygenlimits for synthesized air (% by volume).

**Note 2.** The water content of compressed air required for any particular grade may vary with the intended use from saturated to very dry. If a specific water limit is required, it should be specified as a limiting dewpoint or concentration in ppm. Dewpoint is expressed at one atmosphere absolute pressure in temperature °F (760 mmHg) or in temperature °C (101.3 kPa).

**Note 3.** Ntp=normal temperature and pressure. Other than major constituents, all gas limits are in parts per million (ppm).

**Note 4.** Grade B or better air, less than 50% relative humidity and oil free, is strongly recommended for cooling and the operation of equipment. Grade D or better is required for breathing apparatus. The user should insist on the driest, cleanest air obtainable with the available equipment when operated per manufacturer's recommendations.

### Table 6.3.2B
### Grades of gaseous oxygen for flame spray use

| Limiting characteristics* | Grade E | Grade F | Grade G | Grade H |
|---|---|---|---|---|
| Oxygen min. % | 99.5 | 99.99 | 99.995 | 99.995 |
| Inert gases, ppm |  | 45 | 30 | Balance |
| Odor | none |  | none |  |
| Water vapor, ppm | 6.3 | 10 | 3.0 | 1.0 |
| Dewpoint °F (°C) | −83 (−64) | −77 (−61) | −92 (−69) | −104 (−76) |
| Total hydrocarbons (as methane) |  | 20 | 14 | 1.0 |
| Methane | 40 |  | 10 |  |
| Ethane (and higher) | 3.0 |  | 3 |  |
| Ethylene | 0.2 |  |  |  |
| Acetylene | 0.05 |  | 0.05 | 0.05 |
| Carbon dioxide | 5.0 | 10 | 1.0 | 1.0 |
| Carbon monoxide |  | 10 | 1.0 | 1.0 |
| Nitrous oxide | 1.0 |  | 1.0 | 0.1 |
| Halogenated refrigerants | 1.0 |  | 1.0 |  |
| Solvents | 0.1 |  |  |  |
| By infrared | 0.1 |  |  |  |
| Permanent particulates | Type II 1.0 mg/L and none >1 mm |  | Type II (requires filtering) |  |
| Fibers (<40 units dia.) | Type II none >6 mm in length |  |  |  |

* Except for oxygen, all gas limits are in parts per million (ppm).

### Table 6.3.2C
### Grades of argon gas for plasma spray use

| Limiting characteristics* | Grade D | Grade E | Grade F | Grade G | Grade H |
|---|---|---|---|---|---|
| Argon min. % | 99.996 | 99.997 | 99.9975 | 99.998 | 99.999 |
| Water vapor, ppm | 14.3 | 10.5 | 5.3 | 3.5 | 1.5 |
| Dewpoint °F (°C) | −72 (−58) | −76 (−60) | −85 (−65) | −90 (−68) | −100 (−73) |
| Oxygen | 7 | 5 | 3 | 2 | 1 |
| Nitrogen | 15 | 20 | 15 | 10 | 5 |
| Hydrogen | 1 | 1 | 1 | 1 | 1 |
| Total hydrocarbons (as methane) | 5 | 3 | 1 | 0.5 | 0.5 |
| Carbon dioxide |  |  | 1 | 0.5 | 0.5 |

* Except for argon, all gas limits are in parts per million (ppm).

**Nitrogen.** The various grades of nitrogen used in plasma spraying are listed in Table 6.3.2D. Major impurities to be ascertained are water content, dew point, and oxygen. The nitrogen gas grade nominally used is H or better.

**Hydrogen.** Hydrogen grades are listed in Table 6.3.2E. Gases equivalent to Type I grades F to K, or Type II grades A thru D, are employed for plasma arc spraying. Of concern are water content/dewpoint and oxygen level.

**6.3.3 Miscellaneous Consummbles.** This category includes such items as masking aids, grit blast media, inks, paints, and sealers.

**Masking Aids.** Masking aids are divided into two groups - temporary and permanent. Permanent masking (generally hard tooling) is constructed to perform a singular task. Materials are hard rubber, silicon rubbers, and various metals including steel, brass, and copper. Metal masks should be bright, clean, and smooth. Chrome plate on steel helps to reduce overspray build-up. All masking should be inspected periodically for fit-up, dimensional correctness, and overspray build-up. This last check should assure that adherent overspray from a previous operation does not interfere with the deposition process.

Temporary masking includes tapes, inks, and paints. Tapes should be sufficiently resistant to both the roughening and spray operations. They should lie flat and not exhibit degradation during use. Paints and inks, usually applied to areas outside the roughened zone, should be capable of being easily removed, while not emitting fumes or vapors during the coating process.

**Grit Blast Media.** Abrasives for surface preparation and cleaning or roughening or both, are defined in military specification MIL-A-21380, *Abrasives for Blasting,* (see 3.2.6). Properties to be characterized and controlled are sharpness (angularity), size, and cleanliness.

Blast media should be recycled when practical due to their cost. Before reuse, the abrasive particles should be examined for sharpness with a 10 power magnifier. Inspect the media to assure that particles exhibit sharp, angular cutting edges. While refractory oxides will usually cleave along crystallographic planes, chilled iron grit will dull. This usually occurs after three to five cycles of use. Dulled blasting media should be discarded.

Since refractory oxide grains fracture along crystallographic planes and constantly present sharp cutting edges, the breaking down of the particles results in a finer media, eventually attaining the consistency of dust.

### Table 6.3.2D
### Grades of nitrogen gas for plasma spray use

| Limiting characteristics* | Grade H | Grade J | Grade K | Grade L | Grade M | Grade N | Grade P |
|---|---|---|---|---|---|---|---|
| Nitrogen min. % (Note 1) | 99.99 | 99.99 | 99.995 | 99.998 | 99.999 | 99.9985 | 99.999 |
| Water vapor, ppm | 11.4 | 3.5 | 16.2 | 3.5 | 1.5 | 1.5 | 1.5 |
| Dewpoint °F (°C) | −75(−59) | −90(−68) | −70(−57) | −90(−68) | −100(−73) | −100(−73) | −100(−73) |
| Hydrocarbons condensed | | 0.1 (wt/wt) | | | | | |
| Total hydrocarbons (as methane) | 5 | 3 | | | | 1 | |
| Oxygen | 50 | 50 | 20 | 10 | 5 | 1 | 1 |
| Hydrogen | | | | | | 1 | |
| Argon, neon helium | | | | | | 5 | |
| Carbon monoxide | | | | | | 1 | |
| Permanent particulates | Less than 1.0 mg/L | Less than 1.0 mg/L requires filtering | | | | | |

Note 1: Unless shown otherwise, $\%N_2$ includes trace quantities of neon and helium and small amounts of argon.

* Except for nitrogen, all gas limits are in parts per million (ppm).

**Table 6.3.2E**
**Grades of hydrogen gas for plasma spray use**

| Limiting characteristics* | Type I (gaseous) grades | | | | | Type II (liquefied) grades | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **F** | **G** | **H** | **J** | **K** | **A** | **B** | **C** | **D** |
| Min %$H_2$ | 99.95 | 99.95 | 99.99 | 99.995 | 99.995<br>(Note 1) | 99.995 | 99.995 | 99.9995 | 99.9997<br>(Note 1) |
| Water vapor | 32.0 | 7.8 | 3.5 | 3.5 | 1.5 | | | | |
| Dewpoint °F (°C) | −60(−51) | −80(−62) | −90(−68) | −90(−68) | −100(−73) | | | | |
| Oxygen | 10 | 10 | 5.0 | 5.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| Argon | | | | | | 9.0<br>48 | | | |
| Nitrogen | 400 | 400 | 25 | 20 | 20 | | 2.0 | 9.0<br>(Note 2) | 2.0 |
| Total hydrocarbons (as methane) | 10 | 10 | 5.0 | 1.0 | 0.5 | | 2.0 | | |
| Neon | | | | | | | | | |
| Helium | | | | | | | | 39 | |
| CO dioxide | 10 | 10 | | 0.5 | | 1.0 | | 1.0 | |
| CO monoxide | 10 | 10 | 10 | 1.0 | | | .5 | | |
| Inorganic and organic sulfur compounds | | | 2.0 | | | | | | |
| Hg vapor, ppb | | 4 | | | | | | | |

Note 1: May include up to 50 ppm neon and helium.

Note 2: Includes water.

*Except for hydrogen, gas limits are in parts per million (ppm). Mercury vapor is in parts per billion (ppb).

This is satisfactory for cleaning applications, but is unsuitable for roughening. Materials finer than 120 Mesh (125 μm) should be discarded. Inspection should be performed in accordance with ASTM B 214, *Standard Test Method for Sieve Analysis of Granular Metal Powders.*

The test for powder cleanliness is visual inspection. Grit should be examined for contaminants such as grease, oil, water, scale, and masking residues. If the contaminants cannot be removed, the blasting medium should be discarded. Blasting equipment with built-in sizing control features (cyclones, screens, fans) is preferred.

**Paints and Sealers.** Paints and sealers used with thermal spray coatings are of organic or inorganic base. Their uses are many and their compositions complex.

It is strongly recommended that the primary manufacturer be consulted for application and evaluation techniques.

## 6.4 Equipment

The certification or verification of equipment to apply coatings may be through calibration of meters and gages, or through demonstration of coating application. A combination of these methods proves most suitable.

Electrical meters are easy to calibrate. Remove the instrument from its mounting, install it in a test rig, and evaluate its performance against a known standard. Gas flow and pressure gages are similarly calibrated to a known standard.

## 6.5 Quality Control of Coatings

**6.5.1 Destructive Test Methods.** Adhesion is the most desirable property of a thermal spray deposit. Consequently, this section will concentrate heavily on that attribute. Also presented will be test methods for the determination of other coating properties which may be of interest.

**Standard Method of Adhesive/Tensile Strength Determination.** The adhesion of a thermal spray coating to a substrate is the principal property for determining its quality and application. Coatings on metal substrates are tested in a manner similar to that described by ASTM C633-79, *Standard Test Method for Adhesion or Cohesive Strength of Flame-Sprayed Coatings.* The test consists of coating one face of the substrate and then bonding a loading fixture to the coating with a suitable adhesive. The coating is then ground around the base of the loading fixture so that shear stresses are avoided during the tensile test of the assembly. The test is performed at room temperature due to high temperature limitations of the adhesives. The coatings should have greater than 0.015 in. (0.38 mm) thickness because of adhesive penetration into the coating. The tensile adhesion test is easy to perform and is useful in quality control for providing a ranking of various types of spray systems and resulting coatings. The mode of coating failure, shown in Fig. 6.5.1A, will be either adhesive or cohesive. An adhesive failure occurs when the entire coating separates from the substrate. True adhesive failure rarely occurs because of the rough nature of the substrate surface. Failure in this case takes place near the interface where the fracture surface exhibits areas devoid of coating. A fracture occurring entirely within the coating is of a cohesive nature.

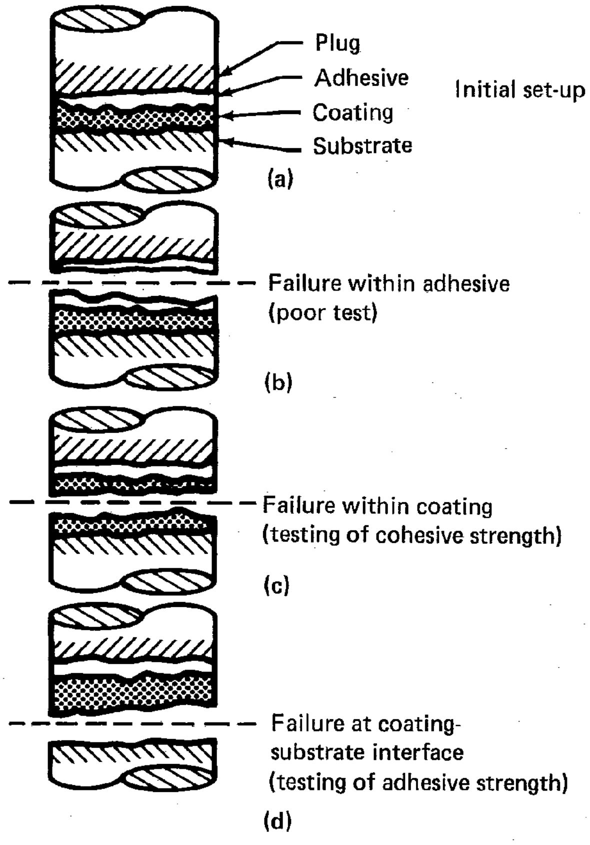


**Fig. 6.5.1A — Modes of coating failure**

The strength is found from the simple relation

$$UTS = L/A$$

Where UTS = cohesive or adhesive strength - force per unit of surface area
L = load to failure - force
A = cross-sectional area of specimen

Many other techniques (see Bibliography) have been devised based on this test method; they all suffer from the possibility of test error and disadvantages such as the following:

(1) If failure occurs within the adhesive only, the area within the coating is used in the calculation to find the stress at failure. This method is inaccurate because the test result has indicated either defective bonding of the sample or askew loading of the sample.

(2) The manner in which the coating is loaded is not typical of stresses observed during its service life.

(3) The value of the measurement is influenced by the symmetry of the experimental setup, and by the penetration of epoxy into pores of the coating.

(4) The adhesive must have a greater tensile strength than the coating.

(5) The elevated curing temperature of the adhesive may affect the adhesion of the coating, since the residual stress distribution may be altered.

(6) The fracture surface of a test specimen may exhibit both adhesive and cohesive failure. In this case, the tensile adhesion test yields only an average value when both of these failure modes act together. It does not establish which failure mode limits the strength of the coating.

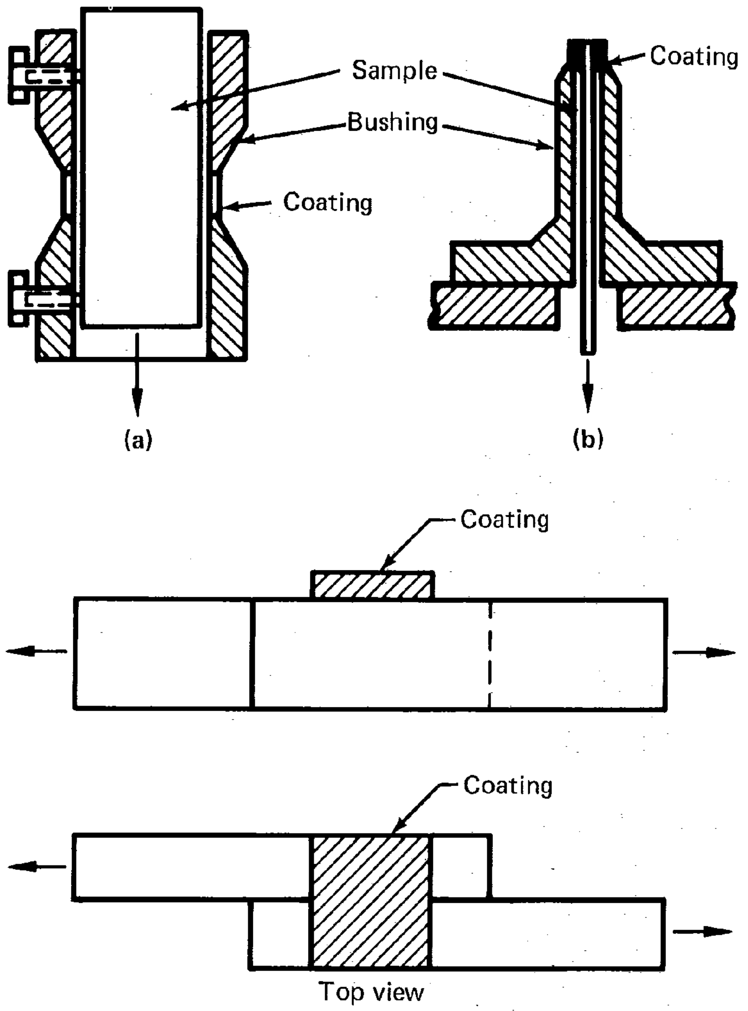
(7) The mechanism by which the coating structure contributes to the adhesion is not readily ascertained without a quantitative assessment of the various modes of adhesion. The tensile adhesion test does not readily permit such mechanistic studies.

(8) Flaws in the form of microcracks, porosity, and second phase inclusions within the coating will affect adhesion. The role of these microstructural features of the coating cannot be examined by the tensile adhesion test.

**Shear Strength.** Figure 6.5.1B shows experimental arrangements used to carry out shear tests. For example, (a) and (b) show how bushings transmit a shear load applied perpendicular to the specimen surface. The applied force causes the deposited splats to slide over the substrate surface so that an additional frictional force must be overcome. If this force exceeds that of particle adhesion, then the rupture of the deposit will appear to be cohesive. The results of the shear test are influenced by the machining of the test specimens, and a certain clearance must be maintained between the specimen and the bushings.

Figure 6.5.1B illustrates a method not affected by these problems, i.e., the coating is sheared in the as-sprayed condition.

**Compressive Strength of Coatings.** Samples are sprayed to a thickness of 0.33 in. (8.4 mm). From the



Two parallel plates with edge coated

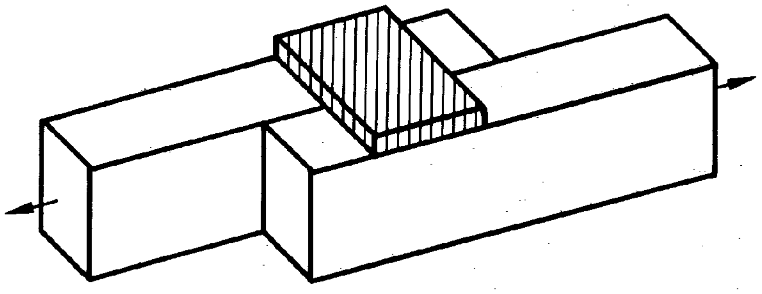


Fig. 6.5.1B — Specimens for shear tests

sprayed layer, minus the substrate, the individual specimens are machined. Specimen size is approximately 0.33 in. (8.5 mm) diameter by 0.20 in. (5 mm) thick. The sample is placed between a male and female die, and loaded in compression in a tensile machine. Compressive strength is given by the formula

$$Gd = F_d/A$$

where $Gd$ = compressive strength, psi (kPa)
$F_d$ = maximum compressive force, pounds (kg)
$A$ = initial area, sq. in. ($mm^2$)

In addition to the compressive strength, the percentage yield, Y, may be determined from

$$Y = (h_1 - h_2)/h_1$$

where $h_1$ = height of specimen before the test
$h_2$ = height of specimen after the test

Evaluation is by comparison of the results with each other and published data.

**Nonstandard Tests for Adhesion.** The resonance test is applied to coating deposits 0.040 in. (1 mm) or thicker that are sprayed onto shafts, or machine ways. The procedure involves tapping the deposit with a steel rod. The rod should be 3/8 to 1/2 in. (9.5 to 12.7 mm) in diameter and 4-3/4 in. (120 mm) long. The workpiece should be able to vibrate freely. A metallic sound represents a good bond, while a dull sound indicates that the coating deposit is partially adherent or totally detached.

The chisel test is used for spray deposits to determine whether base metal roughness is sufficient to ensure bonding. The chisel is placed with its bevelled edge at the interface of the coating and the substrate, and the head is struck. With a satisfactory bond, only small pieces of the coating are loosened, and there is no further separation of the deposit. With an inadequate bond, large sections of coating will come loose. A chisel test is also used for thin deposits; for example, 0.02 in. (.5 mm) or thinner corrosion-protection coatings. It is especially suitable as an in-process test. If random samples are taken from the workpiece, it is necessary to respray these areas after testing. The test involves cutting a 3/4 x 3/4 in. (19 x 19 mm) square in the deposit with a chisel having a bevelled, ground, sharp edge. The chisel is held in an angular position, 30 to 60 degrees to the work, so that damage is limited outside the square. The coating deposit is cut through until the substrate is exposed. The goal is to lift the spray deposit in the form of a square. The bond is adequate if the section is crumbly - smaller than 1/4 in. square (6 x 6 mm); it is inadequate if larger than 1/4 in. square (6 x 6 mm) pieces readily lift.

There are two adhesion tests of coated plastics. Plastics require different testing because of lower bond strengths [200-1000 psi (1.4-6.9 MPa)] and softer substrates. The first resembles the tensile test described, but uses a small hand operated pull tester (Fig. 6.5.1C).

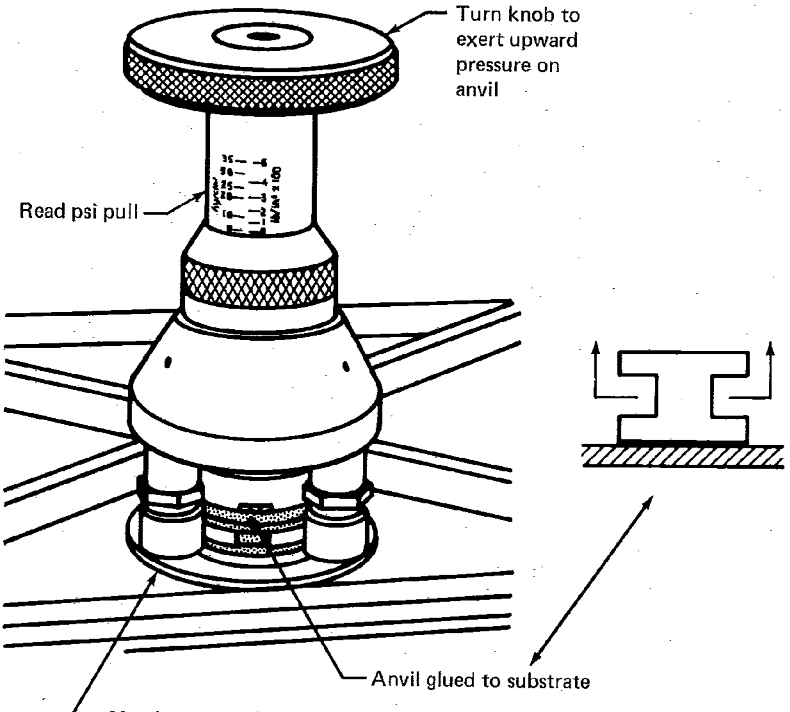


Fig. 6.5.1C — Pull tester for adhesion tests of coated plastics

A premachined anvil, 3/4 in. (19 mm) diameter, is epoxied to the coating and encased with a pressure ring to distribute stresses. The pull tester is then positioned and secured, exerting upward pressure against the anvil. The unit contains a calibrated spring and indicator which returns to its home position when the anvil is removed. A direct reading of the adhesive strength is the result. Failure of coated plastics is generally adhesive.

A scratch test, ASTM D3359-78, *Standard Methods for Measuring Adhesion by Tape Test,* is also used. It consists of scoring a cross hatch pattern on the sprayed surface, overlaying it with adhesive tape and then pulling the tape away (Fig. 6.5.1D). Examination under a 10x pocket microscope indicates the percentage of the coating that has been lifted.

In many plastic coating applications, such as shielding, 200 psi (1.4 MPa) or better is deemed satisfactory, and if it meets the requirements of ASTM D3359-Method B, acceptance is assured.

Both the tape and scratch tests may be spray repaired and thus, are considered nondestructive. An additional advantage of these tests is that they may be performed on actual hardware, not sample coupons.

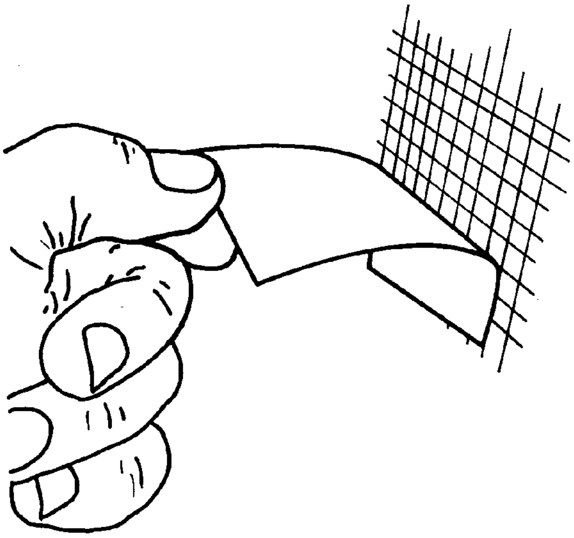


**Fig. 6.5.1D — Scratch test, ASTM D3359-78, Method B, Standard Methods for Measuring Adhesion by Tape Test**

**Cohesive Strength.** Cohesive strength is a measure of interparticle attraction. It is determined by using a free standing, sprayed specimen; that is, a sample of coating deposit detached from its substrate. This sprayed deposit is machined to a standard tensile specimen size and tested in a conventional manner.

The heterogenous structure of sprayed coatings causes them to be less hard than cast or wrought stock. The hardness of individual particles that compose the coating is higher than the overall coating. Hardness of the coating is referred to as its macrohardness; whereas particle hardness, accomplished using light loads and magnifiers to read the impressions left by those loads, is the microhardness.

**Macrohardness Testing.** The macrohardness test generally utilized is the Rockwell Superficial Hardness Test. Indentor loads are light and spread over the largest area possible. The Rockwell 15Y and 15W scales are recommended for softer materials.

In determining macrohardness values, coating thickness is of the utmost importance. Table 6.5.1 is provided as a guide. All thicknesses are after grinding or machining.

**Table 6.5.1**
**Minimum thickness requirements for Rockwell hardnesses determination**

| Rockwell Scale | Thickness (in.) | (mm) |
|---|---|---|
| 15N | 0.015 | 0.40 |
| 30N | 0.025 | 0.64 |
| 45N | 0.035 | 0.90 |
| A | 0.040 | 1.0 |
| B | 0.060 | 1.6 |
| C | 0.070 | 1.8 |
| D | 0.050 | 1.3 |
| 15Y | 0.070 | 1.8 |
| 15W | 0.070 | 1.8 |

The sceleroscope (rebound) test is used for measuring steel coatings with thicknesses greater than 0.040 in. (1 mm). The tester is brought into contact with the machined finish coating. Release of a lock causes a small rebounding hammer to contact the test specimen. Rebound of the hammer actuates the pointer on a scale. The values indicated by the pointer may be converted into Rockwell or Brinell hardness values. This test is used for comparison and verification only.

**Microhardness Testing.** Two types of microhardness testing are the Knoop test and the Vickers or Diamond Pyramid Hardness (DPH) test. The Knoop Hardness Number (KHN) is measured with a rhomboid diamond indentor under loads from 10 to 1000 grams. A 50 gram load is preferred for determining the hardness of single particles, as the light load aids in confining the impression within the boundaries of the splat.

**The Diamond Pyramid Hardness** (DPH) or **Vickers Test** finds application in evaluating deposits of hard materials, especially carbides. The load used is 300 grams. The impression is spread over several particles, and the hardness is the ratio of the load to the area of the impression, computed from the length of the diagonals of the square impression.

The **Hoffman Scratch Hardness Test** is a tool for evaluating the abradability of clearance control coatings. A loaded stylus is drawn across an as-coated surface, minimum thickness 0.035 in. (0.89 mm), to scratch its surface. The width of the scratch indicates abradability; the wider the scratch, the less cohesive the coating and the greater the abradability.

A **file scratch test** is another indicator for estimating the relative hardness of sprayed steel deposits. A sharp flat file should be used. It is helpful to make direct comparison with test bars of known hardness. Evaluation is based upon the fact that, with extremely hard coatings, the file fails to bite, but it easily bites on moderately hard coatings.

**Wear Tests.** The types of wear tests usually performed on industrial sprayed coatings are metal-to-metal lubricated sliding wear, dry sand rubber wheel abrasion, and solid particle erosion tests.

**Sliding wear tests** are useful for determining metal-to-metal wear of various mating combinations. Figure 6.5.1E shows the principle of operation of a typical test machine. The test specimen, a 0.80 in. x 2.33 in. (20 x 60 mm) sample, is machined from a spray coating of 1/4 in. (6 mm) thickness. The specimen surfaces are ground parallel to each other. Evaluation is by comparison with homogenous cast or wrought materials such as aluminum and steel. The same set-up without lubrication may be used for dry sliding wear.

**Abrasion tests** provide information on the ability of materials to resist erosion by hard particles. In the standard dry sand rubber wheel test, shown in Fig. 6.5.1F, an abrasive of specific grit size is applied between the test specimen and a rotating wheel, with a rubber rim of specified hardness.[1] Specimens are weighed before and after the test. The weight loss is converted to volume loss in cubic inches.

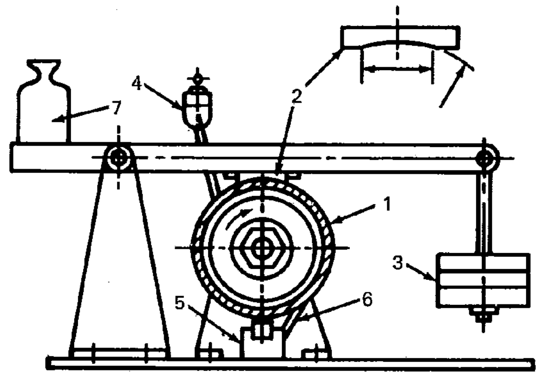
**Erosion tests** utilize a small grit blaster with an alumina nozzle of known diameter. A predetermined quantity of 50 micron (1.25 $\mu$m) alumina powder is blasted against the specimen, using an air flow of 25 CFH (12 L/min) until the powder is consumed. The elapsed time is nominally 100 seconds. The depth of erosion is measured. Erosivity is calculated from

$$E = t/D$$

where E = erosivity

t = time in seconds to spray the measured amount of alumina

D = depth of erosion



1. Test ring
2. Test specimen
3. Loading weights
4. Drip-feed lubricator
5, 6. Oil scrapers
7. Balance weight for lever arm

**Fig. 6.5.1E — Principle of operation of the metal-to-metal lubricated surfaces sliding wear testing machine**

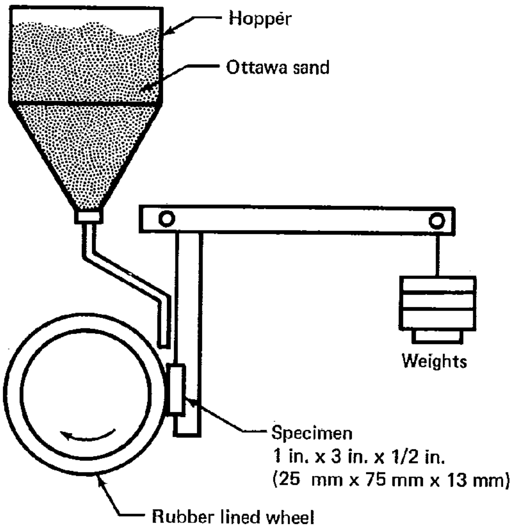


**Fig. 6.5.1F — Schematic diagram of test apparatus for dry sand rubber wheel abrasion test**

**Fatigue Tests.** Fatigue tests are used to determine the effects of

- new methods of surface preparation
- new materials
- application process changes

The coatings or processing should be applied to standard base metal test specimens, whether for high or low cycle fatigue (HCF, LCF). Evaluation is based upon previously established fatigue curves and data.

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[1] Refer to ASTM G65-1981, *Practice for Conducting Dry Sand/Rubber Wheel Abrasion Test*, Philadelphia: American Society for Testing Materials.

**Corrosion and Oxidation Tests.** Resistance to corrosion and oxidation is tested to estimate the life of a particular coating in a given working environment. These are accelerated tests, such as ASTM B117, *Salt Spray (Fog) Testing*. The test environment contains an anticipated contaminant, such as hydrocarbons, salts, sulfur, etc. Test temperature is controlled. In most cases, these are in-house tests designed for a particular product which is engineered to perform under specific conditions.

**Thermal Shock.** Two simple tests for thermal shock are as follows:

(1) A coated sample is heated and rapidly quenched into cold water.

(2) One side of a coated sample is heated while the opposite side is cooled.

The former is an empirical test to evaluate differences in coefficient of thermal expansion; the latter is excellent for ascertaining spalling characteristics of sprayed ceramic coatings, especially thermal barriers. Test temperatures, times, and cycles will vary with testing site, coating, and use.

**Metallographic Evaluation.** The subject of preparation of samples for metallographic evaluation is well documented, but there are some special considerations required for thermal spray coatings. All efforts are directed to preventing the formation of artifacts and producing a sample suitable for studying the degree of microporosity, oxide inclusions, oxide layers, structural composition, coalescence, the effect of surface roughening, and diffusion layers. Micrographs of thermal spray deposits reveal the effects of such spraying conditions as energy setting, spray distance, and atomization.

To determine the level of oxide inclusions and degree of porosity, it is necessary to study both transverse sections and surface samples from segments of the spray deposit. Examination is at a magnification of 100x or greater. The junctions of the spray deposit and base metal are also examined at high magnification. For the examination of diffusion layers, very high magnifications, usually 1000x, are used. Evaluations of the roughened substrate are simplified by etching the spray deposit immediately prior to viewing. Delayed examination gives false indications, as it is not possible to completely remove the etchant from coating pores, and the section tends to be altered with time as the etch leeches out. The same undesirable reactions follow electrolytic polishing. Avoid ultrasonic cleaning, as it causes severe particle pull-out.

Preparation time for grinding and polishing of sections should be as short as possible. This applies particularly to soft materials (e.g., lead, zinc, aluminum, and copper). For hard materials, diamond polishing abrasives are recommended.

In addition to visual inspection at low magnifications of 10x to 50x, it is possible to make quantitative evaluations of voids, oxide inclusions, and other discontinuities. Measurements of particle sizes, thickness, and diffusion layers may be made with a high degree of accuracy. The quantitative television microscope (QTM) is particularly suited for determining percentages of oxides and porosity.

**Coating Density.** Coating density is determined by machining a measurable volume of sprayed coating so that all surfaces are flat and parallel. The volume is calculated and the weight recorded. Coating density is as follows:

$$D = W/V$$

where:

D = density
W = weight
V = volume

To ascertain how coating density compares with the density of the original material, the actual density is divided by the theoretical values, and expressed as a percent.

**Miscellaneous Physical Tests.** Included in miscellaneous physical tests are thermal expansion, electrical resistivity, shrinkage, residual stress, and thermal conductivity. Testing in these areas has been relatively limited.

**6.5.2 Nondestructive Evaluation.** The nondestructive evaluation (NDE) of thermal spray coatings is primarily confined to studies of thickness, roughness, visual appearance, and liquid penetrant tests. Well established procedures use calipers, micrometers, height and thickness gages, profilometers and replica techniques, magnifiers, stereoptic microscopes, and liquid penetrants. Sophisticated techniques for detecting thermal spray properties are currently being evaluated. Many of these NDE concepts are being pursued in laboratories, and they will eventually play an important role in the application of new examination technology. These fall into several major groups, based on thermal, light, sound, magnetic, and electrical measurements.

**Thickness Gages.** The thermal spray industrial standard is the magnetic thickness gage. This is a direct reading gage that measures the thickness of any nonmagnetic coating on an iron or steel base. It is held against the work, and the thickness of the nonmagnetic coating appears on a dial. The gage reports the distance that has interrupted its magnetic circuit.

Coating thickness on nonconductive surfaces can be measured using sensitive resistance measuring equipment. The instrument reads directly in milliohms, which are converted to coating thickness. Care must be taken when operating within 1/2 in. (12.7 mm) of sharp angles and edges; these drastically affect readings. A calibration curve can be generated using samples of known thicknesses. Zinc on plastic yields typical values (Table 6.5.2).

### Table 6.5.2
### Resistance vs. thickness for zinc coatings on plastic

| Thickness | | Resistance |
|---|---|---|
| mils | (mm) | milliohms |
| 1 | (0.025) | 6.08 |
| 5 | (0.127) | 4.98 |
| 10 | (0.25) | 2.51 |
| 18 | (0.20) | 1.98 |
| 30 | (0.76) | .094 |
| 100 | (2.5) | .054 |
| 200 | (5.1) | .041 |
| 300 | (7.6) | .033 |

**Thermal Methods to Observe Lack of Bond.** The rate at which the coating surface loses heat depends on two principle factors: (1) the conductivity of the coating, and (2) its thermal contact with the substrate. Any physical differences between one part of the coating and the next, or any change in the bonding, will therefore affect the surface temperature and be detectable. There are three methods of detecting small changes of surface temperature: infrared (IR) camera, liquid crystals, and thermographic paints. They presently are being applied to laminates, honeycombs, and adhesive bonds.

Infrared cameras are based on liquid nitrogen-cooled indium antimonide IR detectors. They display a television-type picture with sensitivity of 3°F (1.6°C) at 86°F (30°C). Picture storage and slow playback facilities for the analysis of rapid events are available, as are various lens systems for distant or close-up work. Success depends upon the rapid response and storage capability of the camera system. A pulse of heat may be applied to the coating, and the development of the resultant temperature pattern may be observed; or a temperature gradient may be maintained through the depth or across the face of a coating. Unbonded surfaces heat up more rapidly than bonded areas. Nevertheless, small variations in surface temperature are transient, and too fast for the eye to follow; hence, the necessity for system storage and slow playback. Temperatures both above and below room ambient and different geometries are being studied. The tests are relative and not diagnostic because nonstandard patterns of heat flow could result from a number of different causes. Using different heat injection positions, an experienced operator will come to associate certain patterns with certain defects. The best use of thermal methods for analysis is in repetitive work.

Liquid crystals are long chained organic compounds which display a degree of order in their molecular arrangement. The ordered state exhibits various optical properties not shown by a disordered state. The order/disorder change is brought about by thermal stress. Liquid crystals are available as paints or in tape form. This NDE method is presently applied only in examining thermal insulation coatings on low mass components.

Thermographic paints are phosphors activated by ultraviolet light. The phosphorescence is subsequently quenched by heat, over a narrow range of temperature, and the range of operation can be tailored to suit a particular requirement. They offer the possibility of direct application to a coating so that spatial and thermal resolution can be achieved.

**Light Methods to Observe Lack of Bond.** The application of interferometry and holography to sprayed coatings on metal components is in the laboratory stage. They are capable of detecting very small changes in the surface of an object, such as a faulty section of a coating. Light methods require more extensive development before they can detect the subtle defects that can cause a poor bond.

**Sound Measurements.** Acoustic methods generate information relating to mechanical properties. The transission of sound through a solid is closely linked with its soundness. Ultrasonic pulse-echo techniques can successfully detect areas of poor bonding. The method is under development.

Acoustic resonance instruments scan through a range of frequencies and pick up the resonance levels, yielding information regarding unbonded areas or other flaws. Relatively thin layers of coatings sprayed onto thicker and denser metallic substrates are insensitive to this technique.

Release of strain energy in a solid, resulting in acoustic emissions, may be detected by a transducer at the surface. Application to sprayed coatings will require comparing emitted noises with those of an established standard.

**Other NDE Methods.** Eddy Current Testing is an electromagnetic method in which small currents are induced in a material. The flow patterns indicate inhomogeneities to a nearby coil for subsequent electronic processing. Eddy currents in ground-finished surfaces can reveal coating flaws.

Magnetic Flux Analysis employs alternating field and search coils to perform a complex analysis of the stray flux field. This method is useful only on ferromagnetic surfaces. It is a non-contacting method and does not rely on surface smoothness.

# Chapter 7

# Finishing of Coatings

### Chapter Committee

*J. Ritchie, Chairman*
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# Chapter 7

# Finishing of Coatings

## 7.1 Introduction

The means of finishing thermal sprayed metals, ceramics, and cermets is an area of varied opinion and practices. The many methods of finishing coatings have produced the 'proper' methods, procedures, and techniques that should be used to yield specific results. This information refers to surfaces that need further finishing. In many instances, as in corrosion applications, no additional operation is necessary. Plasma transferred arc and fused coatings have more strength and are more homogeneous, and thus may not require the degree of special precautions outlined here.

The machining of coatings is troublesome for the inexperienced operator. Materials, that are abrasion resistant, are difficult to grind. The structure of the sprayed mass is porous; highly reflective finishes are difficult to achieve. The bond between the particles is primarily mechanical; therefore, individual particles can pull out if cutting pressures are excessive. Spray coatings are composed of well defined particles and have poor thermal conductivity compared to the same material in wrought form. Heat transfer away from the point of grinding is slow. The accepted methods, practices, and techniques used to grind and polish materials in their wrought form do not apply to the same materials when sprayed.

## 7.2 Finishing Methods

Thermal spray coating deposits can be ground and finished in many ways. The method chosen can range from simple hand polishing operations, to hand grinding with coated abrasive belts, or to more complex machining, such as the use of precision grinders. Factors which influence the choice of finishing method include type of material to be ground, shape of part, finish and tolerance required, type of equipment available, and economics. Generally, with most spray applications, the finer and more uniform the material applied the better the final finish.

**7.2.1 Hand Stoning, Buffing, Polishing.** Hand stoning, buffing, and polishing can be accomplished with an abrasive stone, stick, wheel, or paper. The surface finish of an as-sprayed deposit can be greatly improved in smoothness and appearance with minimal stock removal.

Hand stoning and buffing develop the most improved surface finish on soft metals. These metals, in addition to aluminum and zinc, are readily polished to a bright finish. The abrasive device is rapidly loaded, which requires frequent dressing. A coarse abrasive should be used initially, followed by progressively finer abrasives until the desired smooth finish is achieved. The type of material involved will largely dictate the specific sizes.

Carbon and stainless steel coating deposits are very difficult to hand stone or buff to a good finish.

Ceramics and cermets are hand stoned to a light finish with the proper choice of abrasives. This method is ideally suited for parts with unusual contours that otherwise would be difficult to finish.

While these are the easiest methods of finishing, care should be taken to avoid breaking through coating edges and, consequently, it may be difficult to maintain a uniform thickness.

**7.2.2 Tumbling and Burnishing.** When smooth finishes are required on a large quantity of very small parts or on parts with unusual contours, a tumbling or burnishing procedure can be cost effective. In tumbling, the parts are placed in a vibrating or rotating tub containing an abrasive medium and water. The interaction of the abrasive and parts polishes the coating. By selecting the proper abrasive and vibratory time cycle, specific finishes can be attained. Burnishing is accomplished in much the same manner as tumbling. Instead of trying to abrade the surface, hard metal balls are used to compress the surface. The smoothness of the resultant coating is a function of pressure and frequency of ball-to-part contacts.

**7.2.3 Abrasive Belt Grinding and Polishing.** Sprayed metals and ceramic coatings can be effectively ground and polished with coated abrasive belts. Abrasive belts are used to improve the surface produced by a prior operation such as single point turning. Coated abrasive belts are used to perform the entire grinding and finishing operation. Developments in backing materials and in grain design have produced strong waterproof belts which are sharp and durable. Belts made from these materials produce excellent finishes with high stock removal rates. Abrasive belts provide several advantages over other grinding media; they cut without overheating, do not require dressing, and can be rapidly changed when worn. Belt costs are lower than comparable machining costs.

When grinding and polishing with coated abrasive belts, the part is fixtured or positioned in a lathe. The part is either traversed or rotated under the belt head. Belt speeds are generally 6,000 to 7,000 sfpm (30 to 35 m/sec). Part speeds range from 25 to 200 sfpm (0.13 to 1.0 m/sec), depending on part size, type coating, and type and size abrasive. Coarse grit belts are used for rapid stock removal; whereas, finer belts are used to improve finishes. Out-of-roundness in the coating is very difficult to remove by belt polishing, and alternate methods should be employed.

### 7.2.4 Machining

**Shafts, Tubing, and Cylindrical Shapes.** Machining of a sprayed coating involves special techniques. Advances in the cutting tool industry, together with faster, more precise, rigid machinery has, in recent years, opened up a new era of machining. This is particularly true of the harder tool materials such as ceramics, carbides, and cermets.

Carbide tools are generally used on machinable thermal spray coatings. Tool angles, and surface speeds and feeds are critical in the success of machining these coatings. Improper tool angles and tool pressure can result in excessive particle pull-out and destruction of the coating substrate bond. Properly sharpened tools can machine hard fused coatings with relative ease.

Machining of a spray coating starts with removal of the heavy overspray at the end of the coated area. Rough machining of the coating can be accomplished at the same or slightly slower speeds (surface feet per minute) and with approximately twice the amount of feed (inches per revolution) of finish machining. The depth of cut can range up to 0.030 in. (0.76 mm) thickness. Approximately 0.005-0.010 in. (0.13 - 0.25 mm) on the radius should be left for finishing. Removal may require multiple passes. See Tables and Figs. 7.2.4A and 7.2.4B for recommendations concerning carbide and high speed tools.

A properly sharpened cutting tool will wear flat at the contact point. This flattening has the effect of smearing the metal and can actually provide a better finish than would result with a sharp tool with a radius. However, should this flattening become excessive, heat buildup increases rapidly, and particle pull-out occurs. Excessive heat buildup can result in catastrophic coating failure.

The newer cutting tool materials, such as boron nitride, oxide coated carbides, ceramics, and diamonds enable very hard metals to be successfully machined at very fast metal removal rates. For optimum results, when using these cutters, the use of rigid machinery is mandatory.

**Flat Surfaces and Other Shapes.** Not all machining is performed on cylindrical parts in lathes. Machining of flat surfaces demands close attention to the use of a cutting tool, especially at the corners or edges of a coating. It is possible to lift a coating at an edge if care is not exercised. Minimal amounts of stock should be removed with each cut.

**7.2.5 Grinding.** Material finish and tolerance requirements may dictate grinding as the only practical means of finishing thermal sprayed parts. Machines commonly used are outside diameter grinders (cylindrical and centerless), surface grinders (horizontal and vertical spindle), and internal grinders.

When using any abrasive medium to grind and polish, it is important to realize that thermal sprayed coatings are vastly different from the same material in wrought or cast form. If wheels of excessive hardness are used, or if they do not cut freely, individual particles can be pulled from the coating surface; or worse, the entire deposit can delaminate from the substrate. Because the ductility of sprayed materials is low, excessive grinding pressure may cause the surface particles to shift or be displaced. With a mechanical bond, heat conduction away from the point of tool contact is not as efficient as when grinding similar wrought materials. Unsatisfactory conditions will result if improper wheels and grinding techniques are used.

## 7.3 Grinding Wheel Selection

The selection of a grinding wheel involves the coating, its hardness and structure, the amount of stock removal, the size of the part, surface finish specifications, and the type, condition and capabilities of the grinding machine. Table 7.3 gives grinding wheel recommendations for selected thermal spray materials. Four rules will aid in grinding wheel selection.

**Rule I. ALWAYS USE THE SHARPEST WHEEL POSSIBLE. SHARP WHEELS CUT RAPIDLY WITHOUT OVERHEATING.** Wheel sharpness is governed by several factors, among which are the type of abrasive grain and the grit size.

**Grain Type.** Four major grain types are used in the manufacture of grinding wheels; the two most commonly used for grinding thermal sprayed surfaces are silicon carbide and diamond. Silicon carbide is chosen for its

### Table 7.2.4A
### Carbide tools — machining recommendations

| Code no. (Chapter 5) | Material | Speed (Surface ft/min) | | Feed (in./rev.) | |
|---|---|---|---|---|---|
| | | Rough | Finish | Rough | Finish |
| **Iron Base** | | | | | |
| 1b | Mn .5; C.10; Fe bal. | 75-100 | 75-100 | .006 | .003 |
| | Mn .6; C.23; Fe bal. | 50-75 | 50-75 | .004 | .003 |
| 4b | C.35; Mn .5; Cr 13.0; Si .5; Fe bal. | 30-40 | 30-40 | .004 | .003 |
| 5b | C.15; Mn 8.5; Ni 5.10; Cr 18.0; Si 1.0; Fe bal. | 100-125 | 125-175 | .006 | .003 |
| 6b | C.80; Mn .7; Fe bal. | 30-40 | 30-40 | .004 | .003 |
| 7b | C.04; Mn 2.0; Ni 4.0; Cr 1.5; Mo 1.5, Fe bal. | | | | |
| **Aluminum Base** | | | | | |
| 3d | 99.0+Al | 250-300 | 300-350 | .004 | .002 |
| **Copper Base** | | | | | |
| 1d | Al 9.5; Fe 1.0; Cu bal. | 250-300 | 300-350 | .006 | .003 |
| 4d | 99.0+C | 250-300 | 300-350 | .006 | .003 |
| 8d | Cu 66; Zn 34 | 250-300 | 300-350 | .006 | .002 |
| 9d | Cu 90; Zn 10 | 250-300 | 300-350 | .006 | .002 |
| 10d | Cu 95; Sn 5 | 250-300 | 300-350 | .006 | .003 |
| 11d | Cu 58.2; Sn .8; Fe .75 Mn .25; Zn bal. | 250-300 | 300-350 | .006 | .003 |
| **Nickel Base** | | | | | |
| 1c | Ni 99.5 | 200-250 | 250-300 | .004 | .002 |
| 11c | Ni 67; C.15; Si .1; Fe 1.5; Mn 1.0; Si .1 Al .1, Cu bal. | 200-250 | 250-300 | .004 | .002 |

## S.I. Soft Conversion
## Table 7.2.4A
## Carbide tools — machining recommendations

| Code no. (Chapter 5) | Material | Speed (Surface m/s) | | Feed (mm/rev.) | |
|---|---|---|---|---|---|
| | | Rough | Finish | Rough | Finish |
| **Iron Base** | | | | | |
| 1b· | Mn .5; C.10; Fe bal. | 0.38-0.51 | 0.38-0.51 | 0.15 | 0.08 |
| | Mn .6; C.23; Fe bal. | 0.25-0.38 | 0.25-0.38 | 0.10 | 0.08 |
| 4b | C.35; Mn .5; Cr 13.0; Si .5; Fe bal. | 0.15-0.20 | 0.15-0.20 | 0.10 | 0.08 |
| 5b | C.15; Mn 8.5; Ni 5.10; Cr 18.0; Si 1.0; Fe bal. | 0.51-1.5 | 0.63-0.89 | 0.15 | 0.08 |
| 6b | C.80; Mn .7; Fe bal. | 0.15-0.20 | 0.15-0.20 | 0.10 | 0.03 |
| 7b | C.04; Mn 2.0; Ni 4.0; Cr 1.5; Mo 1.5, Fe bal. | | | | |
| **Aluminum Base** | | | | | |
| 3d | 99.0+Al | 1.3-1.5 | 1.5-1.8 | 0.10 | 0.05 |
| **Copper Base** | | | | | |
| 1d | Al 9.5; Fe 1.0; Cu bal. | 1.3-1.5 | 1.5-1.8 | 0.15 | 0.08 |
| 4d | 99.0+C | 1.3-1.5 | 1.5-1.8 | 0.15 | 0.08 |
| 8d | Cu 66; Zn 34 | 1.3-1.5 | 1.5-1.8 | 0.15 | 0.05 |
| 9d | Cu 90; Zn 10 | 1.3-1.5 | 1.5-1.8 | 0.15 | 0.05 |
| 10d | Cu 95; Sn 5 | 1.3-1.5 | 1.5-1.8 | 0.15 | 0.08 |
| 11d | Cu 58.2; Sn .8; Fe .75 Mn .25; Zn bal. | 1.3-1.5 | 1.5-1.8 | 0.15 | 0.08 |
| **Nickel Base** | | | | | |
| 1c | Ni 99.5 | 1.0-1.3 | 1.3-1.5 | 0.10 | 0.05 |
| 11c | Ni 67; C.15; Si .1; Fe 1.5; Mn 1.0; Si .1 Al .1, Cu bal. | 1.0-1.3 | 1.3-1.5 | 0.10 | 0.05 |

## Table 7.2.4B
## High speed steel tools — machining recommendations

| Code no. (Chapters) | Material | Tool no. (Fig. 7.2.4B) | Speed (surface ft) per min. | Feed (in./rev.) |
|---|---|---|---|---|
| **Iron Base** | | | | |
| 1b | Mn .5; C.10; Fe bal. | 3 | 75-100 | .003 - .005 |
| | Mn .6; C.23; Fe bal. | 2 | 50-75 | .003 - .005 |
| 5b | C.15; Mn 8.5; Ni 5.10 Cr 18; Si 1.0; Fe bal. | 3 | 100-125 | .003 - .005 |
| 7b | C.04; Mn 2.0; Ni 4.0; Cr 1.5; Mo 1.5; Fe bal. | 2 | 50-75 | .003 - .005 |
| **Copper Base** | | | | |
| 1d | Al 9.5; Fe 1.0; Cu bal. | 3 | 100-125 | .003 - .005 |
| 4d | 99.0 + Cu | 3 | 100-125 | .003 - .005 |
| 8d | Cu 66; Zn 34 | 2 | 100-125 | .003 - .005 |
| 9d | Cu 90; Zn 10 | 3 | 100-125 | .003 - .005 |
| 10d | Cu 95; Sn 5 | 1 | 100-125 | .003 - .005 |
| 11d | Cu 58.2; Sn .8; Fe .75 Mn .25; Zn bal. | 1 | 100-125 | .003 - .005 |
| **Nickel Base** | | | | |
| 1c | Ni 99.5 | 3 | 100-125 | .003 - .005 |
| 11c | Ni 67; C.15; Fe 1.5; Mn 1.0; Si .1; Al .1 Cu bal. | 3 | 100-125 | .003 - .005 |
| **Miscellaneous** | | | | |
| 3d | 99.0 + Al | 3 | 150-200 | .003 - .005 |
| 7d | 99.0 + Zn | 3 | 150-250 | .005 - .007 |
| 14d | 90 Sn; 7Sb; 3 C | 3 | 150-250 | .005 - .007 |
| 16d | 99.0 + Sn | 3 | 150-250 | .005 - .007 |

## S.I. Soft Conversion
## Table 7.2.4B
## High speed steel tools — machining recommendations

| Code no. (Chapters) | Material | Tool no. (Fig. 7.2.4B) | Speed Surface m/s | Feed (mm/rev.) |
|---|---|---|---|---|
| **Iron Base** | | | | |
| 1b | Mn .5; C.10; Fe bal. | 3 | 0.38-0.51 | 0.08-0.13 |
| | Mn .6; C.23; Fe bal. | 2 | 0.25-0.38 | 0.08-0.13 |
| 5b | C.15; Mn 8.5; Ni 5.10 Cr 18; Si 1.0; Fe bal. | 3 | 0.51-0.20 | 0.08-0.13 |
| 7b | C.04; Mn 2.0; Ni 4.0; Cr 1.5; Mo 1.5; Fe bal. | 2 | 0.25-0.38 | 0.08-0.13 |
| **Copper Base** | | | | |
| 1d | Al 9.5; Fe 1.0; Cu bal. | 3 | 0.51-0.20 | 0.08-0.13 |
| 4d | 99.0 + Cu | 3 | 0.51-0.20 | 0.08-0.13 |
| 8d | Cu 66; Zn 34 | 2 | 0.51-0.20 | 0.08-0.13 |
| 9d | Cu 90; Zn 10 | 3 | 0.51-0.20 | 0.08-0.13 |
| 10d | Cu 95; Sn 5 | 1 | 0.51-0.20 | 0.08-0.13 |
| 11d | Cu 58.2; Sn .8; Fe .75 Mn .25; Zn bal. | 1 | 0.51-0.20 | 0.08-0.13 |
| **Nickel Base** | | | | |
| 1c | Ni 99.5 | 3 | 0.51-0.20 | 0.08-0.13 |
| 11c | Ni 67; C.15; Fe 1.5; Mn 1.0; Si .1; Al .1 Cu bal. | 3 | 0.51-0.20 | 0.08-0.13 |
| **Miscellaneous** | | | | |
| 3d | 99.0 + Al | 3 | 0.76-1.0 | 0.08-0.13 |
| 7d | 99.0 + Zn | 3 | 0.76-1.0 | 0.13-0.18 |
| 14d | 90 Sn; 7Sb; 3 C | 3 | 0.76-1.0 | 0.13-0.18 |
| 16d | 99.0 + Sn | 3 | 0.76-1.0 | 0.13-0.18 |

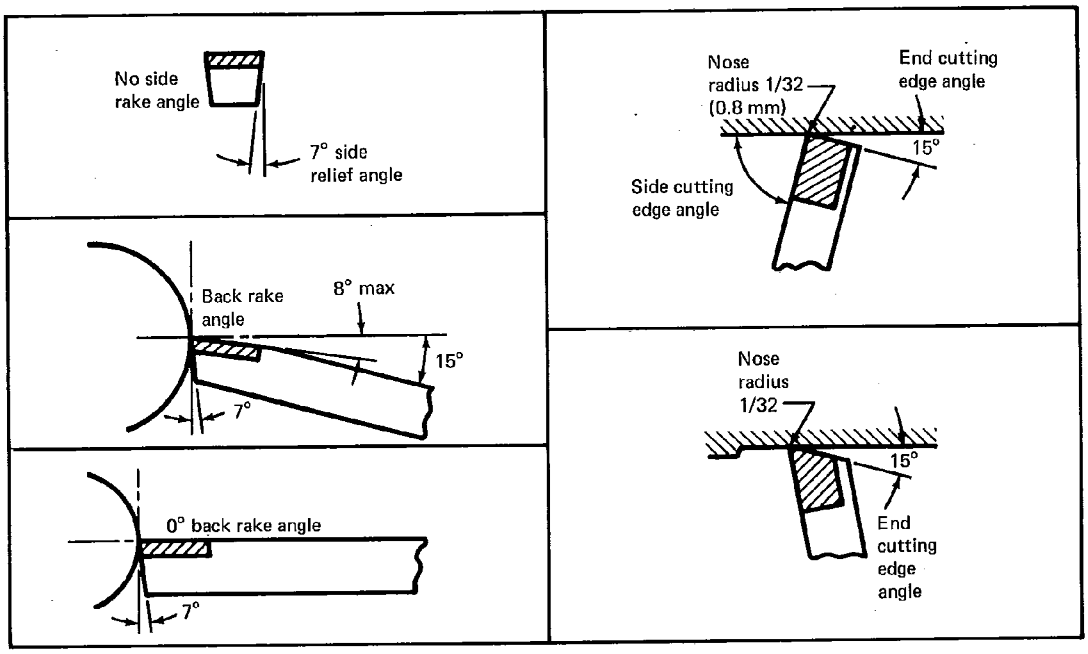
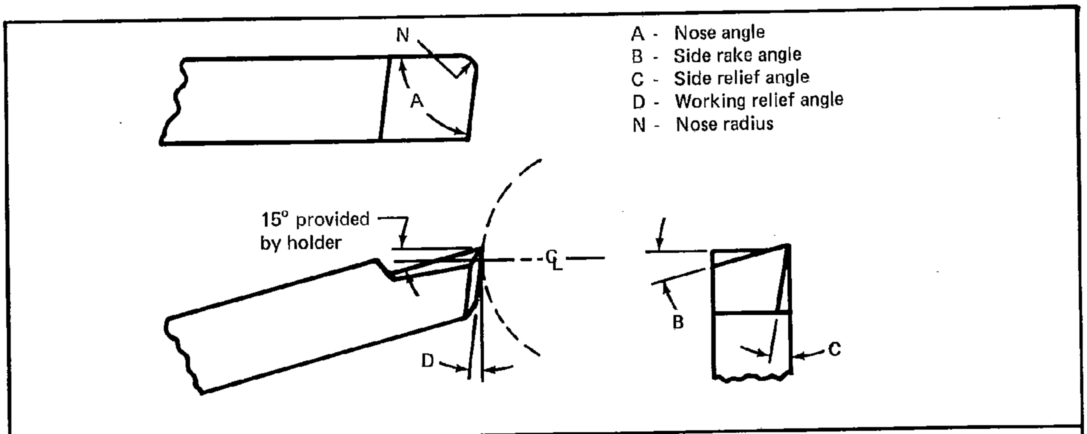


Fig. 7.2.4A — Tool angles for cemented carbide tools



| | | | | | | |
|---|---|---|---|---|---|---|
| Tool No. 1 | A=80° | B= 0° | C=10° | N=0.030 in. (0.76 mm) | D | As little as possible |
| Tool No. 2 | A=80° | B=10° | C=10° | N=0.030 in. (0.76 mm) | D | |
| Tool No. 3 | A=80° | B=15° | C=10° | N=0.040 in. (1.0 mm) | D | |

All tools ground for use in Armstrong type holder.

Fig. 7.2.4B — High speed tool bits ground at angles recommended for machining sprayed metal

## Table 7.3
## Grinding wheel recommendation

| Material | Wheel specifications | Grinding application<br>Centerless | <br>Cylindrical | <br>Internal | <br>Surface |
|---|---|---|---|---|---|
| Alumina<br>Barium Titanate<br>Boron<br>Calcium Titanate<br>Calcium Zirconate<br>Chromium Discilicide<br>Chromium Oxide<br>Cobalt Zirconia<br>Chromium Carbide<br>Columbium<br>Nickel Alumina<br>Nickel Oxide<br>Silicon<br>Tantalum<br>Titania Alumina<br>Titanium Oxide<br>Tungsten<br>Tungsten Carbide<br>Zirconia<br>Zirconia Oxide<br>Zirconia Silicate | Abrasive type: | C (Green) | C (Green) | C (Green) | C (Green) |
| | Grit size: | 80<br>(180 $\mu$m) | 80<br>(180 $\mu$m) | 80<br>(180 $\mu$m) | 80<br>(180 $\mu$m) |
| | Grade: | G | G | J | F |
| | Bond: | Vitrified | Vitrified | Vitrified | Vitrified |
| | Diamond type: | Mfd Ni Clad | Mfd Ni Clad | Mfd Ni Clad | Mfd Ni Clad |
| | Grit size: | 120<br>(125 $\mu$m) | 120<br>(125 $\mu$m) | 150/180<br>(100/83 $\mu$m) | 120<br>(125 $\mu$m) |
| | Grade: | R | R | R/N | R |
| | Concentration | 75 | 75 | 100 | 75 |
| | Bond: | Resinoid | Resinoid | Resinoid | Resinoid |
| Chromium<br>Cobalt<br>Nickel | Abrasive type: | C/A | C/A | C/A | C/A |
| | Grit size: | 60<br>(250 $\mu$m) | 60<br>(250 $\mu$m) | 80<br>(180 $\mu$m) | 46<br>(340 $\mu$m) |
| | Grade: | J | J | L | H |
| | Bond: | Vitrified | Vitrified | Vitrified | Vitrified |
| Iron | Abrasive type: | C (Black) | C (Black) | C (Black) | C (Black) |
| | Grit size: | 46<br>(340 $\mu$m) | 46<br>(340 $\mu$m) | 60<br>(250 $\mu$m) | 46<br>(340 $\mu$m) |
| | Grade: | J | J | M | K |
| | Bond: | Vitrified | Vitrified | Vitrified | Vitrified |
| Magnesium Zirconate | Abrasive type: | C (Green) | C (Green) | C (Green) | C (Green) |
| | Grit size: | 80<br>(180 $\mu$m) | 80<br>(180 $\mu$m) | 80<br>(180 $\mu$m) | 80<br>(180 $\mu$m) |
| | Grade: | G | G | L | F |
| | Bond: | Vitrified | Vitrified | Vitrified | Vitrified |
| | Diamond type: | Mfg Ni Clad | Mfg Ni Clad | Mfg Ni Clad | Mfg Ni Clad |
| | Grit size: | 120<br>(125 $\mu$m) | 120<br>(125 $\mu$m) | 150/180<br>(100/83 $\mu$m) | 120<br>(125 $\mu$m) |
| | Grade: | R | R | R/N | R |
| | Concentration: | 75 | 75 | 100 | 75 |
| | Bond: | Resinoid | Resinoid | Resinoid | Resinoid |
| Molybdenum | Abrasive type: | C (Black) | C (Black) | C (Black) | C (Black) |
| | Grit size: | 60<br>(250 $\mu$m) | 60<br>(250 $\mu$m) | 80<br>(180 $\mu$m) | 80<br>(180 $\mu$m) |
| | Grade: | I | I | N | H |
| | Bond: | Vitrified | Vitrified | Vitrified | Vitrified |

**(Continued)**

### Table 7.3 (Continued)
### Grinding wheel recommendations

| Material | Wheel specifications | Grinding application | | | |
|---|---|---|---|---|---|
| | | Centerless | Cylindrical | Internal | Surface |
| Molybdenum Disilicide Mullite | Abrasive type: | C (Green) | C (Green) | C (Green) | C (Green) |
| | Grit size: | 80 (180 μm) | 80 (180 μm) | 80 (180 μm) | 80 (180 μm) |
| | Grade: | G | G | J | F |
| | Bond: | Vitrified | Vitrified | Vitrified | Vitrified |
| | Diamond type: | Mfg Ni Clad | Mfg Ni Clad | Mfg Ni Clad | Mfg Ni Clad |
| | Grit size: | 120 (125 μm) | 120 (125 μm) | 150/180 (100/83 μm) | 120 (125 μm) |
| | Grade size: | R | R | R/N | R |
| | Concentration: | 75 | 75 | 100 | 75 |
| | Bond: | Resinoid | Resinoid | Resinoid | Resinoid |
| Stainless steel (400 series) | Abrasive type: | A | A | A | A |
| | Grit size: | 60 (250 μm) | 60 (250 μm) | 80 (180 μm) | 46 (340 μm) |
| | Grade: | J | J | L | H |
| | Bond: | Vitrified | Vitrified | Vitrified | Vitrified |
| High nickel, alloys and Stainless steel (300 series) | Abrasive type: | C/A | C/A | C/A | C/A |
| | Grit Size: | 60 (250 μm) | 60 (250 μm) | 80 (180 μm) | 46 (340 μm) |
| | Grade: | J | J | J/L | H |
| | Bond: | Vitrified | Vitrified | Vitrified | Vitrified |

Abrasive Type: C=Silicon Carbide
A=Aluminum Oxide

Notes:
A diamond wheel should be selected first over silicon carbide or aluminum oxide.

The above grinding wheel recommendations are for wet grinding. When grinding dry, it may be necessary to select wheels 1 to 2 grades softer than those indicated.

Recommendations are suggested starting points only. Some adjustments in wheel grade and grit size may be required in order to accommodate such factors as machine conditions and operator technique.

Grit size shown on above charts will yield anywhere from 30 to 50 microinches.
(0.75 to 1.25 μm) microfinish. Finer finishes require finer grit sizes such as 80 or 100 grit in. (180 or 150 μm) for "A" or "C" abrasive.

ability to fracture and present sharp new cutting points during the grinding action. Diamonds are used for their durability and ability to cleanly cut hard alloys, metals, ceramics, and cermets. Aluminum oxide and cubic boron nitride (CBN) are used only on some steel alloys.

**Grit Size.** Because of their smaller surface area and sharper points, fine grit abrasives will penetrate hard materials easier than coarse grit abrasives. Grits normally used to grind sprayed deposits will range from 46 to 80 (37 to 180 $\mu$m), although smaller sizes may be used to generate finer finishes.

### Rule II. CHOOSE WHEELS WITH STRUCTURES AND GRADES WHICH PROVIDE FREE CUTTING ACTION.

**Wheel Structure.** Structure, as it relates to the grinding wheel, is the spacing between the individual abrasive grains within the grinding wheel. Wheels with an open structure tend to cut more freely, since the additional spacing between the grains provide greater chip clearance. Wheel structures are designated numerically. For sprayed materials, structures ranging from 5 to 8 should be employed.

**Wheel Grades.** Grinding wheels can be manufactured in varying degrees of hardness. While harder wheels will last longer, they also tend to cut more slowly, generate more heat, and require more frequent dressing than softer wheels. Wheel grades are designated alphabetically in this system. When grinding sprayed materials, grades ranging between H and L are recommended. Softer grades are used on large areas of contact, when using light grinding pressures, or when attempting to achieve higher stock removal rates. Harder grade wheels are used on small areas of contact or with narrow wheels, and when using heavy grinding pressures, or producing finer finishes.

### Rule III. CHOOSE THE BOND TYPE BEST SUITED TO THE OPERATION AND EQUIPMENT.

**Vitrified Bond** (inert glass-like materials). Vitrified bonds, because of their porosity, rigidity, and strength, can provide high stock removal rates and precision tolerances. They are not affected by water, acids, oils, or ordinary temperature variations. Most vitrified wheels, however, are limited to a safe operating speed of 6,500 sfpm (33 m/s). Although vitrified bonds are the most common type used for grinding sprayed materials, they should be used only after it has been established that the operating speed of the machine does not exceed the safe operating speed of the wheel.

**Resinoid Bond** (thermosetting plastic materials). Designed to operate at speeds of 9,500 sfpm (48 m/s), diamond resin bonded wheels are used for rapid stock removal and to generate fine finishes. Although resin bonded wheels operate safely at high speeds, the machine speed should never exceed the indicated safe operating speed. Resinoid bonded diamond wheels should not exceed 6,500 sfpm (33m/s) for best grinding efficiencies.

### Rule IV. KNOW THE EQUIPMENT — BOTH MACHINES AND WHEELS

**Machines.** It is important to know the machine being used for a particular grinding operation and to understand its limitations.

It is difficult to generate precision ground surfaces and fine finishes on equipment that is not properly maintained. Chucks should be clean and able to hold the work accurately. Gibs and ways should operate smoothly, and machine spindles should run concentric to the wheel face with a minimum of vibration.

**Wheels.** Attention to wheel mounting is important as any irregularity in grinding pressures can cause improper finishes, inaccurate tolerances or the destruction of the work piece. When mounting a wheel, ascertain that it is in balance, that the wheel center hole fits the arbor properly, and that the wheel runs true. Wheel sleeves, collets, and flanges should be carefully checked to assure that they are not worn or distorted. When using cup, diamond, or cubic boron nitride wheels, always maintain them on their own collet after use. This will facilitate remounting and reduce the need for retruing on subsequent operations.

**American National Standard Grinding Wheel Markings.** American National Standards Institute (ANSI) Standard B74.13, *Markings for Identifying Grinding Wheels and Other Bonded Abrasives,* applies to grinding wheels and other bonded abrasives, segments, bricks, sticks, hones, rubs, and other shapes, which are for removing material or producing a desired surface or dimension. It does not apply to diamond wheels or to specialties such as sharpening stones. The same standard markings, made by different manufacturers, may not produce exactly the same grinding action. The desired result cannot be accomplished, due to the impossibility of correlating measurable physical properties of various bonded abrasive products in terms of their grinding action.

The American National Standards Institute should be consulted for "Identification Code for Diamond Wheel Shapes."

**Sequence of Markings.** The accompanying excerpt from ANSI B74.13 illustrates the makeup of a typical wheel or bonded abrasive marking.

| | 1 | | 2 | | 3 | | 4 | | 5 | | 6 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Prefix | Abrasive type | | Grain size | | Grade | | Structure | | Bond type | | Manufacturer's record |
| 51 | — A | — | 36 | — | L | — | 5 | — | V | — | 23 |

The meaning of this and other markings is as follows:

**(1) Abrasive Letters.** The letter (A) is used for aluminum oxide and (C) for silicon carbide. The manufacturer may designate some particular type in either of these broad classes by using his own symbol as a prefix (for example, 51A).

**(2) Grain Size.** The grain sizes used vary from coarse to fine, indicated by the following numbers: 8, 10, 12, 14, 16, 20, 24, 30, 36, 46, 54, 60, 70, 80, 90, 100, 120, 150, 180, and 220. The following additional sizes are used occasionally: 240, 280, 320, 400, 500, and 600. The wheel manufacturer may add to the regular grain number an additional symbol to indicate a special grain combination.

**(3) Grade.** Grades are indicated by letters of the alphabet A to Z in all bonds or processes. Wheel grades from A to Z range from soft to hard.

**(4) Structure.** The use of a structure symbol is optional. The structure is indicated by Nos. 1 to 16 (or higher, if necessary) with progressively higher numbers. The higher the numbers, the finer the grit.

**(5) Bond or Process.** Bonds are indicated by the following letters: V, Vitrified; S, silicate; E, shellac or elastic; R, rubber; RF, rubber reinforced; B, resinoid (synthetic resins); BF, resinoid reinforced; O, oxychloride.

**(6) Manufacturer's Record.** The optional sixth position may be used for in-house manufacturing records.

Standard shapes and size ranges are listed in ANSI Standard B74.

**Diamond Wheels.** The following is an example of a designation for the composition of a diamond wheel:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|
| Abrasive | Grit size | Grade | Concentration | Bond type | Bond modification | Depth of diamond section | Manufacturer's Identification Symbol |
| ASD — | 100 — | R — | 100 — | B — | 56 — | 1/8 — | * |

The meaning of each component in this symbol is below as follows:

**(1) Abrasive Type.** The letter D is used for natural diamond; SD or MD for manufactured diamond; CD for coated diamond; and ASD for armored diamond.

**(2) Grit Size.** The diamond grains of different sizes, referred to as grit, are expressed in numbers indicating screen mesh sizes. Commonly used grit sizes range from 24 to 500 (740 to 30 $\mu$m); for special applications finer grades may be employed.

**(3) Grade.** The grade designates the relative hardness and indicates the grain retaining strength of the bond. Letter symbols are used in alphabetical order from "soft" to "hard." Commonly used grades for various bond materials are as follows: for resinoid bond, from H to R; for metallic bond, from L to R; and for vitrified bond, from J to T.

**(4) Concentration.** The individual diamond grains are held in a bond material, and the proportion of diamond grains in terms of the unit volume of the abrasive conglomerate is termed concentration. The highest concentration, designated as 100 percent, contains 72 carats of diamond grains for each cubic in. ($164 \times 10^{-6} m^3$) of conglomerate. Other concentrations are 75, 50, and 25 per cent (low), indicating a proportionately reduced diamond content.

**(5) Bond.** Resinoid (B) bonds are used. For applications where stronger retention of the grains (i.e., greater hardness is needed), metallic (M), or vitrified (V) bonds may provide better service. (The letters in parenthesis are the respective identification symbols.)

**(6) Bond Modification.** Occasionally, numerals selected by individual manufacturers are used to designate a special bond modification. The example shows a resinoid — 56 bond.

**(7) Abrasive Layer.** The thickness of the abrasive layer applied to the core of the diamond wheel, also called the depth of impregnation or depth of diamond section, may vary for different wheel types. Thicknesses of commonly used sections are 1/32, 1/16, 1/8, and 1/4 in. (0.8, 1.6, 3.2, 6.4 mm). The thicker sections are specified for heavier stock removal rates.

**(8) Manufacturer's Identification Symbol.** This symbol, when used, appears in the eighth position.

Standard shapes and size ranges for diamond wheels can be found in ANSI Standard B74.1.

## 7.4 Grinding Variables

**7.4.1 Wheel Speed.** Wheel speed has an effect on wheel performance, finishing, and stock removal rates. Lower speeds will cause a wheel to behave softer, while high speeds will cause the same wheel to act harder. For example, a K grade wheel, normally operated at 5,000 sfpm (25 m/s), will act like an L grade wheel when operated at 6,500 sfpm (33 m/s). Ideally, the speed of the machine should be controllable, so that the effective operating speed is maintained at a constant rate as the wheel wears.

**7.4.2 Work Speed.** By varying the speed of the work, the cutting action of the wheel can also be altered. By increasing the speed of the work, the wheel will become more aggressive. Traversing the work slowly improves the surface finish.

**7.4.3 Area of Contact.** The basic principle in all types of grinding is pressure per unit area. The greater the pressure, the greater the depth of abrasive grain penetration. On a given machine of fixed horsepower, a narrow wheel, because of its smaller area of contact, will exert more units of pressure per units of area than will a wider wheel. Because of this, narrow wheels are more aggressive than wider wheels. Narrow wheels are very effective against hard materials, when rapid stock removal is required and when low horsepower machines are used.

**7.4.4 Wet Grinding.** Sprayed materials can be ground dry, if proper precautions are taken. However, the advantages of dry grinding are far outweighed by the benefits of wet grinding. When grinding wet, harder wheels may be used without increasing the incidence of blistering or heat checking. Pull-out of surface particles is minimized, and better finishes are obtained. Also, wheels do not load as fast, requiring less dressing. Wet grinding will also help flush out grinding residues that otherwise might become entrapped in the porous structure of the spray coating deposit.

Grinding fluid filtration and proper fluid concentration are as important to surface finish as fluid cleanliness. Water soluble oils with antiwelding agents are used. The manufacturer's recommendation for fluid concentration should be followed.

**7.4.5 Wheel Dressing.** During use, the condition of the grinding wheel cutting face will change. After a period of time, either the abrasive grains on the face of the wheel will wear, so that the height of the grain will equal the height of the bond, or the wheel face will become loaded with the material being ground. When either of these conditions occurs, the cutting ability of the wheel will diminish, and more rubbing (burnishing) than cutting will take place. When this occurs, the wheel face should be reconditioned or dressed. When dressing a grinding wheel with a diamond tool, the rate at which the tool is traversed across the face of the wheel governs the final cutting action of the wheel. A fast traverse will open the wheel face, resharpen the abrasive grains, and allow the wheel to cut more freely. A slow traverse of the diamond tool will close the wheel face, dull the abrasive grains, and cause the wheel to act harder. While slow dressing rates can be used to produce finer finishes on conventional materials, they are not recommended for use on thermal sprayed materials. The use of sharp diamond tools is also important. Periodic rotation of the tool is recommended.

## 7.5 Superfinishing

Superfinishing is the process of improving the finish of a part. This is accomplished by movement of the part (rotation) as abrasive stones or laps oscillate and traverse the part.

In superfinishing, the choice of the lubricant or solvent is critical. The lubricant is a determining factor in the amount of cutting accomplished by the abrasive. To obtain the best finish, the viscosity of the lubricant should be increased. This reduces cutting action and produces finer finishes with minimal stock removal. This is generally a final step following another finishing method. Increased cutting speed is attained by lowering the viscosity of the lubricant. This is generally done by adding kerosene or linseed oil.

## 7.6 Honing

Honing follows the same general principles and results of superfinishing, whether internal or external.

## 7.7 Lapping

Lapping, like superfinishing and free abrasive tumbling, can readily improve the surface finish of thermal spray deposits. Lapping of flat parts can establish exact degrees of flatness. Lapping cylindrical parts can yield high accuracies in size, finish, and straightness.

Lapping of a thermal sprayed coating may produce a certain amount of surface pull-out or pitting. This is the result of separation of coating particles during the lapping process. Generally, this is microscopic and is not visually detected. It lends the impression of a smooth surface appearance.

Lapping is accomplished using a lapping plate, which is usually serrated cast iron, or a cylindrical lap with a lapping compound comprised of abrasives and lubricants. Low speeds and high pressure produce the best results, where the lapping action shears or cuts the material, and particle pull-out is minimized. It is recommended that fused coatings be lapped dry.

## 7.8 Overall Guidelines

Good finishes can be generated on sprayed parts, provided care is exercised during the finishing process. Here is a checklist of grinding techniques:

(1) Use softer, free cutting wheels. Chances of burnishing and pull-out will be greatly reduced.

(2) Maintain the wheel face in a clean and sharp condition.

(3) Observe proper dressing techniques.

(4) Use course grit wheels for maximum stock removal and fine grit wheels for finishing. Attempting to generate fine finishes with coarse grit wheels that have been dressed closed can result in particle pull-out, smearing, and burnishing.

(5) Use light cuts. Sprayed coatings are usually very thin. Excessive grinding pressure can cause delamination of the sprayed surface or pull-out of surface particles.

(6) Do not 'spark out' on the final pass; this tends to glaze or dull the wheel face.

(7) Grind wet whenever possible. Improved finishes, less chance of burnishing, and less contamination will result.

(8) Use finer grit wheels on dense, hard-to-penetrate, sprayed coatings.

(9) Use narrower wheels on machines with low horsepower and for more rapid stock removal of hard materials.

(10) Always keep the coating under compression. By cutting down through the sprayed surface towards the substrate, delamination and pull-out will be minimized.

(11) On encountering problems with a given wheel, experiment with wheel speeds, feed rates, work speeds, and dressing techniques. Changes in variables can have a significant effect on stock removal rates and finishes.

To a great extent, the effectiveness of thermal spray coatings is dependent upon the finishing techniques employed. The fact that the coatings are not a homogeneous mass, but rather many particles bonded together, dictates that sprayed coatings be finished with wheels and techniques not normally used on similar materials in wrought or cast form. By carefully observing the rules governing wheel selection and by employing proper grinding techniques, the grinding of thermal spray coatings can become relatively trouble free.

# Chapter 8

# Post Treatment

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# Chapter 8

# Post Treatment

## 8.1 Sealers

**8.1.1 Introduction.** Thermal spray coatings are inherently porous. Porosity can range from less than 1% to greater than 15%. It may be interconnected and extend from the surface to the substrate. Sealers are used as a post treatment to fill such pores. Reasons for sealing sprayed coatings are

(1) Prevention or retardation of corrosion at the coating/substrate interface

(2) Life extension of aluminum and zinc corrosion preventive coatings

(3) Prevention of fluid and pressure seal leakage in certain machine parts

(4) Prevention of contaminants or grinding debris from entering the coating

(5) Maintenance of dielectric constants of ceramic coatings

**8.1.2 Types of Sealants.** Many sealing materials are available. Properties required in a sealer material include:

(1) Adequate penetration
(2) Resistance to chemicals or solvents
(3) Resistance to mechanical action on coating
(4) Stability at operating temperature
(5) Nondegrading to coating or base metal
(6) Nontoxic (food applications)
(7) Safe to apply

A list of sealant materials, classified according to their mechanism of formation, is presented in Table 8.1.2. Further information about performance, cost, and application procedures may be obtained from suppliers and manufacturers.

**8.1.3 Corrosion Protection.** The corrosion protection of iron or steel substrates by aluminum and zinc sprayed coatings is enhanced with low viscosity sealers. These are based on vinyl, phenolic, modified epoxy-phenolic, or polyurethane resins.

Following thermal spraying, coatings are prepared with a wash primer, generally phosphoric acid. This forms a thin film of complex metal phosphate compounds which aid in the adhesion of the sealer.

**Table 8.1.2**
**List of sealer materials**

**(1) NonDrying**
  (a) waxes, greases
  (b) oils
  (c) greases

**(2) Air Drying**
  (a) paints, chlorinated rubber
  (b) air drying phenolics, epoxy phenolics
  (c) vinyls
  (d) polyesters
  (e) silicone resins
  (f) linseed oil
  (g) coal tars
  (h) polyurethanes

**(3) Baking**
  (a) baking phenolics
  (b) epoxy phenolics
  (c) thinned epoxy resins
  (d) polyesters
  (e) polymide

**(4) Catalytic**
  (a) epoxy resins
  (b) polyesters
  (c) polyurethanes

**(5) Others**
  (a) sodium silicates
  (b) ethyl silicates
  (c) anaerobic methacrylates

It is sometimes possible to improve the role of the sealer by impregnating it with aluminum flake. The aluminum penetrates the coating pores and retards further aqueous penetration.

The American Welding Society 19 year report C2.14, *Corrosion Tests of Flame Sprayed Coated Steel,* demonstrated improved protection of vinyl sealed aluminum and zinc coatings. Chlorinated rubber is an unsatisfactory sealer for aluminum and zinc coatings.

Sealers are thinned to ensure good penetration, and may be applied by spraying or brushing. If maintenance is necessary, vinyl coatings are easily reapplied. The new coat softens and bonds with the original sealant, forming a solid layer. The maximum service temperature of vinyl coatings is 150°F (65°C).

Epoxy, epoxy-phenolic, and silicone resins may be used for certain corrosive conditions up to the temperature limits of their stability. Coal tar epoxy can be used for submerged applications in fresh or salt water.

For high-temperature, oxidizing atmospheres, aluminum pigmented silicone resin sealers are satisfactory up to 900°F (480°C). Typical applications are exhaust stacks, mufflers, and exhaust manifolds. An aluminum containing coal tar sealer has been recommended for sealing sprayed aluminum and nickel chromium alloys operating at temperatures as high as 1600-1800°F (870-980°C). The carbon preserves the aluminum content of the coating during its reaction stage in the first heating cycle when protective iron aluminum compounds are being formed.

Sealers used on coatings involved in edible food production are required to be nontoxic and FDA approved.

**8.1.4 Machine Parts.** Sealers are used on thermally sprayed machine parts to prevent corrosive attack on parts such as high pressure hydraulic rams, and on pump shafts to prevent fluid seepage into the packing. They are also sealed to ensure a better and cleaner ground finish. Sealing before grinding prevents debris from entering the pores of the coating and facilitates wash cleaning after grinding.

There are several types of sealers commonly used today. Wax is an inert material used to prevent infiltration of liquids and to provide lubricity at low service temperatures. Supplied in stick form, it melts at approximately 200°F (93°C). It is applied by directly rubbing it onto the part upon completion of the spraying operation or after preheating the part to above the wax melting temperature. The wax is resistant to both salt and fresh water, most acids, and alkalies. It will not resist organic solvents or hydrocarbons, and when used in lubricated service will gradually be displaced from the coating pores by oils and greases. A wax sealer cannot be used for hydraulic rams with fluids which will dissolve it.

Wax has excellent high pressure lubricating properties and is used for "dry" applications such as bridge pressure pads which cannot be adequately lubricated in service. Since wax is inert, it is used for sealing and lubricating sprayed metal coatings on machine elements in the food and chemical industries where contamination by ordinary lubricants is a problem.

Phenolic resins in solution are widely used sealers. Composition variations are available in air drying and baking types. Service temperatures for these materials range from 300-500°F (150-260°C). When the resin is cured, it exhibits good resistance to organic solvents and weak acids. A typical use of air drying phenolics is the sealing of coatings applied to high pressure hydraulic rams [2000 psi (14 MPa) or greater]. Coating failure often occurs in unsealed parts when the pressure of fluid and air in the deposit lifts the sprayed structure from the substrate.

Generally, a baked phenolic system offers better protection than an air dried system, due to more complete polymerization. Other alternatives are catalytic sealers, which are epoxy or polyester resins that require the addition of a catalyst to produce polymerization. The catalyst should be compatible with the sprayed metal and the application. They are used to seal large areas or parts that cannot be oven baked.

For good penetration, vacuum impregnation is the most effective sealing method. The coated part is immersed in a container of resin, and both are placed in a vacuum chamber. The chamber is evacuated, pulling air from the coating pores. Capillary action draws the sealer into the vacated pores and voids.

Low viscosity methacrylate sealers that cure by anaerobic reaction have the advantage of deep penetration without vacuum. They remain liquid while exposed to air, but harden when confined in pores and deprived of oxygen. They are well suited for sealing coatings in pressurized hydraulic environments such as seal packing glands, hydraulic cylinders, and rams.

Methacrylate sealed coatings have been used in applications to 3000 psi (20 MPa) without leakage. These sealers are stable to 300°F (150° C) and resistant to water, oils, fuels, hydraulic fluids, and solvents. They are applied by brushing at room temperature, since higher temperature speeds curing. Curing occurs within the coating even though the surface remains wet. Penetration and curing times vary from thirty minutes to several hours, depending on coating thickness, type of material, porosity, and part temperature.

Generally, the sealer is applied after spraying and before finish grinding or machining operations. For some applications, sealing is done after finishing. This is because thermal spray coatings contain some isolated pores, not interconnected or extending to the surface, which may be opened by machining or grinding. However, the surface is less porous after machining, and measured penetration is significantly less.

In hydraulic cylinders, the presence of a filler in the surface pores could add some mechanical strength to the coating and reduce leakage along the surface. Grinding fluids or cutting oils should be removed after machining prior to sealing.

## 8.2 Fusing of Self-Fluxing Coatings

**8.2.1 Introduction.** Fusing as a post treatment is the second step in the application of self-fluxing alloy coatings. The first step, spray deposition, positions the powder in place. During spraying, the powder approaches its liquidus temperature, softens, and deforms upon impact. Still, a high degree of interparticle voids remain. The fusing step melts and densifies the coating, eliminating most of the pores. Wetting and coalescence are accomplished through the fluxing of the oxides on the powder and substrate surface. Fusing is required as a post treatment in traditional oxyfuel gas or plasma spraying with most hard, self-fluxing, facing alloys.

**8.2.2 Fusion Process.** The self-fluxing alloys all have wide melting ranges and exhibit very viscous behavior in their partially melted state. In fusing, the sprayed coating deposit is heated to a point between the solidus and liquidus where the surface attains a highly reflective, glassy appearance (called the "slick-up point"). This achieves an optimum combination of particle melting, closing of interparticle gaps, and fluxing of oxides; a shrinkage of about 20% takes place in the coating. The silicon and boron in the alloy form complex silicides and borides within the coating. These compounds remain dispersed through the coating. Wetting and bonding occur between powder particles and base metal, resulting in a dense deposit with low porosity levels.

Proper fusing technique is important in obtaining optimum coating characteristics. If a deposit is underheated, melting and fluxing will be incomplete, resulting in poor bonding and undesired porosity. Heating beyond the slick-up point will produce a liquid phase and induce shrinkage voids, distortion, running of the deposit, and base metal dilution. It is important to heat the coating and conclude the fusion rapidly. This avoids excessive fluxing, which depletes the alloy of silicon or boron, or both, and creates additional slag within the coating.

Fusing temperatures for various compositions of self-fluxing alloys are given in Table 8.2.2. Some alloys possess a wide viscous temperature range, along with a low surface tension. This allows for easier control of the fusing process and lessens the tendency to sag.

**8.2.3 Torch Fusing.** Fusing is most commonly performed with a torch. Single jet or multi-jet torches, using oxyacetylene or oxypropane flames, are employed. On very large components, five or six heavy duty multi-jet torches are used simultaneously. Fusing techniques vary with part size, shape, and base metal. A neutral flame is used for nickel alloys and a slightly reducing flame for cobalt alloys. A low velocity flame is used to prevent flowing of the molten surface. Cylindrical parts are rotated at a speed below that which would (1) cause loss of molten metal due to centrifugal force, and (2) prevent clear view of the surface condition. The entire mass, part and coating, is gradually and uniformly brought to a dull red color [about 1400-1600°F (760-870°C)]. Then the coating temperature is elevated to its fusing range by progressively heating a thin band of coating at a time, while moving the torch from one end to the other. The torch should be moved at a constant rate, slowly enough to heat the overlay, but fast enough to prevent sagging. Control of the temperature requires extensive operator experience, using the coating's color and sudden reflective appearance as a reliable indicator.

Semiautomatic equipment setups are often used for spraying and fusing very long cylindrical parts. The part rotates in a turning device. One or more spray guns, along with several fusing torches, are mounted on a common traverse mechanism. The speed of the traverse, position of the torches, and flow of powder and torch gases are controlled so that the proper coating buildup is achieved in one pass. The optimum fusing temperature is supplied by the last torch in the assembly.

Instrumented control systems have been developed for automatic torch fusing. Operation is by sensing the emissivity or reflectivity of the surface and translating it into an electrical signal which is used to govern the movement of the fusing torch.

**Table 8.2.2**
**Approximate fusing temperatures of some typical self-fluxing alloys**

| Fusing temperature °F (° C) | Hardness (Rc) | Ni | Cr | B | Si | Fe | C | Co | Cu | Mo | W |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2000 (1093) | 21 | Bal. | 5.0 | 1.25 | 3.25 | 2.0 | 0.30 | | | | |
| 1975 (1079) | 30 | Bal. | | 1.5 | 3.5 | 1.5 | 0.25 | | | | |
| 1875 (1024) | 35 | 82.9 | 10.0 | 2.5 | 2.5 | 2.0 | 0.10 | | | | |
| 2012 (1100) | 35-42 | 85.0 | 7.5 | 1.5 | 4.0 | 1.5 | | | | | |
| 1922 (1050) | 49-52 | 77.0 | 10.0 | 1.5 | 4.0 | 4.0 | | | | | |
| 1868 (1020) | 59-62 | 70.0 | 15.0 | 3.0 | 4.5 | 4.5 | | | | | |
| 1875 (1024) | 58-61 | 67.0 | 16.0 | 4.0 | 4.0 | 2.5 | 0.50 | | 3.0 | 3.0 | |
| 1875 (1024) | 60-63 | 70.5 | 17.0 | 3.5 | 4.0 | 4.0 | 1.00 | | | | |
| 2048 (1120) | 43-46 | 13.0 | 19.0 | 1.5 | 2.5 | | 1.00 | 50.0 | | | 8.0 |
| 2050 (1121) | 50 | 27.0 | 19.0 | 3.0 | 4.0 | 1.0 | | 40.0 | | 6.0 | |
| 2057 (1125) | 54-56 | 13.0 | 19.0 | 2.5 | 3.0 | | 1.00 | 45.0 | | | 13.0 |
| 2200 (1204) | 53-58 | 2.0 | 30.0 | 1.5 | 3.0 | | 1.50 | Bal. | | | 14.0 |
| 1920 (1049) | 60-62 | 13.0 | 19.0 | 3.0 | 3.0 | | 1.50 | 42.0 | | | 15.0 |

**8.2.4 Furnace Fusing.** Furnace fusing offers the advantages of controlled heating, cooling, and atmosphere. Due to fairly stringent equipment requirements, furnace fusing is not as commonly used as torch fusing. It is more suitable for flat components, parts with irregular shapes and cross sections, very thin coatings, and high production items. It can also be used on large parts where the torch (or torches) cannot generate sufficient component heat to permit elevating the coating to fusing temperature. Since the heating and cooling rate can be precisely controlled, coating cracks due to expansion are minimized.

Furnace atmospheres of dry hydrogen, argon, or vacuum are necessary. Excellent temperature control and uniformity ± 5°F (± 3°C) over the entire furnace work space are requirements for proper results.

**8.2.5 Induction Fusing.** Induction fusing is becoming increasingly popular, due to the savings in fusion time and energy costs. For very large parts, this method has the advantage of reduced heat and noise levels, thus improving operator comfort. Automated induction fusing has been used on small parts such as sucker rod couplings for oilwell pumping, and on large parts such as steel mill conveyor rolls.

**8.2.6 Precautions with Various Base Metals.** Fusing of self-fluxing coatings to a wide variety of base metals is possible. These include carbon, alloy, and austenitic stainless steels, cast irons, and nickel-base and cobalt-base alloys. They cannot be applied to base metals containing elements whose oxides are not reduced by boron and silicon; e.g., alloy steels with greater than 1% aluminum and titanium. Difficulties will probably be encountered with sulphur or selenium free machining steels, due to the embrittling effects and the formation of porosity in the coating. This is particularly true of thin coatings.

Coefficient of expansion differences between coating and base metal should be compatible to avoid potential cracking problems. The high hardness (>Rc40) nickel base self-fluxing alloys are very brittle and have a high coefficient of expansion [8 to 9 x $10^{-6}$ in/in/°F (14 to 16 x $10^{-6}$ m/m/°C)]. Preheating, other than warming, of carbon steels is not required prior to spraying. Austenitic stainless steels, to prevent coating cracking due to high coefficient of expansion (11 x $10^{-6}$), require a 600°F (315°C) base metal preheat.

High carbon steels generally require heating to 600°F (315°C) after spraying, but before fusing, to avoid cracks in the fused overlay. In general, heating of the base metal must be thorough. Slow cooling after fusing is required to prevent cracking.

Hardenable steels, which undergo expansion during martensitic transformation, present a problem. Safe procedures involve placing the part in a heated furnace immediately after fusing, followed by an isothermal transformation treatment (normalizing).

**8.2.7 Fusing Problems**

**Cracking.** Cracking problems due to the fusing step stem from the alloy's brittle nature and high coefficient of expansion. They are minimized by uniform heating and very slow cooling of the parts. Slow cooling is effectively accomplished by burying the part in an insulating medium, such as vermiculite, or by cooling it in a preheated furnace. Special precautions should be taken with high hardenable steels.

**Porosity.** Excessive porosity in the final coating can result from many sources. Underfusing leaves large voids throughout the coating and interface due to incomplete melting, wetting, and fluxing of the powder particles. Overheating creates large voids, and a large amount of slag within the coating. Excessive porosity can also form in large parts, due to the extensive time required to reach the fusing temperature. High sulfur, selenium, and lead in the base metal, as in free-machining steels, cause porosity problems. Excessive metallic dust (fines) and contamination in the spray powder can result in entrapped oxides during spraying. These are manifested as porosity found during machining and grinding operations. Incorrect spray parameters may also result in porosity.

**Sagging or Runoff.** Sagging or runoff, or both, result from exceeding the optimum fusing temperature. These conditions are more likely to occur in parts that are hollow or vary in wall thickness. It is best to fuse from thin to thick areas to avoid overheated conditions.

**Warpage.** It is not always possible to completely eliminate warpage on irregular shapes or flat pieces which have been coated on one side.

Preheating or uniform heating during fusing also reduces warpage. Thin coatings cause fewer warpage problems than heavy coatings. Warpage can be minimized by choosing the closest match between the coefficient of expansion of the coating and base metal. Self-fluxing alloys incorporating tungsten carbide particles have lower expansion coefficients than the one component, self-fluxing alloys, and therefore can be used to advantage.

## 8.3 Other Post Treatments

**8.3.1 Diffusion.** Thin coatings of aluminum may be diffused into a steel or silicon bronze substrate to protect against the corrosive action of hot gases up to 1600°F (870°C). After being sprayed, the part is coated with a bituminous aluminum sealer or other suitable material to prevent oxidation of the sprayed deposit. The part is heated at 1450°F (788°C) and held at temperature for the required time for diffusion [typically 1 hour for each 1 in. (25.4 mm) of section thickness for large objects]. If the coating is for a service environment exceeding the melting point of aluminum, 1220°F (660°C), this step may be eliminated.

Diffusion heat treatments are often given to vacuum plasma-sprayed turbine engine parts such as blades, vanes, and duct segments (Chapter 4). Temperatures of about 1800°F (980°C) to 2000°F (1090°C) are used with vacuum, hydrogen, or argon atmospheres. Such treatments enhance coating integrity through formation of a metallurgical bond. They improve density, ductility, and resistance to oxidation and corrosion, as well as strength of the coating.

**8.3.2 Impregnation.** Impregnation of sprayed tungsten carbide coatings with solder improves strength and wear resistance. The process is carried out in vacuum at 1830°F (1000°C), or in hydrogen at 1470°F (800°C). At these temperatures, the solder flows to fill spaces between particles without melting the carbides. Capillary action occurs rapidly, permitting holding times of 1 to 2 minutes. It is claimed that most lead, tin, silver, and copper solders provide acceptable results.

**8.3.3 Mechanical Treatments.** Some metallic thermal sprayed coatings can be mechanically treated to close surface connected pores and to improve smoothness. Shot peening is used on some aircraft turbine parts. Peening and rolling can be used on active metal coatings for improvements in cavitation corrosion resistance. The improvement results from pore closure and residual compressive stresses. The cavitation corrosion resistance of a zinc coated steel plate in salt water has been shown to improve by rolling after spraying. No similar improvement, however, was seen in an 85 zinc-15 aluminum spray. Chapter 7 can be consulted for additional details.

**8.3.4 Hot Isostatic Pressing (HIP).** The use of hot isostatic pressing, that is, the simultaneous application of heat and pressure in an inert atmosphere, serves a two fold purpose: (1) it promotes diffusion at the substrate and coating interface, and (2) it serves to collapse the internal pores. Coating ductility, strength, and impact resistance are improved by this process. The expense associated with "HIPing" has limited its use to specialized applications.

**8.3.5 Laser Heating.** Laser treatment of sprayed coatings offers the possibility of performing highly controlled heating or melting. Because of the wide range of energy densities and shapes which can be produced with high power lasers, precise temperatures can be produced at specific depths in the coating. Development work has demonstrated feasibility of laser processing. Advantages include reduced porosity, increased bond strength, modified surface finish, and formation of unique metallurgical phases. Also, with coatings of high temperature materials on lower temperature substrates, the melting and infusion of a thin layer of the substrate at the bond line may be possible without melting of the surface coating.

# Chapter 9

# Ancillary Equipment

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# Chapter 9

# Ancillary Equipment

## 9.1 Introduction

The selection of equipment used in conjunction with the thermal spraying process is one of the key factors in obtaining quality coatings, reproducing them consistently, and in reducing application costs.

## 9.2 Blasting

The function of abrasive blasting equipment is to produce a surface receptive for coating. It is accomplished by cleaning or roughening, or both. Blasting equipment is available in sizes ranging from hand held guns, with a self contained grit canister, to large, totally enclosed, fully automated systems. Figure 9.2 shows such a fully automated system. Primary considerations in selecting blasting equipment are productivity, ability to keep grit clean, proper size, operator comfort, reproducability of results, and protection of the operator and the surrounding area from environmental hazards. Another consideration is the efficient usage of the blasting materials.

**9.2.1 Facilities.** The type, size, and degree of automation of any system should be tailored to the part, environmental standards, and abrasive usage requirements. Blasting should always be performed in an enclosure designed for that purpose, and equipped with exhaust and dust collection facilities. Blast room designs vary with the application. To facilitate visibility and safety, all rooms should be equipped with an exhaust system to draw dust and contaminated material from the part and operator. Room dimensions depend on the size of the parts to be blasted. Abrasive recycling varies from manual shoveling to fully automated systems. In automated self-contained systems, the abrasive falls through a grated floor to either a vibratory plate or a conveyor which transfers it via an elevator to a holding area, where it is cleaned. Cleaning includes rescreening, sizing, and dust removal. Fines are removed, and reusable material is returned to the blasting tank. There are definite health hazards associated with silica dust. These are discussed in Chapter 11.

**9.2.2 Machines.** Blasting machines are available in three types. These are classified by the method of transporting and projecting the abrasive particles: pressure, centrifugal, and suction. Pressure type blasting machines are applicable to large work requiring high production rates. They are more effective and efficient than other systems, since higher velocities are imparted to the abrasive, to afford greater cutting action. Pressure machines utilize a ''Blast Generator'' consisting of a closed hopper for the abrasive, a carrier base, and a blasting nozzle. The generator is pressurized and the abrasive is carried through the hose and nozzle to the workpiece. The blast generator must be periodically recharged with the abrasive. Pressure type machines are suitable for use with chilled cast iron, light oxides, and carbide abrasives.

When a part must be cleaned outdoors, and the abrasive media cannot be recovered, a lower cost grit may be selected if it is in accordance with local and federal regulations. Shielding should be used for this operation to protect the operator and the surrounding area. Disadvantages to this system are (1) degradation rate of the grit is high, causing the need for frequent replacement, (2) blasting particles cannot be reclaimed except in tank interiors, and (3) considerable care is required to prevent embedding grit in the substrate.

Centrifugal blasting is performed without air pressure. The resultant surface of the part is cleaner than that obtained through other methods. The shot or grit is fed onto a rapidly rotating vaned wheel designed to accelerate and propel the particles. The particles achieve a velocity equal to the tip speed of the vanes. The parts are loaded on a conveyor line which carries them through the blasting station to the discharge side of the machine. The blasting station may be robotized, allowing the part to be rotated, as required.

Centrifugal blasting machines have limited application, because economics require high volume conveyor line operation and that the part be large. Crushed cast iron grit should be used, as aluminum oxide and silicon carbide abrasives cause excessive wear to internal parts.

Suction type machines are convenient and versatile for preparing a large variety of components. The abrasive medium is dispensed from a hopper at the cabinet base and air propelled to the substrate. The grit drops through a grate, returns to the hopper, and is recycled. Reuse continues until the abrasive loses its effectiveness. Suction type machines range from small, manually operated units to intermediate sized, and fully automated systems. They can be used with almost any type of abrasive with the exception of the larger sizes of crushed cast iron. Enclosure size and system efficiency are limiting factors.

**9.2.3 Nozzles.** Straight nozzles are commonly used for commercial work. There are many sizes (diameters), lengths, and configurations. Nozzle life depends on many factors including air pressure and type of abrasive. Inexpensive, short life, or expendable nozzles are manufactured from either cast iron or ceramic. Long wear nozzles are carbide or a carbide based composition. They are inserted into a steel or aluminum mounting which protects their hard, brittle, inner core. The internal configuration and length govern the type of blast pattern received at a given distance. Long wear nozzles may give up to 100 times the life of a conventional ceramic or iron nozzle, but are subject to breakage if not handled properly. Table 9.2.3 provides air and sand flow rates, along with power requirements for nozzles of various sizes at various pressures.

The angle nozzle is made from carbide or carbide composition. The offset degree angle is designed for a specific application. They are manufactured with 15°, 45°, and 90° angles.

Centerblast nozzles are used for internal pipe cleaning. The nozzle employs a straight bore fixture that spreads the abrasive pattern 360°. Fixturing allows blasting of internal diameters ranging from 1 in. to 4 in. (25 to 100 mm). The angle of the target has a tendency to roughen in one direction. If sprayed in the opposite direction,

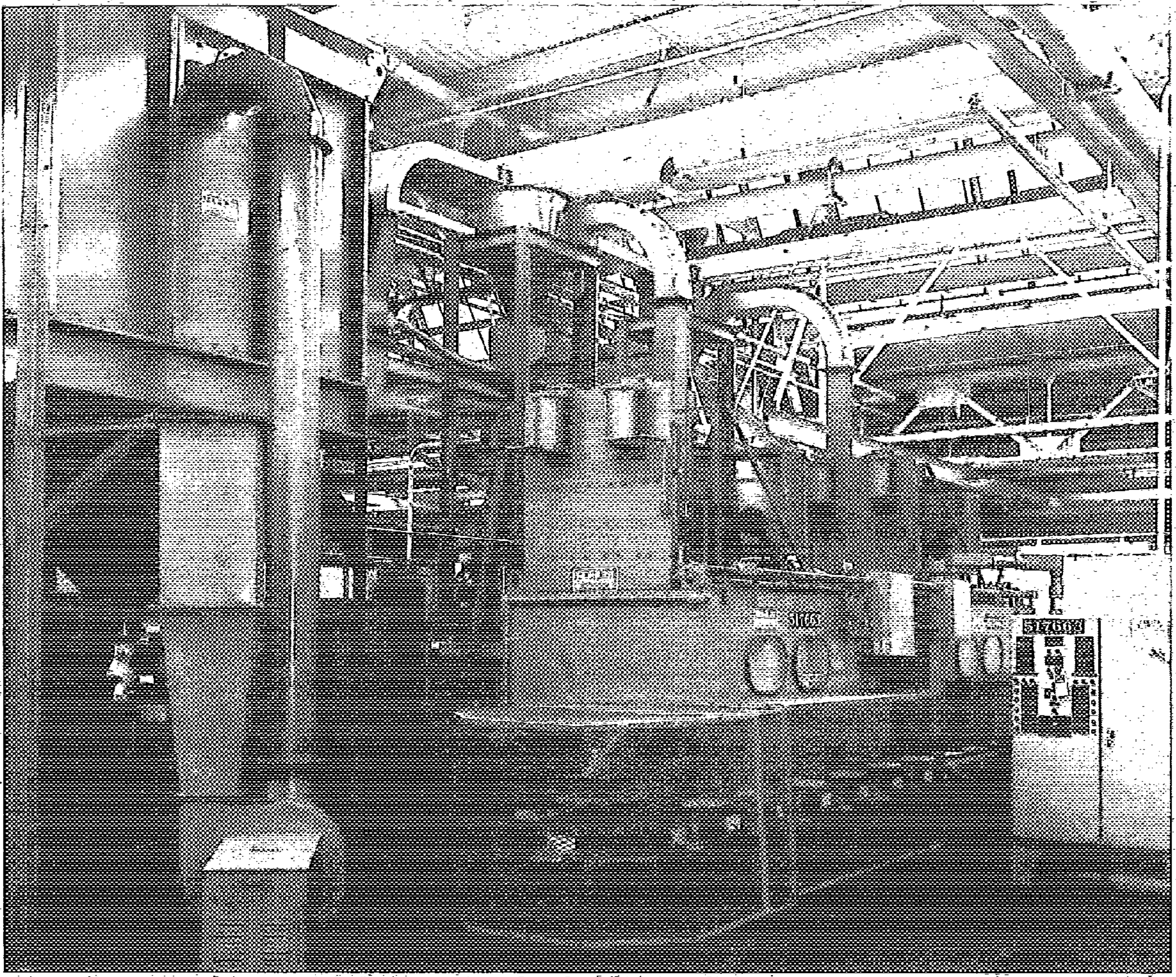

Fig. 9.2 — Fully automated, high production rate, grit blasting system

### Table 9.2.3
### Air, sand flows, and energy requirements for various grit blast nozzle sizes

| Nozzle diameter in. | | Nozzle pressure, psi | | | | | |
|---|---|---|---|---|---|---|---|
| | | 50 | 60 | 70 | 80 | 90 | 100 |
| 1/8 | cfm air | 11.3 | 13.2 | 15.1 | 17.0 | 18.5 | 20.3 |
| | lb/hr | 67.0 | 77.0 | 88.0 | 101.0 | 112.0 | 123.0 |
| | hp required | 1.6 | 2.1 | 2.5 | 3.1 | 3.5 | 4.2 |
| 3/16 | cfm air | 26.0 | 30.0 | 33.0 | 38.0 | 41.0 | 45.0 |
| | lb/hr | 150.0 | 171.0 | 196.0 | 216.0 | 238.0 | 264.0 |
| | hp required | 3.6 | 4.6 | 5.5 | 6.9 | 7.9 | 9.3 |
| 1/4 | cfm air | 47.0 | 54.0 | 61.0 | 68.0 | 74.0 | 81.0 |
| | lb/hr | 268.0 | 312.0 | 354.0 | 408.0 | 448.0 | 494.0 |
| | hp required | 6.4 | 8.3 | 10.2 | 12.4 | 14.2 | 16.8 |
| 5/16 | cfm air | 77.0 | 89.0 | 101.0 | 113.0 | 126.0 | 137.0 |
| | lb/hr | 468.0 | 534.0 | 604.0 | 572.0 | 740.0 | 812.0 |
| | hp required | 10.5 | 13.6 | 16.9 | 20.6 | 24.2 | 28.3 |
| 3/8 | cfm air | 103.0 | 126.0 | 143.0 | 161.0 | 173.0 | 196.0 |
| | lb/hr | 668.0 | 764.0 | 864.0 | 960.0 | 1052.0 | 1152.0 |
| | hp required | 14.8 | 19.3 | 23.9 | 29.3 | 33.2 | 40.6 |
| 7/16 | cfm air | 147.0 | 170.0 | 194.0 | 217.0 | 240.0 | 254.0 |
| | lb/hr | 896.0 | 1032.0 | 1176.0 | 1312.0 | 1448.0 | 1534.0 |
| | hp required | 20.1 | 26.0 | 32.4 | 39.5 | 46.1 | 52.6 |
| 1/2 | cfm air | 198.0 | 224.0 | 252.0 | 280.0 | 309.0 | 338.0 |
| | lb/hr | 1160.0 | 1336.0 | 1512.0 | 1680.0 | 1856.0 | 2024.0 |
| | hp required | 26.7 | 34.3 | 42.1 | 51.0 | 59.3 | 70.0 |
| 5/8 | cfm air | 308.0 | 356.0 | 404.0 | 452.0 | 504.0 | 548.0 |
| | lb/hr | 1875.0 | 2140.0 | 2690.0 | 2690.0 | 2960.0 | 3250.0 |
| | hp required | 42.4 | 54.4 | 68.0 | 82.0 | 96.8 | 115.6 |
| 3/4 | cfm air | 432.0 | 501.0 | 572.0 | 614.0 | 692.0 | 781.0 |
| | lb/hr | 2672.0 | 3056.0 | 3456.0 | 3810.0 | 4203.0 | 4608.0 |
| | hp required | 59.2 | 77.2 | 95.6 | 117.2 | 132.8 | 162.4 |

See Table 3.4.3 for cleaning rates

## S. I. Soft Conversion

## Table 9.2.3

## Air, sand flows, and energy requirements for various grit blast nozzle sizes

| Nozzle diameter mm | | Nozzle pressure, ksi | | | | | |
|---|---|---|---|---|---|---|---|
| | | 34 | 41 | 48 | 55 | 62 | 69 |
| 3.175 | Air, L/min | 320 | 374 | 428 | 481 | 524 | 575 |
| | Kg/h | 30 | 35 | 40 | 46 | 51 | 56 |
| | kW req'd | 1.2 | 1.6 | 1.9 | 2.3 | 2.6 | 3.1 |
| 4.762 | Air, L/min | 736 | 850 | 934 | 1076 | 1161 | 1274 |
| | Kg/h | 68 | 78 | 89 | 98 | 108 | 120 |
| | kW req'd | 2.7 | 3.4 | 4.1 | 5.1 | 5.9 | 6.9 |
| 6.350 | Air, kL/min | 1.33 | 1.53 | 1.73 | 1.93 | 2.10 | 2.29 |
| | Kg/h | 122 | 142 | 161 | 185 | 203 | 224 |
| | kW req'd | 4.4 | 6.2 | 7.6 | 9.2 | 10.6 | 12.5 |
| 7.937 | Air, kL/min | 2.18 | 2.52 | 2.86 | 3.20 | 3.57 | 3.88 |
| | Kg/h | 212 | 242 | 274 | 259 | 336 | 368 |
| | kW req'd | 7.8 | 10.1 | 12.6 | 15.4 | 18.0 | 21.1 |
| 9.525 | Air, kL/min | 2.92 | 3.57 | 4.05 | 4.56 | 4.90 | 5.55 |
| | Kg/h | 303 | 347 | 392 | 435 | 477 | 523 |
| | kW req'd | 11.0 | 14.4 | 17.8 | 21.8 | 24.8 | 30.3 |
| 11.112 | Air, kL/min | 4.16 | 4.81 | 5.49 | 6.14 | 6.80 | 7.19 |
| | Kg/h | 406 | 468 | 533 | 595 | 657 | 696 |
| | kW req'd | 15.0 | 19.4 | 24.2 | 29.5 | 34.4 | 39.2 |
| 12.700 | Air, kL/min | 5.61 | 6.34 | 7.14 | 7.93 | 8.75 | 9.57 |
| | Kg/h | 526 | 606 | 686 | 762 | 842 | 918 |
| | kW req'd | 19.9 | 25.6 | 31.4 | 38.0 | 44.2 | 52.2 |
| 15.875 | Air, kL/min | 8.72 | 10.08 | 11.44 | 12.80 | 14.27 | 15.52 |
| | Kg/h | 850 | 971 | 1220 | 1220 | 1220 | 1474 |
| | kW req'd | 31.6 | 40.6 | 50.7 | 61.1 | 72.2 | 86.2 |
| 19.050 | Air, kL/min | 12.73 | 14.19 | 16.20 | 17.39 | 19.60 | 22.12 |
| | Kg/h | 1212 | 1386 | 1568 | 1728 | 1906 | 2090 |
| | kW req'd | 44.1 | 57.6 | 71.3 | 87.4 | 99.0 | 121.1 |

voids, which form as the coating bridges over the anchor pattern, can yield an unsatisfactory bond.

Spinblast or rotary nozzles are used for internal blasting of larger diameters. This equipment consists of a pressurized, rotating head which carries the abrasive to the target. When the abrasive strikes the target, it is split between two carbide nozzles operating 180° apart. The nozzle is capable of blasting 36 in. (0.91 m) diameter substrates but, due to its weight, should be mounted on a lance with a mechanical traverse device.

## 9.3 Air

Clean, dry air can be used for drying cleaned parts, grit blasting, and air cooling during and after spraying, as well as in the operation of thermal spray equipment. The associated apparatus requires constant surveillance and maintenance. Numerous contaminants, such as water vapor, oil mist/vapor, and dust can be introduced to the air supply.

**9.3.1 Supply Source.** Dirty shop air contributes to interface contamination, poor bond strength, flaking, spalling, cracking, interlamellar oxides, and other defects. To ensure a clean air supply, in-line separators and filters should be located near the spray booth. There are systems that will clean and dry the air for an entire department or for the entire operation at its source. These should be used in conjunction with individual in-line filters.

Moisture should be eliminated to maintain coating quality, increase productivity, and decrease maintenance. Dryers are most efficient with an entering air temperature of 100°F (38°C). This is most economically accomplished by using an aftercooler. With the entering air temperature of 100°F, pressure dewpoints as low as −40°F (−40°C) can be achieved. Refrigerated dryers, unless interlocked with the air flow, consume energy regardless of work load, while delinquescent dryers incur only those costs directly related to the quantity of air being processed.

**9.3.2 Compressors.** Clean, dry air reduces maintenance and replacement costs, down time, and minimizes product rejection. All pneumatic equipment is designed for long life, maximum efficiency, and minimum maintenance, but only when operated with clean, dry air, and when lubricated according to the manufacturer's specifications. Thermal spray equipment does not contain built-in facilities for operation with wet air. The compressor raises the air temperature to 350°F (177°C). It drops to 300°F (149°C) prior to entering the aftercooler and is further lowered before entering the receiver. The saturation point is reached at 160°F (71°C), where water is condensed between 160°F (71°C) and 100°F (38°C). The saturated compressed air is stored in the receiver until required. As air leaves the receiver, it passes through a dryer, lowering the dewpoint before entering the spray equipment.

Compression of air has one basic goal, to deliver air at a pressure and volume suitable to operate various components needed for thermal spraying and complimentary equipment. There are three types of compressors to consider in the selection of a system: Reciprocating, Vane Type Rotary, and Twin Screw Helical Lobe.

Reciprocating compressors are positive displacement machines, in which compression and displacement are accomplished by a piston with a reciprocating motion within a cylinder. The reciprocating compressor can be either a single cylinder compressing at one end of the stroke, or a double acting unit compressing at both ends of the stroke. Two stage reciprocating compressors are proportioned according to the total compression ratio. The second stage is smaller, since the air has already been partially compressed and cooled, occupying less volume than at the first stage inlet.

Vane type rotary compressor elements include the cylindrical casing, the heads, and the rotor assembly. The sliding vane unit has no valves. The inlet and discharge ports open at points in the cycle that are determined by the location of the ports over which the vanes pass. The inlet port is normally wide and is designed to admit air when the pocket between the two vanes is largest. It is closed when the following pocket vane passes the edge of the inlet port. The pocket is uncovered by the leading vane of each pocket. This type of system always compresses air to design values, regardless of the pressure in the receiver into which it is discharging.

Twin screw helical lobe compressors are positive displacement, constant volume, variable pressure machines similar to the vane type rotary. The most common helical screw compressor is the oil flooded single stage unit, which delivers air up to 125 psig (862 kPa). It is heavy duty and can operate at full load for extended periods. Operating economy is less than that of the reciprocating unit, but the lower initial cost offsets the reduced efficiency. It requires no lubrication within the compression chamber and thus delivers oil free air, with proper outlet filters. Inlet and discharge silencers reduce operating noise to acceptable limits.

When selecting a suitable compressor type, the following ratings can be used:

| Type | Horsepower (kW) | Power range ft$^3$/min. (m$^3$/s) |
|---|---|---|
| Reciprocating | 1/4 - 300 (0.2 - 224) | 2 - 1500 (0.001 - 0.7 ) |
| Screw | 2 - 75 (1.5 - 56) | 6 - 350 (0.003 - 0.17) |
| Twin | 5 - 500 ( 4 - 373) | 20 - 2250 (0.01 - 1.1 ) |

Additional information can be obtained from data issued by compressor manufacturers.

## 9.4 Furnaces and Handling

**9.4.1 Furnaces.** Furnace fusion of self-fluxing alloys provides an inexpensive, long wearing surface, but is not applicable to all parts or base metals. Success is predicated upon precise control of the temperature in the furnace and on the surface of the part. A tolerance of ± 10°F (± 5°C) is normal. Furnaces are classified by

(1) the method of heating or source of energy used (oil, gas, or electricity)

(2) atmosphere and salt furnaces, which can be heated by the same three heat sources

(3) operating temperature range: 225°F (107°C) to 1250°F (677°C) — low, 1250°F (677°C) to 1750°F (955°C) — intermediate, and 1750°F (955°C) to 2800°F (1538°C) — high. Each type has its specific use. Low temperature furnaces are used almost exclusively for preheating. The intermediate groups may be used for diffusion heat treating of sprayed coatings. The high temperature group is for fusing self-fluxing coatings according to

(4) the method of operation; i.e., batch or continuous furnaces

(5) the methods of applying heat

**9.4.2 Handling.** Many manual spray operations are performed without the use of manipulating devices. For small pieces, a vertical stand with a heavy base and "C" clamps are satisfactory. They should be coated with an anti-bonding material to facilitate the removal of overspray. Semiautomatic spray operations are more complex, but higher production rates are possible. Manipulation of the part, rather than the spray gun, produces higher quality coatings. This is attributed to retention of the spray particles in the effluent and their continuous heating to impact. The success of this method is dependent upon part geometry and the areas to be coated. Areas and surfaces that are round or circular are the most readily adapted.

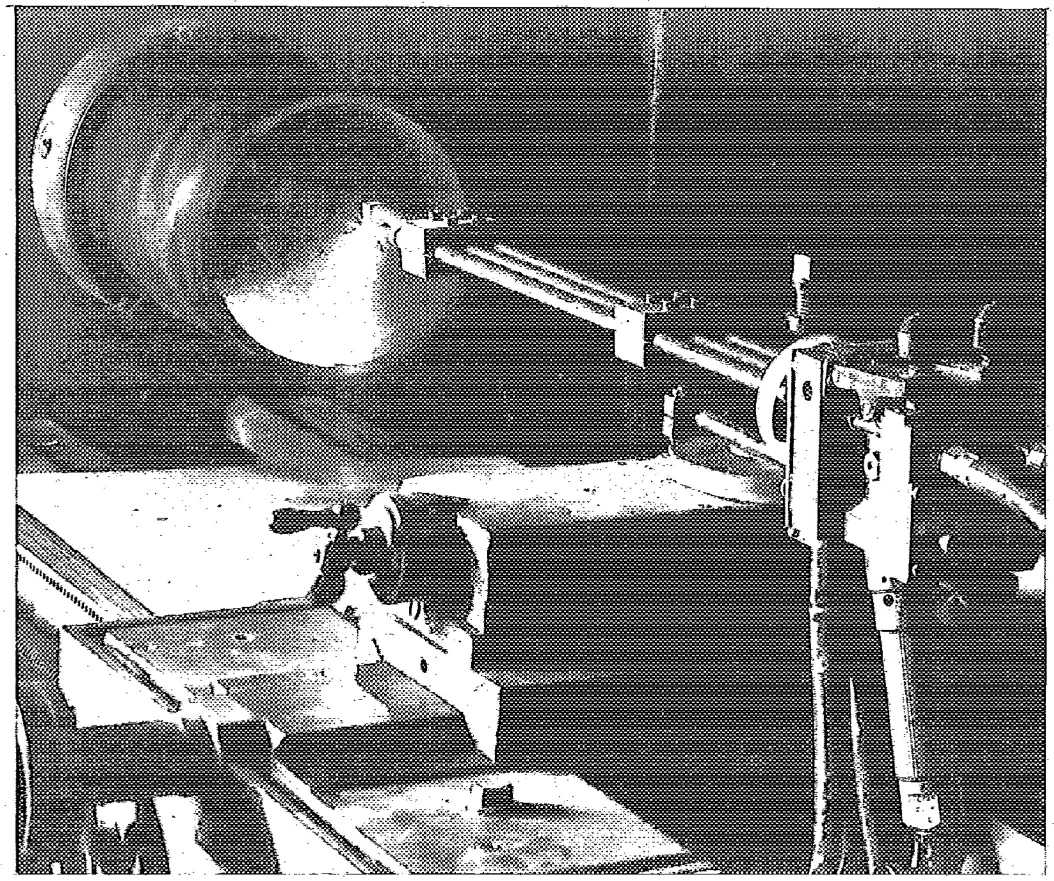

**Fig. 9.4.2A — Use of a lathe to manipulate the part and the gun for spraying the inside surface of a cylinder**

**Rotary Motion.** A simple method of creating rotary motion incorporates a variable speed motor with a chuck. Electric motors should be sealed to prevent short circuits. Cylindrical parts can be sprayed manually or the gun mounted on the tool carriage of a lathe (Fig. 9.4.2A). The capability is limited by the size of the spray enclosure. Manipulation of large parts requires the use of a rotary table or positioner (Fig. 9.4.2B).

Rotational devices should be capable of a wide variety of speeds. The use of rotational velocities of less than 1 rpm, with high gun speeds, make a standard welding positioner practical (Fig. 9.4.2C).

Thermal spray coatings involving high production rates require the use of remotely controlled automated systems. The parts handling equipment is designed for specific operations including features such as batch loading, automatic stationing, multiple station conveying, and multiple station spraying. Spray gun manipulation synchronized with the part by numerical control (NC) or computer controls becomes an integral part of a fully automated system (Fig. 9.4.2D).

Thermal spray manipulators automate gun movements which can reduce cost, improve coating quality and consistency, increase output, and improve operator environment. The complexity of the manipulator can vary from a homemade lathe or chain drive to a sophisticated computer controlled system which not only controls spray gun movement but interlocks, monitors, and controls other variables such as spray rate, pressures, and substrate temperature.

The basic semiautomatic system is the combination of a stationary gun stand and a rotary table. The gun stand consists of a heavy base, a vertical leg and a gun support. The gun is mounted rigidly on the stand, and the target structure is rotated on the table, creating a single band of coating circling the part. This procedure is satisfactory when only a narrow band of material is required.

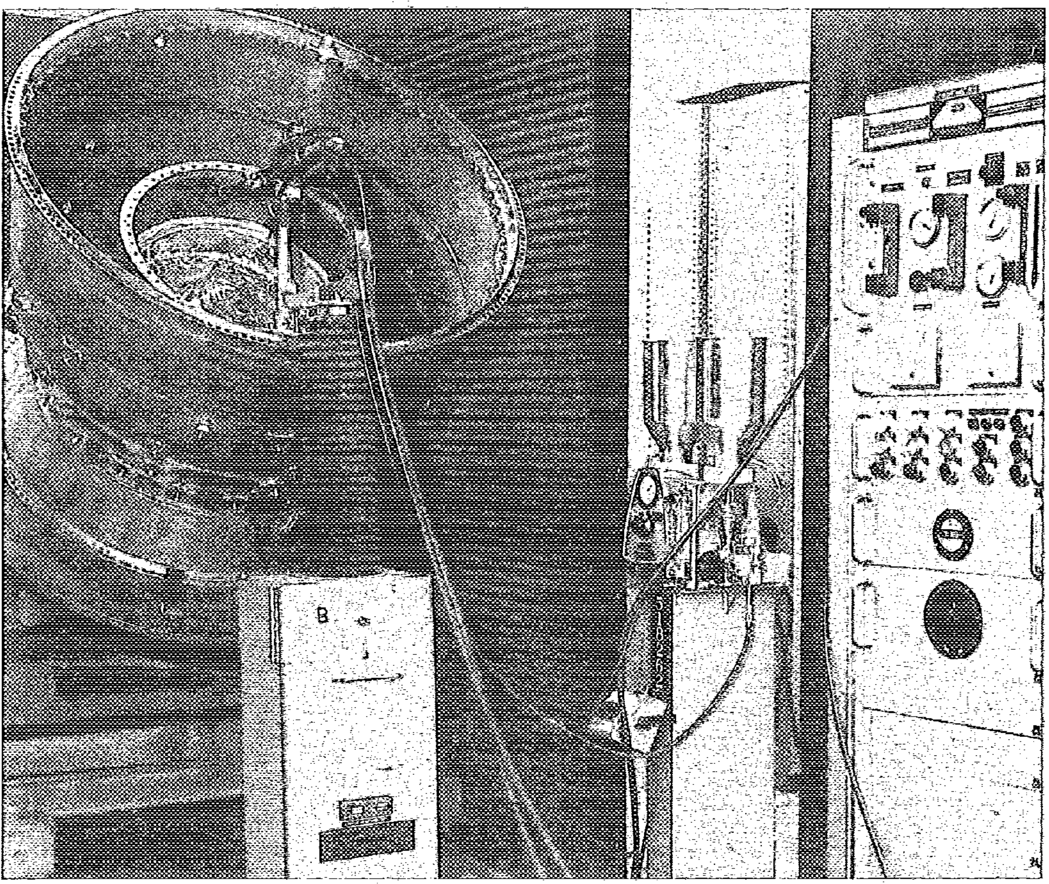

Fig. 9.4.2B — Use of a rotary table for part positioning and a verticle transverser for gun manipulation

The coating of complex structures requires additional handling equipment. Traverse units perform straight line movements along one or two axes (Fig. 9.4.2E).

The vertical traverse unit operates with a continuous motion along the "Y" axis only, whereas the horizontal traverse unit can operate along the "X" or "Z" axis, depending upon the orientation of the unit. The combination units operate along two axes simultaneously, with the horizontal axis having continuous motion and the vertical axis having either intermittent short steps or continuous motion. These motions will form a pattern on a flat surface. This combination also operates as a single axis unit in either "X" or "Y" direction. Current production models of these traverse units are controlled either by microprocessors or by electronic systems employing counters, microswitches, and relays.

Advanced design combination traverse units are also available that are microprocessor or numerical tape controlled, or both. These units are capable of multiple axes manipulations plus initiation and control over attendant equipment (turntables, power feeders, etc.). Complete programs can be stored and recalled as required (Fig. 9.4.2F).

Another type of manipulator is a computer operated robot. Here the entire spray process, including the parts conveyor line, is controlled from the computer console. The motions of the robot are hydraulically or mechanically actuated with a wrist motion at the end of its arm. It is capable of rotational motion from stop to stop in a spherical pattern. Robots are used for atmospheric and vacuum plasma spraying operations. The use of these manipulators is economical where high production rates, a high degree of repeatability, or difficult geometric problems exist (Fig. 9.4.2G).

Robotics may also be required to meet OSHA regulations and to remove the operator from the spray environment.

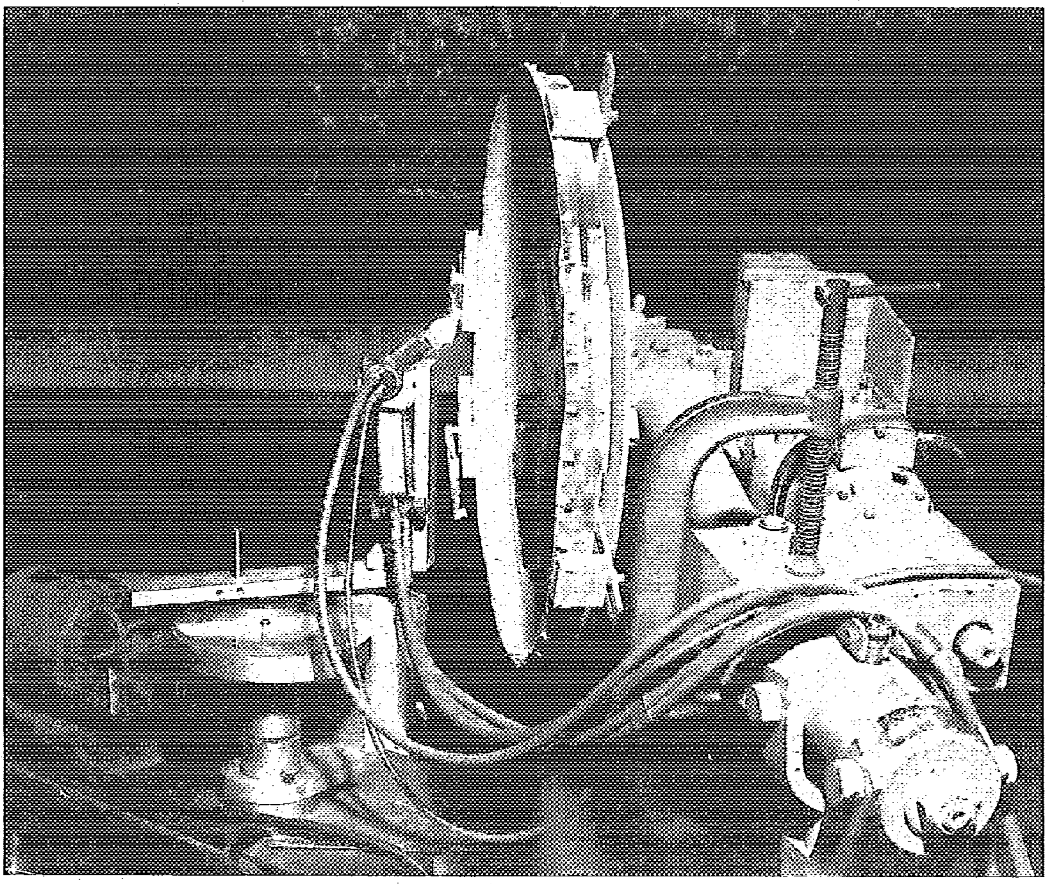

**Fig. 9.4.2C — Use of a welding positioner to rotate parts oriented vertically or horizontally. A variable speed (zero-max) drive unit is being used to oscillate the flame spray gun**

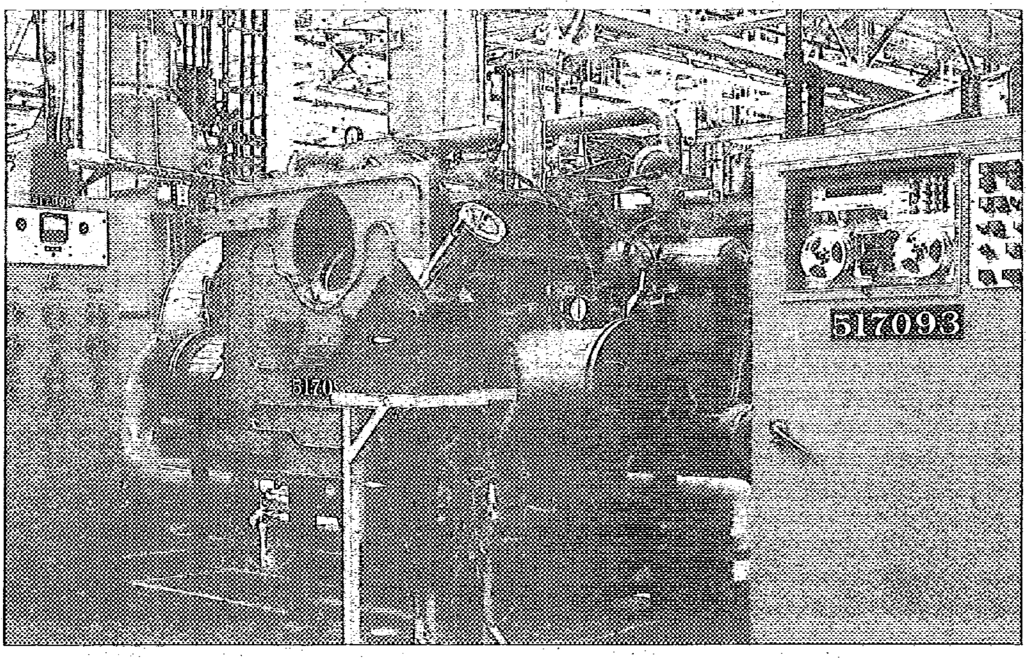

Fig. 9.4.2D — Inert spray chamber and 5 axis numerical control for coating turbine vanes

## 9.5 Spray Booths and Rooms

**9.5.1 General Rules.** General requirements to be considered when designing a fume-dust control system include

(1) When spraying in open booths with copper, aluminum, or aluminum bronze, a minimum air flow of 5,000 cfm (142m$^3$/min) is required and 2,500 cfm (71m$^3$/min) for other materials.

(2) Stagnant areas in the exhaust should be eliminated.

(3) The velocity of air in the gun area, sweeping fumes into the exhaust system, should be at least 300 linear ft/min (90m/min), and in more critical areas on automated systems at least 500 linear ft/min (150m/min).

(4) Transport ducts should be sized to 4,500 fpm (1400m/min) to keep particles airborne. This requires a 16 in. (406 mm) diameter duct operating at 5,000 cfm (142m$^3$/min).

(5) State-of-the-art water wash cleaning systems provide the best overall cleaning efficiency, in the range of 99%. Fines less than 200$\mu$ in. (5 $\mu$m) in size are not completely removed and require higher pressure drop wet scrubbers.

(6) When spraying aluminum, hydrogen may be evolved when the collected powder remains submerged in water. It is important that the exhaust system be activated in advance of any spraying to assure purging of all gases from the exhaust system. Wet collectors should be self-venting.

(7) When spraying, a considerable amount of material may be oversprayed with highest losses occurring with small parts.

(8) Bag filters have been used to collect some powders such as zinc. However, many spray powders are pyrophoric, and hazards exist relative to bag house fires. Bag houses are not recommended except in special situations where the value of the overspray warrants such collection and then only with very competent advice from safety, fire, and insurance experts.

Additional information may be obtained from the AWS

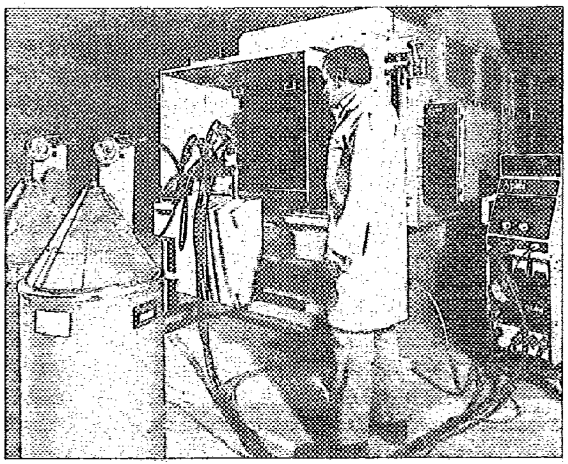

Fig. 9.4.2E — X-Y programmable movement

Research Committee on Safety and Health, equipment suppliers, and dust control equipment manufacturers.

Thermal spraying has a number of undesirable associated features. For environmental control and personnel safety, spraying operations are performed in enclosed areas. Dust and fume overspray must be removed from the work areas as rapidly as possible. Particles less than two microns (80$\mu$ in.) in size can constitute as much as 4 to 15% by weight of the overspray. Nearby personnel must be shielded from ultraviolet radiation, which may cause skin burns and conjunctivitis. Noise limits of 90 dBA or less, per eight hour period, and air flows of 300 linear ft/min (90m/min) or more, depending on the spray process, are necessary to maintain safe operating conditions. The most effective way to achieve these objectives is through the use of spray enclosures.

A limited number of spray enclosures have been specifically designed for thermal spraying operations. Most spray systems are a combination of equipment designed for other purposes. Some manufacturers of either paint or thermal spraying equipment offer a number of basic units that can be built into a system tailored to the needs of the application (Figs. 9.5.1A, 9.5.1B, and 9.5.1C.)

This equipment is applicable to flame and arc spray operations, but is not always suitable for plasma spraying, particularly high energy operations, without an additional protective enclosure for noise control. All spray booths and rooms require an exhaust fan and a wet dust collector to minimize stack emissions. Acoustical treatment may be added or a "sound proof" room enclosure fabricated to enclose the work area. The control console and the operator are located outside the sound proof enclosure. The acoustical room contains the exhaust booth. Some automated applications use exit air velocities of 300 to 500 linear ft/min (90 to 150 m/min). In others, areas that are integral to the building structure are adapted for use as spray rooms. In any case, the specific spray process should be considered, since noise levels vary widely, thus influencing the amount of sound attenuation required.

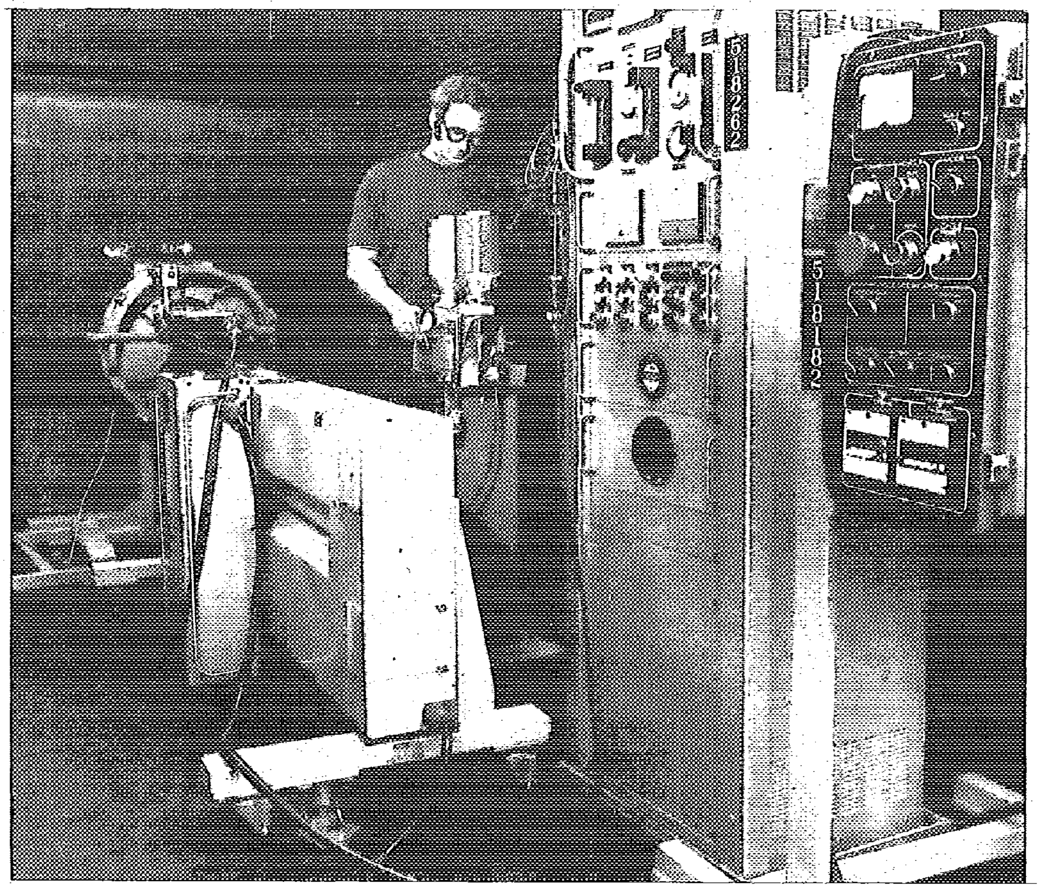

**Fig. 9.4.2F — Numerical tape controlled traverse unit**

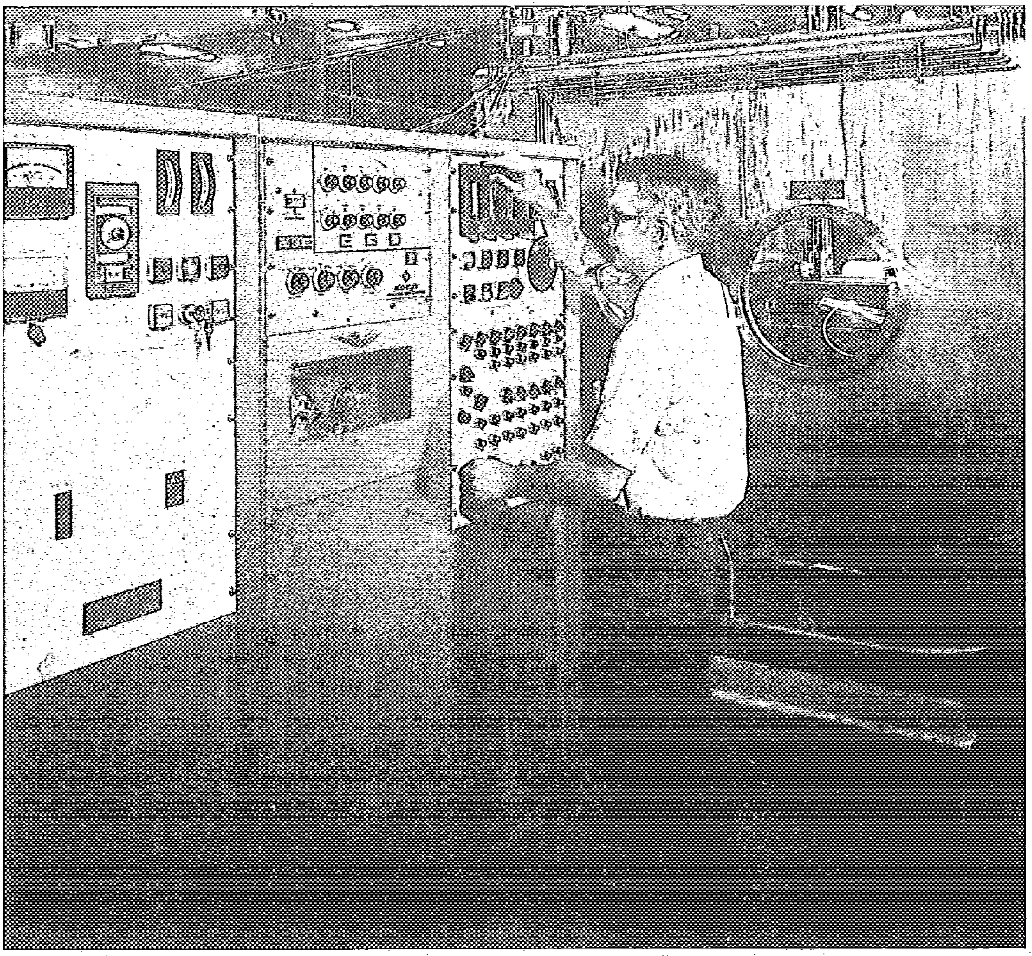

Figure 9.4.2G — Robotic manipulator controls

An alternative approach for providing satisfactory protection is the use of high velocity exhaust spray rooms lined with sound absorbent material. These have built-in facilities for water wash collection of airborne particles, air exhaust, and overhead lighting. They are constructed with three walls, and additional construction may be necessary. The sound absorbent room is constructed larger than the booth to allow for entry of air when the doors are closed. If the operator is working from a remote location, unbreakable windows should be provided for observation purposes.

In cases where the spraying operation must be performed on location, large portable fans and leaded curtains should be used.

The equipment manufacturer should be consulted if specific Environmental Protection Agency (EPA) or state regulations are required relative to stack emissions, since the amount of dust and fume generated depends on many conditions including the type of spray equipment and material.

**9.5.2 Exhaust systems.** Exhaust systems and ventilation equipment complying with safety regulatory requirements are necessary for the protection of personnel. A side effect of thermal spraying is airborne contaminants, such as powder, smoke, and fumes. Dust collectors are required to dispose of these efficiently and quickly.

Wet collectors for thermal spraying are engineered and constructed to remove dust generated during the process. Units are constructed so that the dust laden air passes through a water tank and then through a water screen. Often, units are limited to an exhaust blower and a moisture eliminator (Fig. 9.5.2).

The preferred types of collectors use either the combination of a water pump and an exhaust blower, or a single fan and agitator water pump, to draw the contaminants through a wall of water. A float valve allows replacement of tank water lost through evaporation, and no overflow to area drains occurs.

Bag type collectors consist of a series of fabric filter bags mounted on frames in a dust tight casing. Collection hoppers are located at the casing's base. High velocity air blowers provide circulation. The screen frames are closed at the bottom and either side, leaving the top open for air passage. As dust laden air enters the casing, below the screens, it strikes a baffle plate. This sharp reduction in velocity causes the coarser dust particles to drop directly into the hoppers. Fine airborne dust particles are conveyed to and retained on the dust sides of the cloth screens. The cleaned air passes through the cloth and is discharged through the open top of the screen frames and the collector outlet. Electric or hand powered vibrators, or air pulses, are provided, as required, to dislodge and remove dust particles which adhere to the screens. The capacity of dust collecting equipment depends on the spray powder, the abrasiveness of the dust, and the character and condition of the work.

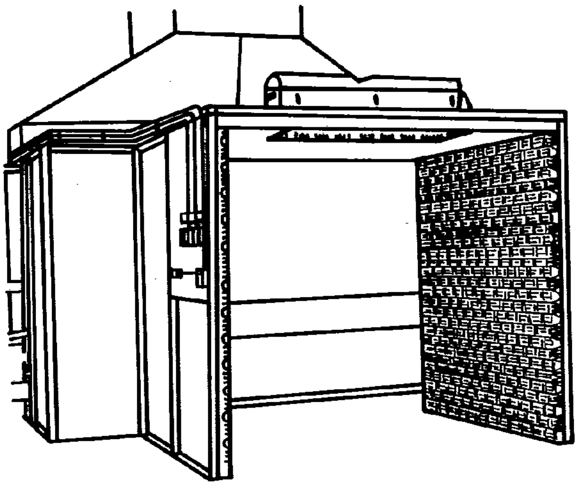

**Fig. 9.5.1B — Tailored spray booth**

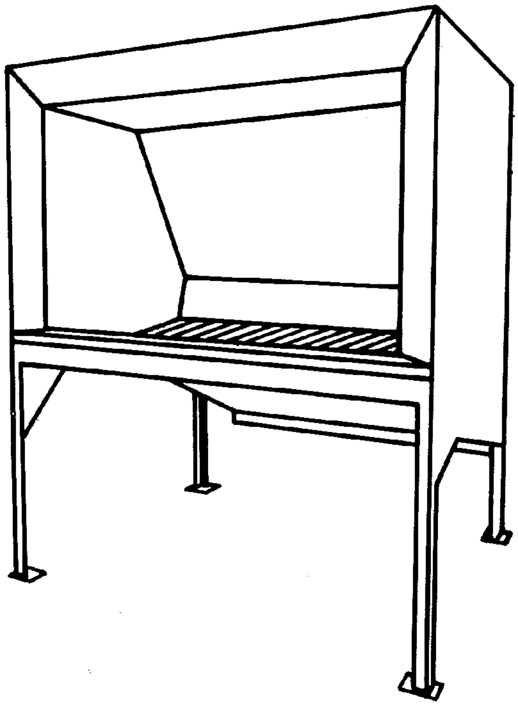

**Figure 9.5.1A — Thermal spray booth (dry)**

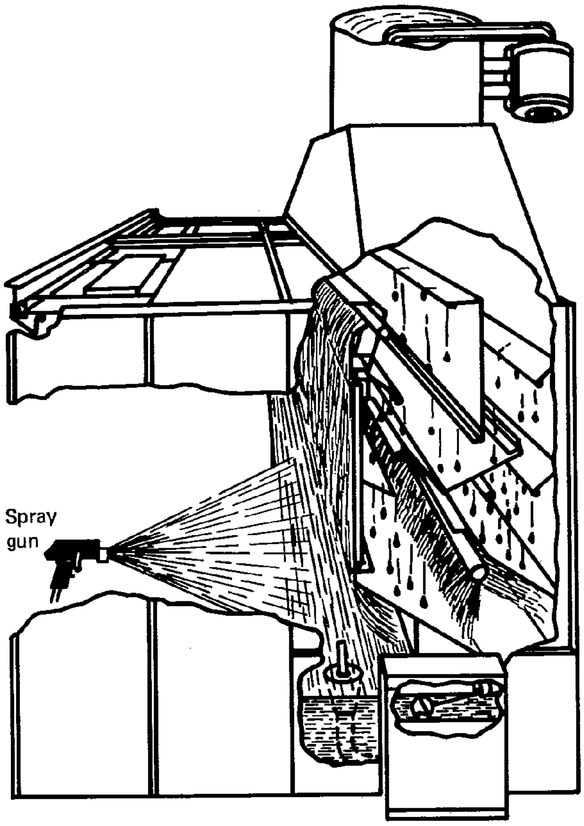

**Fig. 9.5.1C — Integral spray water wash enclosure — basic unit**

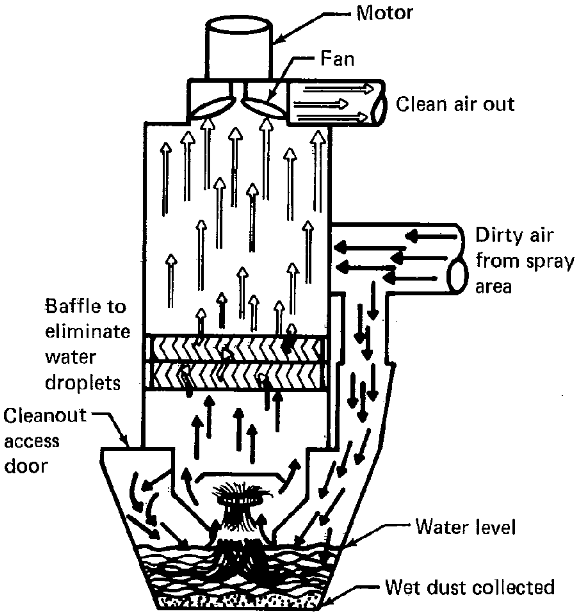

Fig. 9.5.2 — Wet collector

In cyclone collectors and centrifugal cyclone separators, air enters the inlet of these devices, creating a cyclone effect. The air is then drawn through a cone-shaped housing. The heavy particles are forced against the side walls and into the collector box. Clean air exhausts through the center of the turbulent cyclone. These collectors are ideal for controlling bulky particles at their source. All models exhaust outdoors or are equipped with after filters that can save on fuel costs by recirculating cleaned air indoors. This is done only where permitted by law. The self-cleaning material handling fans deliver high performance with low horsepower requirements.

Direct exhaust systems are used where it is permissible to exhaust dust and fumes into the atmosphere. Booths are available with powerful exhaust blowers. The air is circulated through the chamber to accumulate the contaminants and is passed into the atmosphere.

Traveling lathe exhaust units can be mounted on the traversing mechanism. A blower is attached by a flexible hose to the unit. The unit will suffice for short durations of spraying, but does little for actual entrapment of contaminants. A dry type filter can be used on the exhaust side. However, this arrangement hampers the volume of air flow and requires frequent cleaning.

# Chapter 10

# Economics

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# Chapter 10

# Economics

## 10.1 Introduction

It is difficult to discuss the economics of thermal spraying without using specific examples and their related costs. Caution is urged in studying the various examples presented. Every proposed application should be recalculated, based on the specific conditions that will be met in the project under consideration. All the estimates suggested in this chapter are added for reference only. Cost will vary, depending on the type of installation, capital investment, individual overhead, labor cost in the area, stability of raw material, and profit markup. The formats presented can be considered valid, however, and can be used as a basis for generating more exact cost figures.

This chapter considers the economics of various thermal spray processing methods. No comparison is made with other coating processes such as electroplating or welding. Moreover, the reader is cautioned that when this topic is discussed among experts, there are many differing opinions and approaches. For example, if three experienced spray shops were asked how to finish a thermal sprayed coating to obtain the same surface finish in each case, their specific approaches would no doubt differ relative to grinding vs. turning, types of tools, and the like, resulting in quite different cost figures for the finishing steps.

## 10.2 General Considerations

In each application, some or all of the following steps should be cost estimated.

(1) Preparation: chemical cleaning, machining, blasting, and masking

(2) Spray Equipment: process parts, spare parts, backup equipment, operator and safety equipment

(3) Consumables: wire, powder, compressed air, gases, blast media, filters, maskants, sealers, electricity

(4) Labor: preparation, spraying, finishing

(5) Finishing Machinery: cutting tools, grinding wheels

(6) Environmental Equipment: dust control, dust disposal, air cleaners, sound control

Many of the preceeding costs are common to other operations and not specifically restricted to thermal spraying, such as machining and finishing. Information in this chapter will dwell on those items which are directly related to thermal spray operations. Health, safety, and environmental regulations are requirements to be fulfilled, and their impact on cost should be considered. The safety requirements, in Chapter 11, should be carefully followed. These costs primarily revolve around noise control, protection of the operator, and those working in adjacent areas. At times, soundproof rooms should be provided. In some states and localities, certification by regulating agencies is required. Costs are associated with the emissions from the exhaust. The user should be aware of such compliance requirements and be sure that the installation conforms to local ordinances.

With high volume spray applications, dust generation can be costly to control. Filters or scrubbers, or both, have to be installed, and in extreme cases, cost allowances made for the storage, handling, and disposal of dust or sludge.

Similarly, facilities should be available to properly store consumables prior to their use. Some powder materials require a dry, environmentally controlled atmosphere to maintain flowability. All consumables should be protected from excess humidity and kept clean to minimize feeding problems, which increase downtime and operating cost. Facilities should also be provided for safe gas storage and handling.

Adequate supervisory and quality control time should be budgeted to assure adherence to procedures and standards; otherwise, rejects and inefficient procedures can add to costs.

## 10.3 Installation

When contemplating a new thermal spray installation, consideration should be given to the location and the design of the facility. While this may add significantly to initial capital cost, the resultant positive influence on attitude and morale of personnel more than offsets the expense through improvements in productivity and reduced labor turnover. Thermal spray operations are inherently dusty and noisy. If the facility is not properly designed to keep operator areas clean of fumes and dust, and to dispose of that dust, it will be difficult to maintain a staff of high quality, proficient workers. Turnover affects consistent quality and can add to such downstream costs as respraying, coating defects, increased equipment maintenance, and shortened equipment life.

In the case of original equipment manufacturers (OEM) and repetitive manufacturing type operations, the influence of the process on adjacent personnel dictates that spray systems be isolated from surrounding areas by sound insulating barriers or separate rooms. The separate room approach has many advantages in that it isolates odors, fumes, dust, and noise. Recommendations from thermal spray equipment suppliers and other experts should be solicited in these areas.

Different thermal spray processes generate different levels of noise and dust. In addition, the level of toxicity varies with materials. The level of fume generated can vary dramatically, and the design of the spray area should be tailored to specific conditions.

Floor space is a factor that is often ignored until it is unavailable, unsuitable, or inconvenient. Proper floor plans should be established at the outset.

## 10.4 Government Regulations

Government regulations impact both installation and operating costs, particularly in the area of safety procedures and equipment. The selection of proper goggles, fresh air equipment, and respirators contributes to lower costs through satisfied, enthusiastic, confident personnel operating at the highest productivity levels.

State and local environmental exhaust emission codes shall be observed. In extreme cases, the toxicity of the material being sprayed, such as lead, shall be considered. Where emission requirements are stringent, bag houses, electrostatic precipitators, or high energy consumption wet scrubbers may need to be added to the air cleaning system. In many states, maximum emissions are specified. These relate to the weight of dust included in each unit volume of exhaust air discharged from the facility. Typically, this is specified in grains per cubic foot (cubic meter); for example, 0.04 - 0.05 might be a typical number (there are 7,000 grains per pound (15430 grains/kg).

Consider an exhaust stack that is emitting 5,000 cfm (142 $m^3$/min) of air, with a spray rate of 20 lb/h (9kg/h), the overspray is 10 lb/h (4.5 kg/h), and a wet scrubber, 95% efficient, is used to collect the dust. The system efficiency is calculated as follows: 5% of 10 lb/h (4.5 kg/h) overspray is not scrubbed from the air, thus 1/2 lb, 3,500 grains, (227 gm) of material per hour is being emitted from the building. This yields a loading of 0.012 grains per standard cubic foot. Since this value is below the hypothetical acceptable emission level of 0.04 - 0.05 indicated above, the system should pass an emission sampling test. Should the system fail that test, it would be necessary to select a more efficient air cleaning system or pass significantly more dilution air through the collector.

The sample illustrates the need to study any new installation to be assured that environmental codes are met. Estimates for capital and operating costs must include properly sized emission control equipment and allowances for power consumption of associated fans, water pumps, and all related maintenance costs.

## 10.5 Capital and Operating Costs

**10.5.1 Equipment Cost.** The selection of specific thermal spray equipment for the job is treated elsewhere in this manual. Typical cost ranges for equipment at the time of this publication were

| Technique | Equipment cost |
|---|---|
| Wire combustion | \$ 5,000 - \$ 6,000 |
| Electric arc | \$ 8,000 - \$10,000 |
| Plasma | \$15,000 - \$80,000 |
| Powder combustion | \$ 3,000 - \$ 6,000 |
| Rod combustion | \$ 4,000 - \$ 5,000 |

Replacement parts cost depends on the environment and application.

Support equipment such as exhaust systems, scrubbers, and soundproofing rooms can add from \$5,000 to \$50,000 or more to initial installation cost.

**10.5.2 Gas and Energy Costs.** A significant item in the operation of thermal spray devices is the cost of gas. Expenditures vary with volume usage, geographic location, and associated transportation and demurrage charges. Local gas charges should be verified for the anticipated usage. Table 10.5.2 suggests typical system gas and energy costs with assumed gas and electric rates. The data are presented only to serve as a guide for relative gas and energy outlays of the various systems. Material (feedstock) expenses vary widely. Gas and energy consumption charges are sometimes overshadowed by the higher prices of consumables. Also, some spray devices cannot be readily turned on and off, so that the actual energy comsumption, whether gas or electricity, can be much higher than computed for the theoretical spray rates and gas consumptions during a given spraying time.

## Table 10.5.2
## Example of hourly energy cost comparison*

| Type | Air & Gas** | Electricity | Total/h |
|---|---|---|---|
| (1) Nontransferred plasma[a] | $ 8.57 | $ 3.72 | $12.29 |
| (2) Wire arc[b] | 0.32 | 0.23 | 0.55 |
| (3) Combustion wire[c] | 4.75 | 0 | 4.75 |
| (4) Powder combustion[d] | 13.44 | 0 | 13.44 |

a. Nontransferred plasma 7 lb/h (3.2 kg/h)
Argon 75 $ft^3$/h x 8¢/$ft^3$ = $ 6.00/h
Electricity 40 kwh x 6.5¢/kW = 2.60/h
Total $ 8.60/h

To normalize to 10 lb/h: 8.6 x 10/7 = $12.29/h
Nitrogen is cheaper than Argon, but nozzle cost is higher, resulting in similar costs.

b. Wire arc 10 lb/h
Electricity 3.5 kWh x 6.5¢/kW = $0.23/h
Air 35 $ft^3$/min x 60 min/h x 15¢/1000 $ft^3$ = 0.23/h
Total $0.55/h

c. Combustion wire 10 lb/h
Oxygen 90 $ft^3$/h x $0.0204/$ft^3$ = $1.84/h
Acetylene 32 $ft^3$/h x $0.081/$ft^3$ = 2.59/h
Air 35 $ft^3$/min x 60 min/h x 5¢/1000 $ft^3$ = 0.32/h
Total $4.75/h

d. Powder combustion 5 lb/h
Oxygen 95 $ft^3$/h x $0.0204/$ft^3$ = $1.94/h
Acetylene 59 $ft^3$/h x $0.081/$ft^3$ = 4.78/h
Total $6.72/h

To normalize to 10 lb/h: 6.72 x 2 = $13.44/h

*For comparison purposes, costs are shown for the major types of equipment when spraying the same material (stainless steel) at 10 lb/h (4.5 kg/h). This table does not take into consideration the cost of materials. Costs of both energy and materials vary with location, usage, spray gun type, and materials form and size.

**Typical calculations (gas and air rates from Manufacturer's Handbook).

The importance of these various factors varies with the type of material sprayed. For example, when spraying a $1/lb ($2.20/kg) material such as zinc, energy charges are proportionately more significant than they would be when spraying a $30/lb ($66/kg) material. Note that material price can indeed be very high. For example, if a $20/lb ($44/kg) material is sprayed at 10 lb/h (4.5 kg/h), the materials consumption rate is $200/h. Obviously, care should be taken to achieve the best deposition efficiencies consistent with the desired coating properties and production rates.

**10.5.3 Job or Project Costing.** Thermal spraying was used as a repair tool early in its history. Spare parts were often not available within the time frames required for replacement. Under such circumstances, the economics of thermal spraying were very attractive when compared with the value of lost production and the effects on delivery time. As the technology evolved, usage became much broader. In current applications, specific coatings allow use of a less expensive substrate, or economically add properties to the product which are not achieved by other manufacturing techniques. Thus, the economic justification for repairs often is entirely different from the needs of the original equipment manufacturer (OEM). Savings can be so enormous in some repair applications, that the cost of equipment used, or the amount of materials consumed, is insignificant. Timeliness of repair and availability of coating equipment and applicator become more significant. This is not the case for an OEM manufacturer whose process is entirely automated, with a significant portion of the cost evolving from labor, operating cost of the thermal spray equipment, and the cost of consumables.

**10.5.4 Materials.** The cost of spray materials is calculated for known coating requirements; i.e., thickness, area, and deposit efficiency for the process used for each specific part. Some typical coating weights are listed in Table 10.5.4. These numbers can be used to calculate coating material requirements for a specific job or application.

For example, assume

Surface area to be coated $=400$ ft$^2$ ($37.2$ m$^2$)

Effective spray due to loss at holes and edges $=90\%$

Stainless steel feedstock requirement at $100\%$ deposition efficiency (Table 10.5.4)

$=0.035$ lb/ft$^2\cdot 0.001$ in. ($0.17$ kg/m$^2\cdot 0.025$ mm)

Deposit efficiency $=70\%$

Coating thickness $=0.100$ in. ($2.54$ mm)

Spray rate $=60$ lb/h ($27.2$ kg/h)

Amount of spray material required is equal to

$$\frac{\text{Surface area x coating thickness x feedstock required (100\% eff.)}}{\text{Effective spray x deposit efficiency}}$$

$$\frac{400\ \text{ft}^2 \times 0.100\ \text{in.} \times 0.035\ \text{lb/ft}^2\cdot 0.001\ \text{in.}}{0.90 \times 0.70} = 2222\ \text{lb}$$

$$\text{or}\ \frac{37.2\text{m}^2 \times 2.54\ \text{mm} \times 0.17\ \text{Mg/m}^2\cdot 0.0254\ \text{mm}}{0.90 \times 0.70} = 1004\ \text{kg}$$

Material cost can best be determined by obtaining a quoted cost per pound from the appropriate supplier. The same material will vary in cost with volume purchased and form of material; e.g., wire diameter, wire coating, powder size, and type of packaging.

**10.5.5 Spray Time or Production Rate.** Spray time can be calculated for the example just discussed as follows:

$$\text{Spray time} = \frac{\text{amount of material to be sprayed}}{\text{spray rate}}$$

$$= \frac{2222\ \text{lb}}{60\ \text{lb/h}} \quad \text{or} \quad \frac{100\ \text{kg}}{27.2\ \text{kg/h}}$$

$$= 37\ \text{h}$$

The following section of this chapter lists formulas required for job or project costing. Numerous examples are then given to illustrate computations using these varied

## Table 10.5.4
## Typical thermal spray feedstock requirements lb/ft$^2\cdot$0.001 in.

| | Deposit efficiency, % | | | |
|---|---|---|---|---|
| Material | 40 | 60 | 80 | 100 |
| Aluminum | 0.033 | 0.022 | 0.016 | 0.013 |
| Aluminum bronze | 0.083 | 0.055 | 0.042 | 0.033 |
| Alumina (+2% titania) | 0.043 | 0.028 | 0.021 | 0.017 |
| Calcium zirconate | 0.053 | 0.035 | 0.026 | 0.021 |
| Chromic oxide | 0.065 | 0.043 | 0.033 | 0.026 |
| Copper | 0.098 | 0.065 | 0.049 | 0.039 |
| Molybdenum | 0.115 | 0.077 | 0.058 | 0.046 |
| Nickel | 0.098 | 0.065 | 0.049 | 0.039 |
| Nickel 20 chrome | 0.095 | 0.063 | 0.048 | 0.038 |
| Nickel chromium (16% chromium) | 0.098 | 0.065 | 0.049 | 0.039 |
| Stainless steel (17% chrome) (12% nickel) | 0.088 | 0.058 | 0.044 | 0.035 |
| Steel | 0.090 | 0.060 | 0.045 | 0.036 |
| Titania $TiO_2$ | 0.053 | 0.035 | 0.026 | 0.021 |
| Tungsten | 0.220 | 0.147 | 0.110 | 0.088 |
| Tungsten carbide (12% cobalt) | 0.160 | 0.107 | 0.080 | 0.064 |
| Tungsten carbide (17% cobalt) | 0.143 | 0.095 | 0.071 | 0.057 |
| Tungsten carbide (46% nickel) (35% tungsten/cobalt) (11% chromium) | 0.108 | 0.072 | 0.054 | 0.043 |
| Tungsten carbide (33% nickel) (50% tungsten/cobalt) (9% chromium) | 0.120 | 0.080 | 0.060 | 0.048 |
| Zinc | 0.098 | 0.065 | 0.049 | 0.039 |
| Zirconium oxide | 0.070 | 0.047 | 0.035 | 0.028 |

1 kg/m$^2\cdot$0.025 mm = 4.88 lb/ft$^2\cdot$0.001 in.

costing factors. The reader should select from the example segments which would be appropriate to the procedure and process being evaluated. Note that hourly labor costs are not the same in each example, since the skill required for a one-time job is greater than that needed on high production jobs.

## 10.6 Job or Project Costing Formulas

The following will provide guidelines for calculating the cost of a thermal spray coating:

**10.6.1 How to Compute Sprayed Area.** When estimating surface area, an allowance for loss at the edges needs to be made. A good rule is to add 1 in. (25 mm) to each dimension where there is an edge. This compensates for the edge loss. This also applies when estimating the cost of building up a shaft. In this case, add 2 in. (50 mm) to the length to be built up [(1 in. (25 mm) each end].

Area formulae

Circumference of a circle $= \pi d$

Area of a circle $= \pi r^2$

Area of a cylinder $= \pi d\ l$

Area of a sphere $= \pi d^2$

Area of a triangle $= bh \div 2$

Area of a parallelogram $= bh$

Area (lateral) of a cone $= \pi r \sqrt{r^2 + h^2}$

Where $\pi = 3.1416$; b=base; d=diameter; h=altitude; r=radius of base; l=length

**10.6.2 Calculating Costs.** An important factor, when calculating costs, is the normal variation in coating thickness between the thinnest and the thickest area. The extent of this variation depends on the particular job and the manner in which it is coated. For all ordinary coatings, the average thickness should be used in calculating costs. However, if a minimum thickness is specified, be sure to apply an average thickness great enough that no area will be thinner than the specified minimum. If this correction cannot be determined from experience, spray a test area to determine the average thickness required (Table 10.6.2).

**Table 10.6.2**
**Calculation of coating costs per square foot for 0.001 inch average thickness**

| Symbol | Item | Units | | Source |
|---|---|---|---|---|
| | | U. S. Customary | (S.I) | |
| C | Cost of coating | \$ per sq ft for 0.001 in. thick | (\$/m²)<br>(0.25 mm) | Compute |
| P | Spray material cost | Dollars per pound | (\$/kg) | Supplier |
| S | Spray rate | Pounds per hour | (kg/h) | Supplier data or measure |
| E | Equipment operating cost per hour | Dollars per hour | (\$/h) | Section 10.6.3 |
| d | Theoretical density of solid material | Pounds per cubic in. | (g/cc) | Handbook value |
| R | Ratio of coating density to theoretical density | Approximately 85% | (0.85) | Average value |
| v | Vol. of 1 sq ft at 0.001 in. average thickness | 0.144 cubic in./sq ft | (2.4 mm³) | Compute |
| D | Deposit efficiency | Percent | (%) | Supplier data or measure |
| K | Cost of coating | Dollars per pound | (\$/kg) | Compute |
| (PxS) + E | Total operating cost | Dollars per hour | (\$/h) | Compute |
| v x R x d | Coating weight | Pounds/1 sq ft 0.001 in. thick | (kg/m²) | Compute or data bulletins |
| S x D | Spray material deposited | Pounds per hour | (kg/h) | Compute or data bulletins |

Total cost of coating, \$/lb:

$$K = \frac{(P \text{x} S) + E}{S \text{ x } D}$$

Cost of coating, \$ per 0.001 in thickness=

$$C = \frac{[(P \text{x} S) + E]\ [v \text{ x } R \text{ x } d]}{S \text{ x } D} \quad \frac{[(P \text{x} S) + E] \text{ x } 0.122d}{S \text{ x } D}$$

### 10.6.3 Calculation of Equipment Operating Cost

(1) **Combustion Gas and Wire** (see Notes 1, 2, and 3)

Air cost per hour = air used x air cost

Fuel gas cost per hour = fuel gas used x fuel gas cost

Oxygen cost per hour = oxygen used x oxygen cost

$$E = \frac{\text{air cost}}{\text{h}} + \frac{\text{fuel cost}}{\text{h}} + \frac{\text{oxygen cost}}{\text{h}}$$

(2) **Electric Arc** (see Notes 1, 3, and 4)

Air cost per hour = air used x air cost

Electric cost per hour = power (kw/h) x power cost per hour

$$\text{kw} = \frac{\text{dc volts x dc amperes}}{\text{1000 x 0.8 (see Note 4)}}$$

$$E = \frac{\text{air cost}}{\text{h}} + \frac{\text{electric cost}}{\text{h}}$$

(3) **Plasma** (see Notes 1, 2, 3, and 4)

Primary plasma gas cost per hour = gas used x gas cost

Secondary plasma gas cost per hour = gas used x gas cost

Carrier gas cost per hour = gas used x gas cost

Cooling air cost per hour = air used x air cost

Electric cost per hour = power used (kw/hr) x power cost per hour

$$\text{kw} = \frac{\text{dc volts x dc amperes}}{\text{1000 x 0.8 (see Note 4)}}$$

Cooling water cost per hour = water lost or consumed (volume/hour) x water cost

$$E = \frac{\text{Primary gas cost}}{\text{h}} + \frac{\text{secondary gas cost}}{\text{h}} + \frac{\text{carrier gas cost}}{\text{h}} + \frac{\text{air cost}}{\text{h}} + \frac{\text{electric cost}}{\text{h}} + \frac{\text{water cost}}{\text{h}}$$

---

Notes:

(1) Air, gas, electric, and water consumption per hour can be obtained from the equipment supplier's operating manual.

(2) Gas used - volume/unit time.

(3) Include auxiliary items such as dust collectors, water cooling pumps, etc., when applicable.

(4) ac/dc conversion efficiency is approximately 0.8.

### 10.6.4 Six Steps to Establish Cost of Coating

(1) Compute the area to be sprayed

(2) Calculate the volume of the coating

Coating volume = area x coating thickness

(3) Calculate time required

Time = coating volume divided by the volume deposited per hour

$$\text{Time} = \frac{\text{coating volume}}{(\text{spray rate x deposit efficiency})/\text{coating density}}$$

(4) Calculate weight of spray material required

$$\text{Weight} = \text{time required x } \frac{\text{spray rate}}{\text{deposit efficiency}}$$

(5) Calculate equipment operating cost

See Section 10.6.3

(6) Calculate total cost of spraying coating

Total cost of spraying = spray material cost + equipment operating cost + labor cost

Spray material cost = weight used x material cost
Equipment operating cost = values from 10.6.3 x time required
Labor cost = labor cost per hour x time required

---

Note:

The above information relates only to the cost of SPRAYING. The cost of the job also includes

- surface preparation before spraying
- fusing (if required)
- sealing (if required)
- machining, grinding, or other finishing needed after spraying.

Where finishing of the coating is required, include the material to be removed when calculating the thickness of coating to be sprayed.

## 10.7 Case History #1 — Small Spring Spraying

**10.7.1 Background and Problems.** A small AISI Type 302 stainless steel spring used to hold a ceramic ignitor on the gas control burner in clothes dryers required protection to continuous operating temperatures of 1200°F (650°C). Before the springs were coated, they would react with the ignitor and eventually corrode, allowing the ignitor to fall from its position. The coating resisted the reaction.

Tests determined that a 7 mil (0.18 mm) aluminum coating was best for this application. Because of part size and quantity to be processed, the optimum approach was through batch processing. There are 300 springs per pound (136/kg); they are 3/4 in. wide x 1 in. long x 1/32 in. thick (19 mm x 25 mm x .79 mm) and crimped longitudinally with a 5/32 in. (4 mm) bend on two corners which prevents them from adhering during processing. Batch quantities are between 15,000 and 50,000 pieces with a yearly quantity of 200,000 to 300,000 pieces.

**10.7.2 Process.** Initially all parts are vapor degreased to remove stamping oils, and the springs are tumble blasted, with aluminum oxide. After roughening, the parts are sprayed immediately in the same tumble mode. A combustion wire spray gun is used to apply a 0.007 in. (0.18 mm) coating of pure aluminum over all surfaces. The wire spray gun was selected, because it applies a very finely textured deposit and has the low spray rate necessary to prevent part sticking.

**10.7.3 Costs.** Aluminum consumption was 0.01 ounces (.28 g) per part. Because of the tumble spray operation, deposit efficiency was approximately 40%. Other measured costs were

| | |
|---|---|
| Labor cost of preparation | $0.005 per part |
| Labor cost of thermal spraying | $0.005 per part |
| Initial cost of tumble blaster, turning fixture, and thermal spray unit amortized over one million parts | 0.0109 per part |
| Material cost including gas, oxygen, and wire | $0.003 per part |
| Total cost | $0.0239 per part |

Finishing of the coating was not required.

These estimates are added for reference only. Costs will vary depending on the type of installation, capital investment, individual overhead, labor cost in the area, stability of raw material costs, and profit markup.

## 10.8 Case History #2 — Mandrel Repair

**10.8.1 Background and Problems.** Forming mandrels are used in manufacturing plastic pipe. Mandrel size varies with the range of plastic pipe manufactured. Mandrel diameter may be from 8 to 20 in. (0.20 to 0.50 m) and be as long as 23 ft (7 m). The majority of mandrels have a journal at each end that is 2-15/16 in. (75 mm) outside diameter by 16 in. (406 mm) long. Mandrel composition is low carbon steel. Due to a high replacement cost, a method was required to repair scored and worn mandrels.

**10.8.2 Process.** The arc process was selected for its cost effectiveness. A stainless steel (420) coating was chosen for its hardness, wear, and corrosion resistance. The mandrel repair consisted of the following steps:

(1) Set up mandrel in a lathe or grinder, check for straightness.

(2) Straighten mandrel, if required.

(3) Pregrind mandrel, 0.040 in.(1 mm) undersize, using an outer diameter grinder.

(4) Grit blast mandrel.

(5) Coat mandrel, 0.050 in. (1.3 mm) overside on diameter, for a total buildup of 0.090 in. (2.3 mm).

(6) After spraying, finish grind the mandrel to a 16 microinch finish, and polish. Grinding costs are estimated in the total time per mandrel.

The deposition efficiency for this application at 20 lb/h (9.07 kg/h) is 80% with approximately 206 lb (93 kg) of wire consumed per mandrel, i.e.:

Coating area

U. S. = 3.1416 x 8 in. minimum dia x 23 ft x 12 in./ft = 6937 in.$^2$

S. I. = 3.1416 x 0.203 m x 7 m = 4.46 m$^2$

lb metal/mandrel

U. S. = 6937 in.$^2$ x 0.33 lb wire/in.$^3$ x 0.090 in. thk = 206 lb

S. I. = 4.46 m$^2$ x 0.150 kg/in.$^3$ x 61024 in.$^3$ x 0.00229 m = 83.5 kg

$$\text{(U.S.) time} = \frac{206}{20 \text{ lb/h} \times 0.80} = 12.9 \text{ hours}$$

$$\text{(S.I.) time} = \frac{93.5}{9.07 \text{ kg/h} \times 0.80} = 12.9 \text{ hours}$$

**10.8.3 Costs.** The total time required per mandrel is 95 man hours.

| | | |
|---|---|---|
| Labor and overhead | 95 h x $50/h | $4750 |
| 420 spray wire | 270 lb x $3/lb (122/kg x $6.61/kg) | 810 |
| Electricity | 8 kW x 12.9 h x $0.10/kW | 10 |
| Spray air | 35 cfm x 60 x 12.9 h x $1.15/1000 ft$^2$= (59,459 L/h x 12.9h x $0.0000052/L) | 4 |
| Blast air | Similar to spray | 4 |
| Abrasive | 30 lbs $A1_20_3$ x $0.50/lb (13.6 kg $A1_20_3$ x $1.10/kg) | 15 |
| | | $5593 |

The replacement cost for an 8 in. (203 mm) diameter mandrel 23 ft (7 m) long is approximately $13,000.00. Including profit, the repaired forming mandrel saved almost $5,000 compared to a replacement unit.

These estimates are added for reference only. Costs will vary depending on the type of installation, capital investment, individual overhead, labor cost in the area, stability of raw material costs, and profit markup.

The two alternative approaches to repair of the mandrels are as follows:

(1) Manufacture a new mandrel - this would be twice as expensive as the repair process.

(2) The existing mandrel could be chrome plated. This is not economically practical because of the large buildup required per mandrel.

## 10.9 Case History #3 — EMI Shielding of Plastic Cabinets

**10.9.1 Background and Problems.** Manufacturers of small computers and word processors switched to plastic cabinets for cost and cosmetic purposes. Owing to Federal Communications Commission regulations on the amount of radiation permitted from such devices, and interference with circuits within the word processors from outside electrical radiation, the cabinet required coating with a conductive material.

Vacuum metallizing was attempted but deemed excessively expensive and required large capital investments. Available paints were insufficiently conductive, while coating with metal foils was costly and unreliable.

**10.9.2 Process.** Some plastics required grit blasting with 80 mesh aluminum oxide, to produce adequate zinc adhesion, while others merely required a clean surface. Manufacturers determined that 0.002 in. to 0.003 in. (0.05 mm to 0.08 mm) of sprayed zinc was the most economical and reliable way to shield cabinet interiors. Zinc was selected because of its excellent bond strength, ease of application, and low cost. Manual application procedures were selected due to the varied and complex cabinet shapes, and the short time required to enter into production.

**10.9.3 Costs.** Estimated application costs of the arc-spray zinc coating depend on the number of parts to be sprayed, their complexity, and size. It is difficult to arrive at a generalized cost number. However, the following data are presented which can be interpolated for a particular application. The amount of metal deposited depends on the complexity (ribs and pillars) of the surface sprayed. For such complex shapes, manipulation of the gun (to keep the spray stream at 45° to 90° to the surface and to assure a dense coating) may result in localized buildup.

Guidelines to estimate process costs will be indicated for a typical polycarbonate part of approximately 3 sq ft (0.28 $m^2$) surface area with 2 in. (51 mm) high side walls, 2 structural ribs, and 6 support columns 1-1/2 in. (38 mm) high. Table 10.9.3 summarizes the cost that must be considered. An arbitrary labor rate of $12/h has been used.

These figures include no profit and are based on a 200% overhead factor. Masking charges, special packaging, or unusual handling are not included in this example; add appropriate time and labor figures relating to the specific part processed. Again, the purpose of the example is to indicate a format for calculations and to demonstrate the increased productivity and the possibility of reducing spray time with automation. For example, automated installations have demonstrated a 20% reduction in materials costs and a 30% decrease in labor. If production were to be increased by 20% through faster spraying, the cost savings on the annual production rate of 138,240 units produced would be 16¢/$ft^2$ (1.72/$m^2$) or $66,355. This would amortize a typical automated system in one year.

The utilization rate on volume applications will depend on the particular application. For automated systems, it may approach 70% to 90% and for manual operations 50% to 70%.

In making cost projections, note that the amount of metal spray varies with the complexity of the part. In addition, other factors such as surface preparation prior to spray vary greatly with different plastics. Likewise, masking of screw holes, support posts, and the like can increase costs. Masking costs are common to painting and thermal spraying.

The estimates in Table 10.9.3 are added for reference only. Costs will vary depending on the type of installation, capital investment, individual overhead, labor cost in the area, stability of raw material costs, and profit markup.

## 10.10 Case History #4 — Diesel Engine Connecting Rod Bearings

**10.10.1 Background and Problems.** Diesel engine crankshaft and wrist pin bearing areas of connecting rods are babbit lined. This is an excellent bearing surface, sufficiently soft to prevent damage by seizure. It is capable of resisting galling without wearing the mating part. The traditional method of lining connecting rod bearings has been by casting over them with molten babbitt. After the babbit has cooled, the parts are trimmed and machined to dimension.

Poured bearings present a number of costly and time consuming problems. Thin coatings are required for high load, high speed, and heavy duty bearings. It is technically difficult to pour high quality thin coatings because of porosity and crazing resulting during cooling. Thus, thick coatings must be poured and machined down to thinner dimension. Such a coating is spongy, weak, poorly bonded, and structurally inferior. The need for a bearing of greater integrity led to the testing of flame sprayed babbit coatings.

Spraying proved to be the best method of constructing the preferred thin babbitt bearings. Laboratory and field tests demonstrated that sprayed bearings can withstand greater loads than can the more compressible poured bearings. This, coupled with the ease of application, has promoted the use of spray.

Users of sprayed bearings report that they outwear poured bearings 2 to 1. This is partly due to intersplat oxides and the retention of lubricants in the coating micropores.

Poured bearings suffer undesirable segregation of alloy constituents resulting in premature and costly failures. Reports indicate that this is not the case with flame sprayed bearings. Tin-antimony-copper babbit wire is used for this application. The coating is machine finished.

### Table 10.9.3
### Arcspray zinc metal shielding cost using 2-3 mil (0.05 to 0.08 mm) thickness

**Assumptions:**

- Manual application
- 60% time utilization of equipment
- 3 shift operation 48 weeks/year = 240 days/year
- zinc wire cost — $1.00/lb, ($2.20/kg) 20,000 lb (9072 kg) per year quantity
- grit blasting required
- equipment to be amortized in 2 years
- 5 men required/shift
- labor plus overhead $12/h
- air cost 15¢/1000 cf (28.3 m³), consumption 4032 cfh (114.2 m³/h), @ 90 psi (620 kPa)
- electric consumption 15 kva
- 3 sq ft surface/part

**Equipment required:**

| | | |
|---|---|---|
| arcspraying units | (2) | $14,400 |
| grit blasters | (2) | 6,000 |
| water wash booths | (2) | 10,000 |
| handling equipment, etc. | (2) | 30,000 |
| **Total Capital** | | **$60,400** |

**Measured items:**

3 minute spraying time/part
0.5 lb (.23 kg) zinc/unit

Using the above data, the following costs were developed to produce 576 pieces per day: 1728 ft² (160.5 m²)/day, or 414,720 ft²/year (38529 m²/year)

**Summary Arcspray Coating Cost**

| | |
|---|---|
| Equipment amortization (2 years) | 7¢/ft² |
| Labor 5 men/shift x 3 shifts x 52 weeks x $12/h | 90¢/ft² |
| Zinc | 17¢/ft² |
| Air, electricity, replacement parts | 2¢/ft² |
| Total Cost | $1.16/ft² |

**10.10.2 Process.** Manufacturing steps are as follows:

(1) Melt out the existing babbit in a furnace or with a hand torch, and clean the area to be coated with a stainless brush.

(2) Disassemble the parts, shim as required, and mask to limit deposit areas.

(3) Heat the bearing and tin the surface to improve the bond of the sprayed coating.

(4) Use suitable spraying conditions to produce a coating [allowing 0.010 in. (0.25 mm) for fine finishing] which, when machined, will produce a long, continuous chip rather than a fine, broken chip.

(5) Machine to finished dimensions.

**10.10.3 Costs.** Consumables per square foot of surface (0.09 m²) area coated to produce a 0.040 in. (1 mm) coating are 2.016 lb (0.914 kg) babbitt wire, 1.568 cu ft (0.044 m³) oxygen, and 0.898 cu ft (0.025 m³) acetylene. A combustion wire gun was used with a capital cost of $6000. Typical costs for 4 in. (102 mm) dia x 6 in. (152 mm) long bearing are

| | |
|---|---|
| Labor 32 min x $20.00/h | = $10.66 |
| Amortization — cost per spray time | = 1.54 |
| Materials — babbit [1/8 in. (3.2 mm)] 2.016 lb x $8.50/lb | = 17.14 |
| Gases — Oxygen, Acetylene | = .30 |
| **Total cost/part** | $29.64 |

Cost by alternate process for new rod bearing is $50 to $75

This approach to bearing repair has reduced costs over conventional pouring methods by more than half, and permitted repair of large bearings with significantly less capital equipment.

These estimates are added for reference only. Costs will vary depending on the type of installation, capital investment, individual overhead, labor cost in the area, stability of raw material costs, and profit markup.

## 10.11 Case History #5 — Farm Machine Blades

**10.11.1 Background and Problems.** Knives, blades, flails, and bars of crop harvesting machines encounter severe abrasive wear by soil impact and the produce they cut. This wear is compounded by the swinging, rotating, and cutting of the blades against cornstalks, wheat, barley, and hay. Some knives operate at 3600 rpm and provide 70,000 cutting strokes per minute. This causes damage and dulling of the cutting edges, resulting in reduced efficiency and productivity. Damaged parts have to be replaced, and worn parts sharpened. While replacement costs are a concern, the major problem is downtime. Any interruption in the harvesting cycle is very costly.

Research was conducted to determine a means of increasing part wear life to a full season's operation. Thermal spray hard facing was shown to be a solution. Sprayed cutting blades outwear the original hardened steel parts by up to 5 to 1. Market acceptance has been demonstrated by an increasing use of sprayed knives, flails, and bars. Since the cutting blades rotate at high speeds, balance and weight distribution are important to prevent vibration and wear of bearings. When spraying, the knife-to-bar clearances and other dimensions are readily maintained because of the ease of depositing any required coating thickness.

A tungsten carbide-containing self-fluxing alloy was selected for this application. The deposit is fused after spraying. Since the softer base metal wears first, leaving the hard tungsten carbide cutting edge exposed, it promotes a self-sharpening effect.

**10.11.2 Process.** Parts are stack coated, with 4 to 20 blades being sprayed at a time. They are prepared and coated on a semiautomataic production basis. Mechanical shielding and overlapping of parts in fixtures are generally used for blasting and spraying.

A blend of tungsten carbide plus cobalt with a cobalt base self-fluxing alloy is used on hardenable steel such as 4130, 4140, or the 400 series stainless steels. The hardness of the carbides in the coating is HRC75; the hardness of the matrix is HRC58-60. Both are harder, tougher, and more wear resistant than the original steel parts.

A blend of tungsten carbide plus cobalt-nickel with a nickel base self-fluxing alloy is used on mild steel parts. Both coatings are fused either by torch or by induction heating. The steps are as follows:

(1) Degrease the part thoroughly.
(2) Blast with coarse alumina.
(3) Apply coating 0.008 in. (0.20 mm) to 0.015 in. (0.38 mm).
(4) Fuse.
(5) No finishing required.

**10.11.3 Costs.** Consumables per square foot (0.09 m$^2$) of coating are 0.765 lb (.347 kg) powder, 2.295 cu ft (0.065 m$^3$) oxygen, and 1.262 cu ft (0.036 m$^3$) acetylene.

For a part with a dimension of 14 in. x 3 in. x 7/16 in. (356 mm x 76 mm x 11 mm) with 0.015 in. (0.38 mm) of material coating, costs are as follows:

| | | |
|---|---|---|
| Labor 20 min x $50.00/h | = | $16.67 |
| Amortization — auxiliary equipment and powder combustion system $10,000 2 year, 20 h/week | = | 1.67 |
| Tungsten carbide, cobalt powder | = | 5.25 |
| Gases — oxygen, acetylene | = | .12 |
| Total cost/part | | $23.71 |

This application extended part life 3-5 times over new, uncoated blades.

These estimates are added for reference only. Costs will vary depending on the type of installation, capital investment, individual overhead, labor cost in the area, stability of raw material costs, and profit markup.

## 10.12 Case History #6 — Gripping Fingers — Paper Bag Machines

**10.12.1 Background and Problems.** Finger grip assemblies are used in paper bag manufacturing machines. Generally, there are eight such assemblies per machine. Bags are made in stages: cutting, forming, gluing, and trimming. Conveying the bags from one stage to the next is automatic. At each stage of operation, the bag is pulled out of the jaws of the finger assembly, processed, and conveyed to the next stage.

Paper is abrasive, particularly recycled paper used for cement, charcoal, coke, sand, and grain. This abrasiveness rapidly wears the fingers, requiring maintenance and replacement. A method of reclaiming the worn fingers was needed. Welding and chrome plating were tested. Both proved unsatisfactory. Welding was rejected because of excessive heat and warpage. Chrome plating was costly and time consuming. Plasma spray was found to offer an alternative wear solution. Ease of application and extension of service life were the factors that led to the selection of a sprayed coating.

Plasma spraying with a tungsten carbide blend provides a surface more wear resistant than the original base material and has a hardness of HRC52 compared to HRC34 for the base part.

Sprayed parts outwore the original parts at least 4 to 1; one year compared to 90 days.

**10.12.2 Process.** Manufacturing steps are as follows:

1) Degrease.
2) Mask areas not to be coated.

3) Grit blast with coarse alumina.
4) Apply coating to a thickness of 0.015 in. (0.38 mm).
5) No finishing is required.

**10.12.3 Costs.** Consumables per square foot (0.09 $m^2$) of coating to produce 0.015 in. (0.38 mm) thick coating are 1.320 lb (0.599 kg) tungsten carbide/cobalt powder, 4.693 kw electricity, 22 cu ft (0.622 $m^3$) nitrogen, and 1.5 cu ft (0.042 $m^3$) hydrogen.

For a part with a dimension of 14 in. x 3 in. x 7/16 in. (356 mm x 76 mm x 11 mm) costs are as follows:

| | | |
|---|---|---|
| Labor — 12 min x $50.00/h | = | $10.00 |
| Amortization — cost per spray time<br>Plasma system $30,000 2 years,<br>20 h/week (4.5 parts/h) | = | 3.30 |
| Material — tungsten carbide plus cobalt | = | 5.57 |
| Gases — nitrogen | = | 0.53 |
| — hydrogen | = | 0.06 |
| Electricity—0.39106 kWh x 0.12 kW/h | = | 0.05 |
| Total cost/part | | $19.51 |

The cost of a new gripper finger: =$62.00 ea.

These estimates are added for reference only. Costs will vary depending on the type of installation, capital investment, individual overhead, labor cost in the area, stability of raw material costs, and profit markup.

## 10.13 Case History #7 — Grinder Spindles

**10.13.1 Background and Problems.** Manufacturers of precision parts use grinders for close tolerance finishing operations. Working to tight dimensions [such as 15 millionths of an inch (0.38 $\mu$m) on concentricity and tenths of thousandths (0.25 mm) on the diameter], spindle bearings must remain tight to prevent slight spindle play. Under such extreme conditions, shafts wore in several days. The combination of replacement cost plus downtime made the operation very expensive. Chrome plating proved unsatisfactory. Special tool steels were also evaluated, but the spindle journals continued to wear prematurely.

Technically and economically, thermal sprayed coatings proved to be best of all the processes evaluated. Various spray materials were tested. Some, such as molybdenum, were used successfully before the development of powder flame sprayed ceramic coatings. The ceramic coatings provided outstanding results on repaired parts and have been incorporated in original equipment manufacturing. Easily processed, lower priced steel base materials have replaced the earlier used special forgings. Low cost hardened steel base materials have replaced the costly bronze babbitt originally used to make the mating bearings.

Flame sprayed spindles outwear the original forged spindles 24 to 1. The lower friction of a ceramic coated journal reduces wear on the mating bearing, and it is not corroded by grinding coolants.

**10.13.2 Process.** The powders used are a nickel aluminum bond coat, followed by a titania top coat. Alumina titania coatings may also be used for this application. Manufacturing steps are as follows:

(1) Degrease.
(2) Undercut 0.012 in. (0.30 mm) on the radius.
(3) Mask areas not to be coated.
(4) Preheat to 300°F (149°C) for one hour. This can be done in a furnace or oven.
(5) Check temperature with pyrometer to assure that it is at least 250°F (121°C). If not, torch heat to 250°F (121°C).
(6) Apply a 0.006 in. (0.15 mm) nickel-aluminum bond coat.
(7) Apply titanium dioxide 0.25 in. (6.4 m m) thick. This allows 0.013 in. (0.33 mm) for finish grinding.
(8) Seal with a room temperature curing phenolic. Air dry 30 to 60 minutes. Oven heating at 275°F (135°C) will dry the sealer in 15 to 30 minutes.
(9) Grind, using either a diamond or a silicon carbide wheel.
(10) Reseal as required.

Procedures for repair are the same as shown above, except that the worn coating must be removed.

**10.13.3 Costs.** Consumables per square foot (0.9 $m^2$) of surface area coated are 0.006 in. (0.15 mm) nickel-aluminum bond or 0.252 lb (0.114 kg) powder, 1.470 cu ft (0.042 $m^3$) oxygen, 1.050 cu ft (0.030 $m^3$) acetylene, 0.025 in. (0.64 mm) titania coating or 0.900 lb (0.408 kg) titania powder, 21.15 cu ft (0.60$m^3$) oxygen, and 12.60 cu ft (0.36 $m^3$) acetylene.

For a 2 in. (51 mm) diameter x 3 in. (76 mm) long part, the costs are as follows:

| | | |
|---|---|---|
| Labor — 25 min x $20.00/h | = | $ 8.33 |
| Amortization — cost per spray time<br>Powder combustion system $4,500,<br>lifetime 2 Years, 20 h week | = | 2.16 |
| Material — nickel-aluminum bond | = | 0.83 |
| — titania | = | 2.33 |
| Gases — nickel-aluminum bond | | |
| oxygen | = | 0.07 |
| acetylene | = | 0.21 |
| — titania bond | | |
| oxygen | = | 0.10 |
| acetylene | = | 0.21 |
| Total cost/part | | $14.24 |

The cost of a replacement spindle is $1000.00.

These estimates are added for reference only. Costs will vary depending on the type of installation, capital investment, individual overhead, labor cost in the area, stability of raw material cost, and profit markup.

## 10.14 Case History #8 — Automotive Valve Seats

**10.14.1 Background and Problems.** An automotive cylinder valve controls the intake of fuel gases and the exhaust of the cylinder residue. In operation, the valve frets and traps hard carbon particles between mating valve seats, which tend to hold the valve open. This results in a gap which permits abrasive and corrosive particles to pass over the seats at high velocity and high temperature. This causes excessive wear.

To counter this problem, tests were conducted to identify a coating that would withstand the operating conditions.

On valves, a flame sprayed, fused coating of aluminum proved to be a good solution. It is used on many of the valves being produced. The process consists of applying a thin aluminum coating and fusing it. This forms intermetallic compounds which provide the required wear and corrosion resistance.

Prior to applying the sprayed aluminum coating, the valves were dipped in molten aluminum. This proved to be slow, inefficient and unsafe.

With more recent engine designs, the performance demands created a requirement for a coating other than aluminum. Special metals were evaluated, but they failed. Coating by hard chrome plating and brazing was also evaluated, but this proved ineffective.

Flame sprayed coatings of fused self-fluxing nickel-chromium alloys provided the best protection, and proved to be the most practical of all methods tested. It easily dovetails with automatic handling equipment, is lowest in cost, and is the least dependent on technique. The system offers consistent reproducibility, assuring quality, and production efficiency.

Sprayed valves outwear uncoated valves at least 2 to 1, resist wear by abrasive grains at high temperatures, and resist fretting, erosion, and corrosion at high temperatures.

### 10.14.2 Process

**Aluminum Coating (Wire).** By the combustion wire process, aluminum wire is sprayed and subsequently fused to form the desired coating. The process steps are as follows:

(1) Grind valve seat to final dimensions.
(2) Degrease.
(3) Load onto conveyor stations.
(4) Induction preheat to 450°F to 475°F (232°C to 246°C).
(5) Using 15 gauge aluminum (1.45 mm), apply a "fog" coating 0.00075 in. (19 $\mu$m) to 0.001 in. (25 $\mu$m).
(6) Induction fuse at 1450°F (787°C).
(7) Finishing is not required.

**Self-Fluxing nickel chromium coating.** These alloys are applied by the combustion powder process. The process steps are as follows:

(1) Degrease.
(2) Grit blast with coarse alumina grit.
(3) Preheat part to 250°F to 300°F (120°C to 150°C).
(4) Apply a self-fluxing alloy 0.25 in. (6.4 mm) thick. This thickness allows for normal cooling shrinkage and for finishing. Use a concentrating nozzle for controlled high deposit efficiency.
(5) Fuse coatings either by automatic torch or induction heating.
(6) Grind to size.

**10.14.3 Costs.** Consumables per square foot (0.09 m$^2$) of coating 0.001 in. (0.025 mm) thick are 0.014 lb (6.35 gm) aluminum wire, 0.108 cu ft (0.003 m$^3$) oxygen, and 0.48 cu ft (0.0136 m$^3$) acetylene.

For a part dimension of 1 3/4 in. (45 mm) diameter x 3/8 in. (9.5 mm) high, costs are as follows:

| | |
|---|---|
| Labor — 15 min x $20.00/h | = $5.00 |
| Amortization — cost per spray time | = 0.25 |
| Wire combustion system $6,000, lifetime 2 years, 20 h week (3 shifts) | |
| Materials — aluminum wire 1/8 in. (3.2 mm) diameter | = 0.0051 |
| Gases — oxygen | = 0.004 |
| acetylene | = 0.00076 |
| Total cost/part | $5.26 |

Cost of alternate dipping process was 50% higher.

These estimates are added for reference only. Costs will vary depending on the type of installation, capital investment, individual overhead, labor cost in the area, stability of raw material costs, and profit markup.

## 10.15 Case History #9 — Anti-Fretting Coatings on Jet Engine Stator Vanes

**10.15.1 Background and Problems.** The air flow within high pressure compressor military and commercial jet engines is directed around and through stationary airfoils referred to as *vanes*. They are individually mounted in a circumferential dovetailed slot on the stator inner diameter. Quantity and size depend upon the engine's thrust, but normally may exceed 1000 and are larger than 1 in. (25 mm) long.

The purpose of a stator vane is to help orient air flow. Thus, as the air is compressed and forced back into the turbine, it exerts intermittent loads upon the vanes. This load is transmitted to vane footings within the stator dovetail slots. Vane footings are also of a dovetail configuration. The vane, as it rocks in the slot, causes fretting wear to both its upper surfaces and the outer diameter of the slot. To reduce metal loss, a lubricating wear coating is introduced onto the mating surfaces. Normal lubricants, such as colloidal graphite or molybdenum disulfide, when stressed under engine operating loads, rapidly extrude outward, leaving bare metal contact surfaces.

It has been determined that a 0.002 to 0.004 in. (0.05 to 0.10 mm) layer of plasma sprayed copper-nickel-indium alloy will afford wear protection and provide a reservoir for the lubricant. Indium provides lubricity, while coating pores and valleys retain the lubricant. Batch quantities are between 15,000 and 20,000 pieces, with an annual requirement of 500,000 pieces.

**10.15.2 Process.** All vanes are solvent washed to remove grease or oils remaining from machining and forming operations. After cleaning, the vanes are loaded into a fixture which protects them during both the blast and spray operations (Fig. 10.15.2).

A typical fixture is 48 in. (1.2 m) long and may hold 20 to 40 vanes. Thus, batch processing is possible. Once loaded, the vanes are grit blasted in an automatic machine; from there, the fixtured vanes are surfaced by a straight line plasma gun manipulator. Four passes, two on each side of the vane, apply the CuNiIn alloy. After being sprayed, the vanes are taken from the fixtures, power wire brushed to remove loosely adherent particles, and given a final inspection.

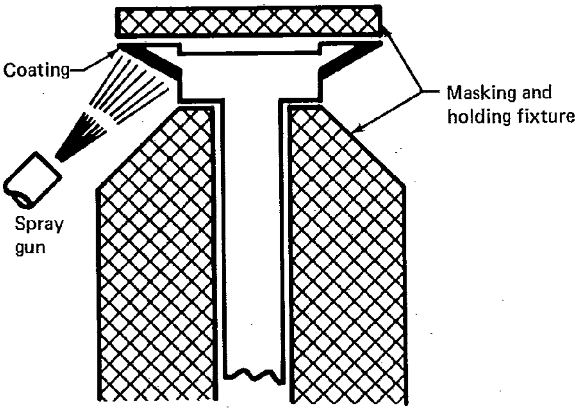

**Fig. 10.15.2 — Vane loaded in fixture**

**10.15.3 Costs.** The amount of CuNiIn deposited per part varies with part size. Use of a concentrating nozzle optimizes deposit efficiency at 65%. Typical costs per part are

| | |
|---|---|
| Labor | |
| Degreasing | $ 0.005 |
| Fixturing | 0.04 |
| Grit blasting | 0.02 |
| Spraying | 0.02 |
| Clean-up | 0.08 |
| Inspection | 0.10 |
| Consummables | |
| Solvent | $ 0.005 |
| Gases | 0.10 |
| Powder CuNiIn | 0.16 |
| Total cost/part | $ 0.53 |
| Amortization of equipment | |
| Fixturing | $ 5,000/set/stage |
| Plasma system | 80,000 |
| Gun manipulator | 12,000 |

In this case there were no competitive costs for comparison.

These estimates are added for reference only. Costs will vary depending on the type of installation, capital investment, individual overhead, labor cost in the area, stability of raw material costs, and profit markup.

## 10.16 Case History #10 — Abradable Clearance Control Coatings for Gas Turbine Compressors

**10.16.1 Background and Problems.** Compressors for advanced turbine engines used to power jumbo jets are designed with higher pressure ratios, fewer stages, and higher tip speeds than employed in engines of simpler construction. Under these conditions, leakage over compressor blade tips can result in substantial performance losses. Attempts to reduce these losses by reducing tip clearances are often hindered by excessive tip rubs. A rub can lead to

- Blade wear and, hence, increased clearance
- Blade tip damage or failure

- Generation of debris which can stick to airfoils or clog cooling passages, and thus further reduce performance

Rub coatings sprayed on the blade tips are abradable, thereby producing minimal damage to blade tips. They retain tight clearance and generate nonsticking, inert debris. These coatings can produce significant improvements in engine performance.

The application of abradable-clearance control materials by thermal spraying techniques has proven to be a satisfactory means of producing acceptable sealing surfaces with excellent rub characteristics.

Typically, a large jet engine's front compressor case is slightly conical, measuring approximately 40 in. (1 m) high with a diameter varying from 28 to 32 in. (0.71 to 0.81 m). The unit may be constructed from titanium or a martensitic stainless steel.

**10.16.2 Process.** Casings are initially steam cleaned and solvent washed to remove dirt or oil residues. A combination of silicon rubber, teflon, and stainless steel masking is employed to protect areas not to be roughened, coated, or both. The entire inner diameter is then grit blasted with SAE 120 alumina, after which it is mounted on a turntable to be rotated during plasma spray application. The plasma spray process was selected owing to the high integrity of the coating.

The abradable-clearance control coating is a duplex system comprised of a 95Ni/5Al barrier bond coat, 0.004 to 0.007 in. (0.10 mm to 0.18 mm) thick, overlayed with 0.022 to 0.027 in. (0.56 mm to 0.69 mm) of pure aluminum. The aluminum, to assure satisfactory aerodynamic air flow, is machined.

**10.16.3 Costs.** Typical costs per casing are as follows:

| Labor | |
|---|---|
| Degrease | 0.5 h |
| Mask | 8.0 |
| Grit blast | 4.0 |
| Spray | 6.0 |
| Clean-up/inspect | 2.0 |
| Total | 20.5 h |

| | | |
|---|---|---|
| Labor and overhead-20.5 h x $40 | | $820.00 |
| Machining | 150.00 | |
| Materials | | |
| Solvent | $ 2.00 | |
| Masking tape | 14.00 | |
| Powder | | |
| 9 lb NiAl @ $20/lb | 180.00 | |
| 9 lb Al @ $8/lb | 72.00 | |
| Grit | 45.00 | |
| Total | $ 313.00 | |
| Total coating cost | | $1,283.00 |
| Tooling/masking | | $8,000.00/set |
| Equipment | | |
| Typical spray cell with attendant equipment | | $150,000.00 |

No competitive process is available; hence, the increase in engine performance and reliability pay for the coating costs in a fraction of a year's operations.

These estimates are added for reference only. Costs will vary depending on the type of installation, capital investment, individual overhead, labor cost in the area, stability of raw material costs, and profit markup.

## 10.17 Case History #11 — Corrosion Protection

The economics of corrosion protection is a vital but complex issue. It has been estimated that on an annual basis, corrosion destroys the equivalent of one-fifth of the world's annual production of ferrous metals, and that in the United States 40% of all steel production goes to replace corroded parts and products. The total cost of corrosion damage in the United States was calculated to be $70 billion (1975). Ten billion dollars of this was probably avoidable. These figures indicate the enormity of the problem.

The economic imperative should be to choose a corrosion protection system which will have a low initial cost and provide adequate protection to a structure throughout its projected lifetime, with a minimum of expensive maintenance. Unfortunately, there are many variables which should be considered when deciding what is an adequate protection system. Each system can be expected to last for varying lengths of time, depending on the specific environment. What will be adequate in one set of circumstances may prematurely fail in another. Moreover, it is difficult to compare specific costs, since these vary widely from job to job and from one geographical location to another. Even for a given structure in a given locality, cost estimates may vary considerably from one company to another, as well as from one system to another.

There are, however, certain general factors that should be considered in establishing and comparing the effective overall cost of different corrosion protection systems. First, it should be recognized that it is essential to take into account not only the initial cost of protection, but also maintenance costs over the design lifetime of the structure. While initial costs are a known factor, the cost of future maintenance is unpredictable and increasingly expensive. Each successive maintenance operation can be expected to cost more. Labor and material costs are continuously rising, and the quality of future maintenance cannot be guaranteed. Environmental considerations have led to government imposed regulations. The financial impact on maintenance operations is substantial. New regulations relating to toxic and noise hazards are likely to lead to still more stringent and costly restrictions in the future. While these expenses may lead to unacceptably high maintenance costs over the intended life of the structure, they cannot be easily planned or controlled. Maintenance is not always merely expensive; in many cases, due to geographical or other logistical constraints, it may be virtually impossible. Furthermore, the economic and social consequences of removing a structure from service, which is often necessary in order to carry out maintenance work, can not be ignored. This is especially true where, as in the case of the closing of a bridge or major roadway, the disruption becomes an economic disaster. It is therefore essential to choose a corrosion protection system which will minimize both maintenance costs and the number of maintenance operations.

On these counts, thermal spraying has outstanding economic advantages. Spraying a steel bridge with zinc can assure its essentially maintenance-free life for 20 or more years. When maintenance is eventually required, surface preparation for repair of sprayed zinc coatings, whether sealed or painted, is a simple matter of removing dirt and any loose sealer or paint, and then applying a new top coat. This is in sharp contrast to the extensive, and costly, surface preparation necessary to remove rust which frequently forms on structures protected by paint alone. The cost of building scaffolding, often required to carry out repair work on site, is extremely high, and the labor-intensive nature of such repair increases the costs still further. Moreover, material costs for maintaining a complex paint system containing a number of raw materials, often derived from petrochemicals, can be expected to rise far more steeply in the future than the material costs involved in maintaining a simple sprayed metal coating. Corrosion protection systems based on paint, which require frequent and regular maintenance in order to preclude early protection failure, also demand far more frequent, and hence more costly, inspection procedures than do protection schemes based on metal spraying.

Aluminum and zinc sprayed coatings have the further economic advantage of providing considerable flexibility in corrosion protection systems, since the thickness of sprayed coatings can be tailored to meet specific environmental requirements. In instances where maintenance can be expected to be unusually difficult or expensive, the thickness of the coating can be increased to give additional years of maintenance free life. In such cases, the extra corrosion protection afforded by the thicker coating will add little to the total initial expense of the project and will be highly cost effective in the long run. Also, a sealer can be applied which, for a modest cost, will significantly extend the life of the coating.

On an overall cost basis, with the expense of future maintenance included in the calculations, metal spraying has long been competitive with most other corrosion protection systems. A 1971 British study of structural steel protection costs determined that spraying zinc or aluminum was approximately 10 to 20% more expensive than comparable paint schemes on an initial cost basis. However, the lifetime protection provided by these paint schemes, in the same environmental conditions, is a minimum of 5 to 15 years shorter than the maintenance free protection provided by metal spraying. Thus, with the expense of maintenance factored in, the apparent initial cost advantage of paint schemes is quickly eliminated. In long term use, metal spraying provides better protection at lower cost.

This experience is being confirmed in the United States. In a service evaluation program started in 1978, 22 of a fleet of railroad tank cars have been metal sprayed to evaluate the performance and economy of various thicknesses of zinc both with and without sealers. The cost of zinc coating an average tank car in this program was $1042, or approximately two times the cost of an average paint job. However, the spraying cost could have been substantially reduced had the cars been treated during manufacture, where the benefits of automation would have been possible. Furthermore, it is anticipated that the zinc coatings will last the 20-year life of the cars, with only cosmetic touch-ups required. A painted tank car, on the other hand, is taken out of service and repainted approximately every 5 years over a 20-year lifetime. Thus, even without the lowered cost made possible by automation, thermal spraying will yield a substantial savings over the lifetime of the car. For example, in the program cited above, it has been projected that thermal spraying of a fleet of 1200 railroad tank cars will lead to an annual savings of $80,000.

Cost estimates are added for reference only. Costs will vary depending on the type of installation, capital investment, individual overhead, labor cost in the area, stability of raw material costs, and profit markup.

It is important to note that more recent studies indicate that there is a trend towards metal spraying becoming cheaper than comparable paint schemes, even on a first cost basis alone. A survey, conducted in the United Kingdom during November 1977, of the comparative costs per square meter of surface for protecting different types of fabricated steelwork using various protection systems, found that unsealed sprayed zinc was approximately 20% cheaper on a first cost basis than comparable paint schemes. Sealed sprayed zinc was about the same or slightly cheaper than comparable paint schemes on a first cost basis.

Compared with high quality paint schemes, zinc or aluminum sprayed coatings are often completely competitive, even on an initial cost basis. When the increased maintenance costs and shorter protection times of paint systems are included in the economic calculations, the cost advantages of corrosion protection by metal spraying are obvious. Furthermore, inadequate corrosion protection may lead not merely to the need for extensive and expensive maintenance operations, but also to the premature failure of the structure as a whole. This will necessitate a replacement long before its planned lifetime. In an age when conservation of the world's natural resources has financial as well as an environmental priority, corrosion protection methods should both last the life of the structure and even lengthen its life. Metal spraying accomplishes this and also avoids the waste of resources which would be required for their replacement and maintenance. The more reasons society has to perpetuate the life of existing or new steel structures, the more metal spraying is viewed as economically desirable.

Considerable promotion of metal spraying is underway in the United States at technical, governmental, and commercial levels. It is suggested that the reader contact various equipment suppliers and thermal spray contractors and investigate available literature for further information.

# Chapter 11

# Safety

**Chapter Committee**

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# Chapter 11

# Safety

## 11.1 Scope

The potential hazards associated with thermal spraying, including the preparation and finishing processes, and the safe practices applicable to those operations, are discussed in this chapter. The words *approved* or *approval* mean acceptable to the authority having jurisdiction.

**11.1.1 Safety Guides.** It is recommended that all personnel concerned with thermal spraying become familiar with these safe practices and the safety regulations contained in established standards. Such pertinent standards are listed in 11.10 at the end of this chapter.

Local, state, and federal health (OSHA Standards) should be thoroughly understood for proper compliance, especially when handling toxic materials.

**11.1.2 Disposal of Toxic Wastes.** Toxic materials may be generated by the thermal spraying process, during preparations for the process, the process itself, or subsequent finishing operations. Their disposal shall be in accordance with the regulations of EPA *Resource Conservation and Recovery ACT (RCRA)* governing the disposal of toxic wastes.

**11.1.3 Flammable Solvents and Sealer Bases.** Certain hydrocarbon degreasing solvents and sealer bases are flammable, and special handling precautions should be observed relative to their use, handling, and storage in and about the thermal spray area.

## 11.2 Fire Prevention and Protection

The basic precautions for thermal spraying are essentially the same as for welding and cutting. Consult *ANSI/AWS* Z49.1, *Safety in Welding and Cutting*; NFPA 51B, *Standard for Fire Prevention in Use of Cutting and Welding Processes;* and NFPA 58, *Standard for the Storage and Handling of Liquified Petroleum Gases.*

Airborne metal dusts, finely divided solids, or accumulations should be treated as explosives. To minimize danger from dust explosions, adequate ventilation should be provided to spray booths. A wet collector of the water wash type is recommended to collect the spray dust.

Bag or filter-type collectors are not recommended, except in special applications where the material to be collected is not explosive. Such collectors should only be used after consultation with those experienced and knowledgable in the field. Further, when operational conditions do require these collectors, only the disposable type should be used. Reusable bag or filter-type collectors are difficult to clean of spray dust and so present an explosion or fire hazard.

Good housekeeping in the work area should be maintained to avoid accumulation of metal dusts, with particular attention given to inspecting for dust on rafters, tops of booths, and in floor cracks.

The extremely hot conditions of thermal spraying operations require additional precautions such as, not pointing thermal spray equipment at any person, or at material that will burn. Paper, wood, oily rags, and cleaning solvents can be ignited and should not be stored or contained within the spray room or enclosure.

## 11.3 Safe Operating Considerations

**11.3.1 Storage, Handling, and Use of Compressed Gas Cylinders.** Local, state, municipal, and federal regulations relative to the storage of cylinders should be investigated and their rules complied with.

Storage, handling, and use of oxygen and all fuel gas cylinders shall be in accordance with ANSI/AWS Z49.1, *Safety in Welding and Cutting,* and with CGA Pamphlet P-1, *Safe Handling of Compressed Gases.* The improper storage, handling, and use of gas cylinders constitute a safety hazard in the thermal spraying operation.

Oil or grease should never be used on oxygen equipment. Only special oxidation resistant lubricants may be used with oxygen equipment. When in doubt, a qualified dealer or the equipment manufacturers should be consulted.

Manifolding of cylinders is frequently required when spraying. This permits longer spray times before changeover. These installations should be in accordance with ANSI/AWS Z49.1.

Pressure reducing regulators should be installed and used in accordance with ANSI/AWS Z49.1. Only the appropriate regulator for each gas cylinder should be used. Only acetylene regulators should be used on acetylene tanks or manifold systems. It is important to use the correct size wrench to connect the regulator to the cylinder valve outlet; never force or overtighten a connection. Oil or grease should never be used on a regulator.

**11.3.2 Flow Meters.** Flow meters should be installed and used in accordance with ANSI/AWS Z49.1. If a flow meter with glass tubes is used, a protective shield should be placed between the flow meter and the gun. In addition, backflow prevention devices should be used in conjunction with flow meters to avoid unsafe operating conditions and to ensure proper flame balance.

Hose and hose connections should be installed and used in accordance with ANSI/AWS Z49.1 and *Specification for Rubber Welding Hose,* published jointly by the Rubber Manufacturers Association and the Compressed Gas Association. Damage to hoses should be avoided. Hoses for applications for which they were not designed should never be used.

When connecting oxygen and fuel gas cylinders, pressure reducing regulators, and flow meters, the connecting nuts should be drawn up tight, but should never be overtightened. (Overtightening is likely to collapse the nose of the nipple.) If the fitting cannot be sealed without undue force, the fitting should be replaced.

Adequate ventilation of the work area should be provided before opening any of the gas valves.

The pressure reducing regulator should be drained of gas and the regulator adjusting screw fully released before opening the cylinder valves.

Cylinder valves should be opened slowly. One should stand to the side of the pressure reducing regulators when releasing the cylinder valves.

Regulator adjusting screws should be turned in slowly to prevent surges that may crack or burst flow meter tubes. Hoses should be blown out to remove any dust that may be present in them. Sources of ignition should be avoided.

The hoses to the thermal spray gun should be checked for leaks at all connections, with soapy water applied to each joint while the system is under pressure. A flame should never be used to check for gas leaks. Soapy water is safer and provides a more sensitive test than a flame.

When connections are found to leak, the following operations should be performed: depressurize, open the connection, wipe the sealing surfaces clean, see that the threads are clean, retighten, repressurize, and retest for leaks. If a leak persists, the system should be depressurized. Leaking thermal spray equipment should never be used. A **Danger--Do Not Operate** tag should be placed on the defective equipment.

Obstructions in the gas lines caused by defective hoses, collapsed hose stems, or dirt in the gas passages of the gun head or the nozzle jets will require excessive pressure to obtain proper gas flow.

Acetylene pressures in excess of 15 psig (103 kPa) are dangerous and must not be used — the gas may detonate. When acetylene pressure of 15 psig (103 kPa) is insufficient, another fuel gas should be used. If both oxygen and fuel gas pressure required are more than 3 psi (21 kPa) over recommended pressures, a fouled nozzle or incorrect air cap adjustment is usually indicated. Pressures that are too low usually indicate a serious leak. Equipment should be shut down and the condition corrected before attempting to reuse the system.

**11.3.3 Compressed Air.** Compressed air should be referred to by its proper name to avoid confusing it with oxygen or fuel gas. Compressed air should never be used to clean clothing. Similarly, oxygen and fuel gas should not be used for this purpose.

Compressed air for thermal spraying or blasting operations should not be used at pressures other than those recommended by the equipment manufacturers. The air line should be free of oil and moisture. A qualified air compressor dealer or thermal spraying equipment manufacturer should be consulted for recommendations regarding filters and after coolers.

## 11.4 Flame Spray Equipment

Flame spraying guns should be maintained in accordance with the manufacturer's recommendations. Each thermal spraying operator should be familiar with the operation of the flame spraying gun. The gun instruction manual should be thoroughly read and understood before lighting the gun for the first time.

If a gun is equipped with valves, such as a taper valve for controlling the flow of oxygen, fuel gas, or compressed air, they should be properly seated and lubricated. This will enable the gun to operate freely and to be completely shut off.

Matches should not be used for lighting flame spraying guns. This may result in personal harm. A friction lighter, a pilot light, or arc ignition may be used.

When a gun has backfired, it should be extinguished as quickly as possible.

Reignition of a gun that has blown out or backfired during spraying should not be attempted without first determining the cause of the trouble.

A flame spraying gun or its hoses should not be hung on regulators or cylinder valves. A fire or explosion may result.

When spraying is terminated, or the equipment is shut down, left unattended, or taken down, all gas pressure should be released from the regulators and hoses. This is done in the following sequence: (1) close gun valves, (2) close cylinder valve, (3) open gun valves, (4) turn regulator screw out until free, (5) close gun valves, and (6) close tank valve or manifold valve ahead of regulator.

When cleaning flame spraying guns, oil should not be allowed to enter the gas mixing chambers.

The use of ordinary oils or greases should be avoided for lubricating the valves or other parts of a flame spraying gun that are in contact with oxygen or fuel gases. Only special oxidation resistant lubricants recommended by the equipment manufacturers should be used.

## 11.5 Plasma and Arc Equipment

The plasma and arc methods involve apparatus not used in other thermal spraying equipment. High voltages and amperages represent an electrical hazard. The operator should be thoroughly instructed and trained by qualified personnel in the operation of the equipment before use.

Familiarity with the operating and safety recommendations in the instruction manuals, and at the same time observing standard, safety precautions taken with electrical equipment, is imperative. All operations should be in accordance with ANSI/AWS Z49.1.

The plasma or arc equipment itself should be safe to operate. Heavy duty industrial push buttons, pilot lights, plugs, and cables should meet the standards of the ANSI/NFPA 70-1979, *National Electrical Code.* Exposed electrodes and cable connections of plasma guns should be grounded or adequately insulated.

On some handling equipment, the rotational speed for coating parts is high. In some cases, the parts should be fixtured and balanced. The equipment operator should be protected in the event a rotating part becomes airborne. The equipment should not be left unattended while in operation.

Periodic inspections of cables, insulation, hoses, and gas lines should be made. Faulty equipment should be repaired or replaced immediately.

No attempt should be made to adjust, clean, or repair any part of the power supply, console, or gun without first disengaging the entire system, including the power supply.

Arc guns and power supplies should be cleaned frequently to prevent the accumulation of metal dust which may cause shorts. Instructions contained in the manufacturer's operation manual should be followed. Wire control units used in conjunction with arc equipment should be adequately grounded or insulated. If the plasma or arc gun is suspended, the suspension hook should be insulated or grounded.

Contact between any ungrounded portion of the plasma or arc gun and the spray booth or chamber should be avoided. In addition, all ground cables should be interconnected.

Plasma guns and nozzles should be electrically isolated from their support bracket to prevent stray high frequency currents from damaging other electrical equipment and controls.

## 11.6 Abrasive Blast Machines

Abrasive blast machines should be maintained and inspected according to the equipment manufacturer's recommendations. Worn parts should be removed and repaired or new parts installed as recommended by the manufacturer.

Blast hoses should be as straight as possible between the blast machine and blasting area. Sharp bends in the hose will cause excessive friction and wear, possibly resulting in a blowout at those areas. If a hose must be curved around an object, use long radius curves.

Blast hoses should be stored in cool dry areas to avoid rapid deterioration. A blast nozzle should never be pointed at the body, either your own or others. Air pressure in a blast tank should not exceed the pressure recommended by the equipment manufacturer.

Blast hose controls should require continuous pressure on the activating lever by the operator. When the pressure is released, the equipment should shut off (dead man control).

Most blasting operations require that the operator be provided with some form of respiratory protective device. The selection, operation, and maintenance of this device should be in accordance with ANSI Z88.2 *Standard Practices for Respiratory Protection,* and as described in the following section.

## 11.7 Protection of Personnel

The general requirements for the protection of thermal spraying operators are the same as for welders, as set forth in ANSI/AWS Z49.1, *Safety in Welding and Cutting;* ANSI Z87.1, *Standard Practices for Occupational and Educational Eye and Face Protection;* ANSI Z88.2, *Standard Practices for Respiratory Protection;* and ANSI Z89.1, *Standard Practices for Industrial Head Protection with Low Voltage Hazards.*

**11.7.1 Eye Protection.** Helmets, hand shields, face shields, or goggles are necessary to protect the eyes during all spraying or blasting operations. These are described in ANSI Z87.1 and Z89.2. It is necessary for operators to use goggles for protection against infrared and ultraviolet radiation and flying particles. All helpers and adjacent operators should be provided with proper eye protection.

The helmet, hand shield, or goggles should be equipped with a suitable filter plate to protect the eyes from excessive ultraviolet, infrared, and intense visible light radiation (Table 11.7.1).

### Table 11.7.1
### Recommended shade numbers

| | |
|---|---|
| Wire flame spraying (except Molybdenum) | Shades 2-4 |
| Molybdenum wire spraying | Shades 3-6 |
| Flame spraying of metal powder | Shades 3-6 |
| Flame spraying of exothermic ceramic powder or rod | Shades 4-8 |
| Plasma and arc spraying | Shades 9-12 |
| Plasma and arc spraying (when this equipment is provided with its own shield) | Shades 3-6 |
| Arc bonding | Shades 2-4 |
| Fusing operations | Shades 4-6 |

When thermal spraying in an open area or at a lathe, where ventilation is adequate to eliminate the need for additional respiratory protection, goggles alone may be worn. These should be the eyecup type, fitted with lenses of about 2 in. (50 mm) diameter, or the covercup type for those wearing corrective lenses.

The goggles should have indirect ventilating fins to eliminate danger from flying particles and to reduce fogging. In plasma spraying, the goggles should be replaced by helmets or hand shields that provide face, chin, and neck protection from ultraviolet and infrared radiation.

While blasting, face shields or abrasive blasting helmets equipped with dust hoods are used to protect the eyes, face, chin, and neck. Respiratory protection should also be provided, as discussed in the following paragraphs.

**11.7.2 Respiratory Protection.** Most spray and blast operations require that respiratory protective devices be used by the operator. The nature, type, and magnitude of the fume and gas evolved determine which respiratory protection devices should be used. The selection of these devices should be in accordance with ANSI Z88.2. This standard contains descriptions, limitations, operational procedures, and maintenance requirements for standard respiratory protective devices. All devices selected should be of a type approved by the U. S. Bureau of Mines, National Institute of Occupational Safety and Health (NIOSH), or other approved authority for the purpose intended. While the selection of these devices should follow the guidelines of ANSI Z88.2, those listed below are suggested for typical thermal spraying and blasting operations.

For blasting in the open, a mechanical filter respirator should be used in conjunction with the face shields and dust hoods cited above. Alternatively, an air line respirator may be used.

For blasting in confined or enclosed spaces, a continuous flow air line respirator for abrasive blasting is required. This consists of a standard continuous flow air line respirator, the full face piece or helmet and dust hood, which have been reinforced to protect the head and neck from rebounding abrasive. Minimum air flow to the respirator is 4 cfm (6.6 $m^3/h$) at the face piece and 6 cu ft of air per minute (10 $m^3/h$) entering the helmet or hood. Fresh air blowers are preferable to compressed air as a source of respirator air.

An in-line vortex cooler should be used when possible for operator comfort. The air supply line should contain a suitable filter to remove objectionable odors, oil or water mist (or both), and rust particles from air generated by the compressor blower. Care should be exercised in situating the air intake to ensure that the air supplied to the respirator is clean and dry. The air supply line filter will not provide protection against gaseous contaminants such as carbon monoxide unless a separate air purifier is used. In Table 6.3.2A, Grade D or better compressed air is considered breathable.

For thermal spraying in the open or at a well ventilated work area, additional respiratory protection may not be necessary. In borderline cases, such as for light work of short duration, with nontoxic materials, but with dust exposure, only approved mechanical filter respirators for protection against dust and metal fumes should be used. These are fitted with filter pads (and flutter valves) to remove dust.

When spraying in confined or semiconfined spaces, an air line respirator should be used. This is of the same design as the abrasive blasting air line respirator, except that it need not be reinforced on the helmet or face piece and hood for protection against rebounding abrasive. For this reason, an abrasive blasting continuous flow air line respirator may be used for both spraying and blasting.

Continuous flow air line respirators provide adequate respiratory protection for thermal spraying operations involving most commonly employed materials. If the air supply to the respirator fails, the operator may remove the supply line and return to respirable air, if the contaminant in the confined space is not immediately harmful to health. When applying highly toxic materials, the contaminated air should be considered immediately harmful. Since the operator should not remove the respirator in this situation, the air line respirator used should be equipped with an emergency auxiliary cylinder of respirable air.

In the event of a failure in the air supply, the operator should remove the air supply lines and use the auxiliary air supply while escaping.

Alternatively, when applying highly toxic materials, a hose mask with blower may be used to provide respiratory protection.

**11.7.3 Noise Protection.** All personnel in the vicinity of the thermal spraying operation should be provided with ear protection if the noise exposure exceeds the limitations established by OSHA in paragraph 1910.95 entitled **"Occupational Noise Exposure"** of the Occupational Safety and Health Standards.

The thermal spraying processes generate excessive noise levels. It is mandatory to limit employee exposure to excessive noise in accord with federally recognized standards as prescribed under the Occupational Safety and Health Act.

**Background and Measurement.** In the United States, the *Occupational Safety and Health Act of 1970* is administered by a division of the U. S. Department of Labor, the Occupational Safety and Health Administration (OSHA).

OSHA requires employers to provide employees with safe working conditions and requires employees to comply with all rules, regulations, and orders which apply to their own actions and conduct.

Even though OSHA is not specific on thermal spraying operations, it has established general rules for the control of unsafe and unhealthy elements.

The following paragraphs describe (1) The nature of noise and how it is measured; (2) noise levels created by thermal spraying equipment and OSHA limitations; and (3) general guides to the control of thermal spraying noise to facilitate compliance with OSHA rules.

Noise is sound which is unneeded and objectionable. Excess noise has a number of effects on people. It reduces productivity, causes tension, hearing impairment, nervousness, and slows reaction time.

Noise level is determined by measuring the energy (pressure) of the sound waves with a meter consisting of a microphone, amplifier, and read-out.

The human ear does not percieve an increase in sound energy as an equivalent increase in loudness, nor does it respond equally to all frequencies. To be useful, the instrument used to measure sound pressure level should simulate human hearing response. To accomplish this, "weighting" networks are used with characteristics based on international acoustical standards.

To match the response of the ear, a sound level meter "weights" sound measurements by frequency and uses a slow response to average out brief, high level noises such as the sound of hammering.

The meter is calibrated in decibels (dB). In perceiving loudness, the ear has a range of approximately 130 decibels.

Typical noise levels in various environments are indicated in Table 11.7.3A. Wherever there is the possibility of a problem, noise measurements should be made. Without an accurate sound level survey, there is no certainty a problem exists.

The physiological effect of noise is caused by its loudness and duration. The louder the noise, the shorter the permissible exposure to it. Table 11.7.3B indicates tolerable noise limits for various exposure times. An equal amount of additional noise raises the sound level by only 3 dBA. For example, two 80 dBA machines side-by-side produce a noise level of 83 dBA. Two more nearby 80 dBA machines will increase the noise from 83 to 86 dBA.

If an added noise is less than the existing noise, it has a negligible effect on the total noise. If the added noise is within 0 to 10 dBA louder, 3 dBA or less will be added to the total noise. If the added noise is more than 10 dBA louder than the existing noise, the total noise will be essentially the value of the added noise.

Noise and exposure should be controlled in three categories. These concern exposure of operators, nearby workers, and transient passers-by to thermal spray noise. Consideration should be given to protecting all three against the effects of the noise.

Noise can be controlled at the source, during its transmission, or at the receiver. Controlling any one of these items can solve the noise problem. However, there are so many variables in every noisy situation that each case should be treated individually. There is no simple solution for every noise problem, except isolation.

Both engineering and administrative controls can be used to reduce noise, or reduce exposure to noise.

Engineering controls include (1) redesign equipment, (2) relocate equipment, (3) change operating conditions, (4) isolate equipment acoustically, (5) insulate work area, and (6) provide operator hearing protection.

In the area of administrative controls, one can plan and schedule to reduce exposure time.

**Redesign Equipment.** Mufflers on thermal spraying equipment have proven to be impractical and ineffective. Simple baffles between the gun and nearby personnel are not effective because noise is scattered and reflected around the baffle.

Specially designed sound absorbent materials provide a 5 dB reduction to adjacent areas. Significant investment in such materials on walls and in hanging baffles also re-

### Table 11.7.3A
### Typical noise levels for thermal spraying equipment

| Equipment | Set-up | dBA |
|---|---|---|
| Arc guns | Steel — 24 volts/200 amps | 111 |
| | 32 volts/500 amps | 116 |
| Powder guns<br>-Normal | Acetylene — w/o spray booth | 89 |
| | w/ spray booth | 90 |
| | w/ spray booth and air jet cooling | 110 |
| | Hydrogen — w/o spray booth | 100 |
| | w/ spray booth | 101 |
| -High capacity | Acetylene — w/ spray booth | 94 |
| | w/ spray booth and air jet cooling | 111 |
| Wire combustion guns 1/8 in. and 3/16 in. (3.2 and 4.8 mm) wire | Acetylene | 114 |
| | Propane | 118 |
| | Propane and nonload hardware | 125 |
| | Methylacetylene-propadiene gas | 118 |
| Plasma gun | Nitrogen — 600 amps | 134 |
| | Nitrogen/hydrogen — 600 amps | 133 |
| | Argon — 1000 amps | 128 |
| | Argon/hydrogen — 600 amps | 132 |
| | Argon/helium — 600 amps | 127 |
| | Argon/nitrogen — 1000 amps | 131 |
| Typical gritblasting equipment | | 80-85 |
| Typical exhaust equipment | | less than 90 |

### Table 11.7.3B
### Allowable noise level duration

| dBA | H/day |
|---|---|
| 90 | 8* |
| 92 | 6 |
| 95 | 4 |
| 97 | 3 |
| 100 | 2 |
| 102 | 1.5 |
| 105 | 1 |
| 110 | 0.5 |
| 115 | 0.25 or less |

duce nearby levels (but does not give much help to the operator).

**Relocate Equipment.** The greater the distance from the source of noise, the lower the sound pressure level. In a large room with no sound-reflecting surfaces, the sound pressure level decreases 6 dBA for each doubling of distance. In actual practice, which usually includes reflected surfaces, the reduction with distance will be somewhat less. Table 11.7.3C indicates typical decibel reduction with distance in a free field.

### Table 11.7.3C
### Typical decibel reduction

| Distance from source | dBA reduction theoretical |
|---|---|
| 3 ft (1 m) | 0 |
| 10 ft (3 m) | 10 |
| 30 ft (9 m) | 20 |
| 90 ft (27 m) | 28 |

**Change Spray Gun Operating Conditions.** The noise level of a thermal spraying gun can be reduced 3 to 5 dBA by reducing spray gun settings and spray rates to lower values.

A 3 to 5 dBA reduction in the noise of combustion wire and powder guns can be achieved by lowering the flow of gases and air flows. Less heat will be produced, so the spray rate can be reduced. The resulting coating, compared with a standard spray coating, is less dense, softer, and has a coarser texture.

With plasma, noise can be reduced by lowering the amperage. A corresponding reduction in spray rate is required. Decreasing gas flows will reduce noise, make less heat available, and reduce coating quality.

Arc spray noise can be reduced by lowering the amperage (spray rate) or the flow of atomizing air, or both. If both are lowered, the effects on the coating will be similar to those described above. If the spray rate is lowered and the atomizing air flow is not lowered, the as-sprayed coating will have a finer texture, and the coating will be denser and, with some materials, contain more oxide.

**Isolate Equipment.** Noise can be isolated by moving it away from affected personnel, or placing the equipment in an acoustically insulated enclosure.

Standard booths are available which are designed to house spray operations and confine the noise. The noise level outside the room can be specified to be in full compliance with OSHA maximum limits for eight-hour exposure. In most instances involving flame or arc spray, a simple sheetrock enclosure will suffice.

If the user decides to design and construct an acoustically insulated area, it is recommended that it be done in consultation with a noise control expert.

**Insulate Work Area.** Very significant noise reduction can be obtained by blocking the path of transmission of the noise. This can be done by lining the work area with sound absorbing materials. High performance materials are available for such an installation. Recommendations should also be obtained from local services.

**Provide Hearing Protection.** Under the OSHA regulations, if engineering and administrative controls do not achieve acceptable limits of maximum noise and exposure duration, the law permits suitable personal protective equipment to be used. This also applies while engineering and administrative controls are being established to achieve those limits.

**Plan and Schedule to Reduce Exposure Time.** Engineering controls are intended to eliminate, reduce, or contain the noise hazard. Administrative controls are directed toward reducing exposure time.

Planning and scheduling can be used in maintenance departments and job shops where spraying is intermittent. Usually, spraying time is a small percentage of the total, compared with setup, surface preparation, and finishing.

If spraying time exceeds the permissible limits for noise exposure, jobs can be scheduled over more than one shift or day to hold the noise exposure within maximum limits. Jobs can be scheduled to be sprayed by more than one operator, to hold the exposure of any one person within limits. Off-hour spraying, outside day shift hours, can control the exposure of personnel in the vicinity of the operation. It is also possible to rotate the assignments of personnel in the vicinity of the thermal spraying operation to control exposure.

**11.7.4 Protective Clothing.** Appropriate protective clothing required for any spray or blast operation will vary with the size, nature, and location of the work to be performed.

When working in confined spaces, flame resistant clothing and leather or rubber gauntlet gloves should be worn. Clothing should be strapped tightly around the wrists and ankles to keep sprayed materials and abrasive dust away from the skin.

For work in the open, ordinary clothing, such as overalls, may be used. However, open shirt collars and unbuttoned pocket flaps are potential hazards.

High top shoes should be worn. Cuffless trousers should cover the shoe tops.

When spraying lead or other highly toxic materials in confined or partially open spaces, all clothing and respiratory protective devices worn should be changed each day and before any meal breaks. The used clothing and respiratory devices should be thoroughly washed or cleaned of all lead dust or other toxic materials before being reused.

The intense ultraviolet radiation of plasma spraying has been known to cause a "sunburn" through normal clothing. When using this process, clothing should be worn that will provide protection against radiation. Thick, tightly woven wool clothing is generally sufficient. For exposure to more intense radiation, leather capes or aluminized clothing is necessary. Exercise care so that radiation is not reflected from an aluminized bib into the inside of the face shield, causing face burns. This can be done by attaching the bib to the outside of the shield. Aluminized gloves should be used in conjunction with dark, fire retardant clothing. Aluminized clothing, however, may present a danger from electric shock.

Protection against radiation from arc spraying is similar to that used for electric arc welding and is outlined in detail in ANSI/AWS Z49.1. There is one definite difference, however; most arc spraying guns are equipped with an arc shield. With this in place, the operator is not exposed directly to the arc. Eye protection, in this case, can be reduced to a No. 3 or No. 6 shade lens, but a helmet should be used if parts of the body are exposed to direct arc radiation, or if exceptionally radiant materials or reflective substrates are sprayed.

**11.7.5 Confined Spaces.** Confined spaces are restricted spaces such as a closed tank, boiler, pressure vessel, or compartment of a ship. If the confined space has previously held combustible materials, it should be rendered safe for work before entering. AWS F4.1, *Recommended Safe Practices for the Preparation for Welding and Cutting of Containers and Piping That Have Held Hazardous Substances* should be consulted.

Ventilation is a prerequisite to work in confined spaces. Ventilation requirements are contained in 11.8.

When thermal spraying is in any confined space, the gas cylinders should remain external to the areas.

When thermal spraying or blasting operators must enter a confined space through a manhole or other small opening, means should be provided for quickly exiting in the event of an emergency. When safety belts and life lines are used for this purpose, they should be attached to the workman's body so that jamming in a small exit opening cannot occur. At least one attendant trained in rescue work should be stationed outside at all times, and proof of this person's ability to remove the operator from the confined space should be demonstrated before the operation begins.

In order to eliminate the possibility of gas escaping through leaks or improperly closed valves, the gun valve should be closed and the gas supply to the gun shut off at a point outside the confined area. Where practical, the gun and hose should be removed from the confined space. Potential oxygen deficiencies in the confined space should be evaluated with a standard miner's safety lamp.

## 11.8 Ventilation

A number of factors determine the amount of contamination to which the workman is exposed when performing blast and thermal spray operations. These include the following:

(1) Volume of space in which the thermal spraying operation is to be done

(2) Number of spray and grit blast operators

(3) The evolution of hazardous fumes, gases, or dusts according to the abrasive used or material being sprayed

(4) Heat generated by the spraying process

(5) Presence of volatile solvents

All of the preceding should be considered in order to better protect the operators and to supply adequate ventilation to the spray room.

Local exhaust or general ventilation systems should be provided to control toxic fumes, gases, or dusts, and their removal from the work area.

Where thermal spraying operations are incidental to general operations, it is good practice to apply local exhaust ventilation to the spray areas. This prevents contamination of the general work area.

Individual respiratory protective devices should be well maintained. They should not be transferred from one employee to another without being cleaned and disinfected. Forced air respiratory devices require Grade D or better air, in accordance with Table 6.3.2A. (For methods of cleansing and disinfecting, ANSI Z88.2 should be consulted.)

Mechanical ventilation is required in spraying and blasting operations that are not performed in the open or in a properly designed and ventilated room. Otherwise, the dust will rapidly fill a large tank, building, or semienclosed space.

The ventilation equipment for most field thermal spray and blast operations consists of engine or motor driven portable exhausters with flexible piping or ducts. This removes the dust rapidly and allows operators suitable visibility. Systems of this type have deficiencies, and operators should wear respiratory devices as described in 11.7.2.

When removing dust with portable exhausters, it is necessary to attach a dust collector to trap the dust and prevent contamination of the surrounding areas.

The use of bag or filter type collectors for gathering spray dust is not recommended (see 11.2). A wet collector of the water wash type is recommended. This limitation does not apply to dust from abrasive blasting operations. Dust bags should be replaced before entrapped dust seriously reduces the efficiency of the system.

If thermal spraying operations are performed on a machine tool such as a lathe, an exhaust hood should be mounted at the edge of the carriage so that it travels with the gun. This allows the dust and fumes to be exhausted into the dust collector. The gun is aimed so that the sprayed material enters the face area of the hood. The average size of the opening in a lathe hood is about 2 sq ft (0.2m$^2$), and the velocity of the air entering the opening should be a minimum of 200 ft/min (1m/s). The hood opening should eliminate turbulence along the sides that could force the spray dust into the operator's breathing zone. In some permanent installations, the entire lathe, rotary table, or machine tool is enclosed except the front, and the velocity of the air entering the enclosure is approximately 300 ft/min (1.5 m/s). The top of the hood can be hinged, permitting use of a crane for loading or unloading. In automatic and production spraying, the entire mechanism is often totally enclosed, and the dust is exhausted into a water wash and collecting system. *Industrial Ventilation,* published by the American Conference of Governmental Industrial Hygienists, should be consulted.

During dry grinding or lapping operations on sprayed coatings, precautions should be taken to provide proper exhaust equipment. ANSI Z43.1, *Ventilation Control of Grinding, Polishing, and Buffing Metals,* should be consulted.

Spray cabinets used for spraying small and medium size parts should be equipped with exhaust ventilation, with an air velocity of 200 to 400 ft/min (1 to 2 m/s) entering the hood. The spray equipment should be operated within the face area of the hood and directed into it. Again, the design of the cabinet should be such that turbulent eddy currents are eliminated. When spraying toxic materials, minimum enclosure face velocity of 400 ft/min (2 m/s) should be used. *Industrial Ventilation,* published by the American Conference of Governmental Industrial Hygienists, should be consulted.

Blasting rooms should be designed to be well lighted and adequately ventilated. Ventilation should provide down draft and longitudinal air flow with a velocity of 80 to 100 ft/min (0.2 to 0.5 m/s).

The blasting room should be equipped with a dust collecting system. This is usually required by local ordinances. Further, local, state, and federal regulations should be investigated before exhausting directly into the atmosphere. The blasting room may also occasionally be used for spraying. This is not good practice and should be avoided whenever possible. Spray dust will quickly clog most cloth dust collectors used in the blasting rooms. Moreover, when spraying in a blasting room, the dust collector system will require more frequent maintenance to prevent fire or explosion due to accumulation of metallic dust (see 11.2). Workmen in the blasting room should be provided with respiratory protection as detailed in 11.7.2.

When ventilating confined spaces, all air replacing that withdrawn should be clean and respirable. Fans should be sized to give at least 10 air changes per minute. If portable gasoline or diesel engine driven ventilators or compressors are used, they should be located so that engine exhaust gases cannot be drawn into the ventilating system. This precaution will also prevent exhaust gases from entering the intake of the compressor. This is particularly critical if the air is to be used for respirators.

If dust collectors are used, closed type collectors should be provided with blowout holes or relief panels. Blowout panels should also be provided in ventilation piping.

All fans, pipes, dust arrestors, and motors should be grounded. Ground to piping that carries fuel gas or oxygen should not be used. Ventilating fans should be kept running when cleaning out booths, pipes, etc. This prevents the accumulation of dust or fumes in the system. Aluminum and magnesium dusts present an explosive hazard which requires special attention. Adequate wet collector systems should be used on either of these metals. Care should be exercised, since these metallic dusts may generate hydrogen gas in water. These systems should be designed to prevent hydrogen accumulation. Frequent cleanout operations should be performed to reduce residues.

When spraying on unusually large objects or in large confined spaces, such as encountered in boilers and tanks, it is imperative that fresh air helmets and protective clothing be worn.

No welding or cutting should be done in the repair of any ventilation or dust collecting equipment unless the equipment has been thoroughly cleaned.

## 11.9 Toxic Materials

All materials, in finely divided form, may be damaging to the respiratory system, and the precautions necessary for protecting the health of spray operators vary according to the type of material being sprayed. Careful attention to this health problem is particularly important because the damage does not cause an immediate sensory effect. In addition to respiratory requirements, extreme care should be exercised to maintain floors, work benches, and booths free from dusty residues for optimum health protection. Used clothing should be properly processed to remove dusts, or they should be discarded.

**11.9.1 Beryllium.** Beryllium and its compounds are highly toxic and potentially hazardous. Thermal spraying indoors, outdoors, or in confined spaces involving beryllium-containing alloys should be done only when using adequate local exhaust ventilation and air line respirators. The only exception occurs when atmospheric tests, under the most adverse conditions, have established that the operators exposure is within acceptable concentrations (defined by the American National Standards Institute or the American Conference of Governmental industrial Hygienists).

The exhaust of the ventilation system shall be handled in a safe manner, and directed to a restricted area. In all cases, workers in the immediately vicinity of the thermal spray operations shall be protected as necessary by local exhaust ventilation or air line respirators (see 11.7.2 and 11.8).

When working with beryllium, expert advice should always be obtained. Such advice may be obtained from certified industrial hygienists, the Nuclear Regulatory Commission, insurance companies, state agencies, and the Occupational Safety and Health Administration (OSHA).

**11.9.2 Cadmium.** Cadmium is highly toxic and hazardous. Respiratory protective equipment, such as fume respirators approved by the U. S. Bureau of Mines, National Institute of Occupational Safety and Health (NIOSH), or other approving authority for these purposes should be used (see 11.7.2 and 11.8).

**11.9.3 Lead, Lead Alloys, Cobalt, Chromium, and Tellurium.** When spraying or blasting these materials, the principal hazard is from ingestion, inhalation, and subsequent absorption of fumes, dust, or vapors.

The fumes and dust of lead, lead alloys (such as solder and lead base babbitts), chromium alloys (such as stainless steels, nickel-chromium, and chromium oxide) and tellurium are toxic and potentially hazardous. When spraying these metals and other highly toxic materials, respiratory protection and adequate ventilation should be provided wherever the fume and dust concentration is above the threshold limit value (see 11.7.2, 11.8, and 11.9.5).

**11.9.4 Solvents.** The radiation from an arc, such as encountered in plasma or arc spraying, causes rapid decomposition of chlorinated hydrocarbon solvent vapors into noxious and toxic gases. Solvents such as trichlorethylene and perchlorethylene decompose rapidly, even at considerable distance from the arc, and create phosgene gas. This problem can be reduced by slow extraction of the part from the solvent cleaning tank. Special precautions should be taken when spraying materials which have been vapor degreased to see that all the solvent has been removed prior to thermal spraying coating.

Liquid films or drops of solvent caught by pockets and crevices should be avoided. Solvent vapors should not be present in the spray area. The ultraviolet radiation from plasma and arc spraying generates ozone in the air. The amount of ozone produced may exceed the maximum allowable concentration value in confined spaces.

**11.9.5 Threshold Limit Values.** Threshold limit values (TLV) are air concentration levels of hazardous materials, which have been established for exposures not exceeding a total of eight hours daily. Threshold limit values, adopted by the American Conference of Governmental Industrial Hygienists (ACGIH), are published annually by the ACGIH under the title *Threshold Limit Values, Recommended and Tentative.* A current listing of the TLV should be consulted concerning the maximum allowable concentration of toxic material that may be encountered.

Air sampling should be conducted to determine the ventilation requirements for operations involving the above metals or solvents, or both. When less toxic metals are sprayed, the concentration of dust or fumes in the work area should never exceed the TLV for eight hour exposure. Respiratory protective devices and exhaust ventilation should be provided when the dust or fume concentration is sufficiently high to cause operator discomfort, even when the appropriate TLV is not exceeded.

**11.9.6 Tin and Zinc.** Tin and zinc, usually encountered in the forms of their oxides, may cause violent illness. However, all evidence indicates that tin and zinc are not toxic. The symptoms are coughing, headache, and particularly in the case of zinc oxide fumes, nausea, vomiting, chills, fever, pain in muscles and joints, and marked thirst. (In the case of zinc oxide, the effect has been known as "brass founder's ague," "brass chills," "zinc fever," or "metal fume fever"). Temporary short term immunity can be developed.

Preventive measures consist of adequate ventilation and proper respirators (see 11.7.2 and 11.8). Operators with pulmonary diseases or those who continue to suffer discomfort, even with proper ventilation and respirator measures, should be precluded from the work.

## 11.10 Safety Standards

Mandatory Federal Safety Regulations have been established by the Occupational Safety and Health Administration. For information on these regulations, refer to OSHA Standards, *Code of Federal Regulations, Title 29, Part 1910.*

Among the principal safety hazards associated with the thermal spraying process is the handling of compressed gases. In this publication, the safe handling of compressed gases is covered by reference to ANSI/AWS Z49.1, *Safety in Welding and Cutting,* and in accordance with the *Williams-Steiger Occupational Safety and Health Act of 1970* (84 Stat. 1943). More recently, the newly enacted *Resource Conservation and Recovery Act* (RCRA), dealing with the disposal of toxic wastes, has a potential for additional impact upon this industry and requires consultation as that legislation is clarified.

Where standards and other documents are referenced in this publication, they refer to the latest edition.

Occupational Safety and Health Act Standards (29CFR 1910), available from the Superintendent of Documents, U.S. Government Printing Office.

*Ventilation Control of Grinding, Polishing and Buffing of Metals,* ANSI Z43.1, available from the American National Standards Institute.

*Safety in Welding and Cutting,* ASC/ANSI Z49.1, available from the American Welding Society.

*Standard Practices for Occupational and Educational Eye and Face Protection,* ANSI Z87.1, available from the American National Standards Institute.

*Standard Practices for Respiratory Protection,* ANSI Z88.2, available from the American National Standards Institute.

*Safety Requirements for Industrial Head Protection,* ANSI Z89.1, available from the American National Standards Institute.

*National Electrical Code,* ANSI/NFPA 70-1979, available from the National Fire Protection Association, updated annually.

*Safe Handling of Compressed Gases,* CGA Pamphlet P-1, available from the Compressed Gas Association.

*Oxygen,* CGA Pamphlet G-4 available from the Compressed Gas Association.

*Recommended Safe Practices for the Preparation for Welding and Cutting of Containers That Have Held Hazar-*

*dous Substances,* ANSI/AWS F4.1, available from the American Welding Society.

*Safety Release Device Standards — Cylinders for Compressed Gases,* CGA Pamphlet S1.1, available from the Compressed Gas Association.

*Safety Release Device Standards — Cargo and Portable Tanks for Compressed Gases,* CGA Pamphlet S1.2, available from the Compressed Gas Association.

*Standard for Gaseous Hydrogen at Consumer Sites,* CGA Pamphlet G5.1, available from the Compressed Gas Association.

*Power Piping,* ANSI B31.3, available from the American National Standards Institute.

*Acetylene,* CGA Pamphlet G-1, available from the Compressed Gas Association.

*Oxygen-Fuel Gas Systems for Welding and Cutting,* ANSI/NFPA 51, available from the National Fire Protection Association.

*Standard for Fire Prevention in Use of Cutting and Welding Processes,* ANSI/NFPA 51B, available from the National Fire Protection Association.

*Standard for the Storage and Handling of Liquified Petroleum Gases,* ANSI/NFPA 58, available from the National Fire Protection Association.

# Appendix: Commonly Used Metric Conversions

## Inch-millimeter conversion

1 in. = 25.4 mm exactly

To convert inches to millimeters, multiply the inch value by 25.4.

To convent millimeters to inches, divide the millimeter value by 25.4.

Inch and millimeter decimal equivalents of fractions of an inch

| Inch | | Millimeter | Inch | | Millimeter |
|---|---|---|---|---|---|
| Fraction | Decimal | | Fraction | Decimal | |
| 1/64 | 0.015 625 | 0.396 875 | 33/64 | 0.515 625 | 13.096 875 |
| 1/32 | 0.031 250 | 0.793 750 | 17/32 | 0.531 250 | 13.493 750 |
| 3/64 | 0.046 875 | 1.190 625 | 35/64 | 0.546 875 | 13.890 625 |
| 1/16 | 0.062 500 | 1.587 500 | 9/16 | 0.562 500 | 14.287 500 |
| 5/64 | 0.078 125 | 1.984 375 | 37/64 | 0.578 125 | 14.684 375 |
| 3/32 | 0.093 750 | 2.381 250 | 19/32 | 0.593 750 | 15.081 250 |
| 7/64 | 0.109 375 | 2.778 125 | 39/64 | 0.609 375 | 15.478 125 |
| 1/8 | 0.125 000 | 3.175 000 | 5/8 | 0.625 000 | 15.875 000 |
| 9/64 | 0.140 625 | 3.571 875 | 41/64 | 0.640 625 | 16.271 875 |
| 5/32 | 0.156 250 | 3.968 750 | 21/32 | 0.656 250 | 16.668 750 |
| 11/64 | 0.171 875 | 4.365 625 | 43/64 | 0.671 875 | 17.065 625 |
| 3/16 | 0.187 500 | 4.762 500 | 11/16 | 0.687 500 | 17.462 500 |
| 13/64 | 0.203 125 | 5.159 375 | 45/64 | 0.703 125 | 17.859 375 |
| 7/32 | 0.218 750 | 5.556 250 | 23/32 | 0.718 750 | 18.256 250 |
| 15/64 | 0.234 375 | 5.953 125 | 47/64 | 0.734 375 | 18.653 125 |
| 1/4 | 0.250 000 | 6.350 000 | 3/4 | 0.750 000 | 19.050 000 |
| 17/64 | 0.265 625 | 6.746 875 | 49/64 | 0.765 625 | 19.446 875 |
| 9/32 | 0.281 250 | 7.143 750 | 25/32 | 0.781 250 | 19.843 750 |
| 19/64 | 0.296 875 | 7.540 625 | 51/64 | 0.796 875 | 20.240 625 |
| 5/16 | 0.312 500 | 7.937 500 | 13/16 | 0.812 500 | 20.637 500 |
| 21/64 | 0.328 125 | 8.334 375 | 53/64 | 0.828 125 | 21.034 375 |
| 11/32 | 0.343 750 | 8.731 250 | 27/32 | 0.843 750 | 21.431 250 |
| 23/64 | 0.359 375 | 9.128 125 | 55/64 | 0.859 375 | 21.828 125 |
| 3/8 | 0.375 000 | 9.525 000 | 7/8 | 0.875 000 | 22.225 000 |
| 25/64 | 0.390 625 | 9.921 875 | 57/64 | 0.890 625 | 22.621 875 |
| 13/32 | 0.406 250 | 10.318 750 | 29/32 | 0.906 250 | 23.018 750 |
| 27/64 | 0.421 875 | 10.715 625 | 59/64 | 0.921 875 | 23.415 625 |
| 7/16 | 0.437 500 | 11.112 500 | 15/16 | 0.937 500 | 23.812 500 |
| 29/64 | 0.453 125 | 11.509 375 | 61/64 | 0.953 125 | 24.209 375 |
| 15/32 | 0.468 750 | 11.906 250 | 31/32 | 0.968 750 | 24.606 250 |
| 31/64 | 0.484 375 | 12.303 125 | 63/64 | 0.984 375 | 25.003 125 |
| 1/2 | 0.500 000 | 12.700 000 | 1 | 1.000 000 | 25.400 000 |

## Conversions for Fahrenheit — Celsius temperature scales

Find number to be converted in center (bold face) column.

Converting Fahrenheit degrees, read Celsius equivalent.

Converting Celsius degrees, read Fahrenheit equivalent.

| °C | | °F | °C | | °F | °C | | °F | °C | | °F | °C | | °F |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| −40 | **−40** | −40 | 132 | **270** | 518 | 543 | **1010** | 1850 | 932 | **1710** | 3110 | 1321 | **2410** | 4370 |
| −34 | **−30** | −22 | 138 | **280** | 536 | 549 | **1020** | 1868 | 938 | **1720** | 3128 | 1327 | **2420** | 4388 |
| −29 | **−20** | − 4 | 143 | **290** | 554 | 554 | **1030** | 1886 | 943 | **1730** | 3146 | 1332 | **2430** | 4406 |
| −23 | **−10** | 14 | 149 | **300** | 572 | 560 | **1040** | 1904 | 949 | **1740** | 3164 | 1338 | **2440** | 4434 |
| −17.8 | **0** | 32 | 154 | **310** | 590 | 566 | **1050** | 1922 | 954 | **1750** | 3182 | 1343 | **2450** | 4442 |
| −16.7 | **2** | 35.6 | 160 | **320** | 608 | 571 | **1060** | 1940 | 960 | **1760** | 3200 | 1349 | **2460** | 4469 |
| −15.6 | **4** | 39.2 | 166 | **330** | 626 | 577 | **1070** | 1958 | 966 | **1770** | 3218 | 1354 | **3470** | 4478 |
| −14.4 | **6** | 42.8 | 171 | **340** | 644 | 582 | **1080** | 1976 | 971 | **1780** | 3236 | 1360 | **2480** | 4496 |
| −13.3 | **8** | 46.4 | 177 | **350** | 662 | 588 | **1090** | 1994 | 977 | **1790** | 3254 | 1366 | **2490** | 4514 |
| −12.2 | **10** | 50.0 | 182 | **360** | 680 | 593 | **1100** | 2012 | 982 | **1800** | 3272 | 1371 | **2500** | 4532 |
| −11.1 | **12** | 53.6 | 199 | **390** | 734 | 599 | **1110** | 2030 | 988 | **1810** | 3290 | 1377 | **2510** | 4550 |
| −10.0 | **14** | 57.2 | 204 | **400** | 752 | 604 | **1120** | 2048 | 993 | **1820** | 3308 | 1382 | **2520** | 4568 |
| − 8.9 | **16** | 60.8 | 210 | **410** | 770 | 610 | **1130** | 2066 | 999 | **1830** | 3326 | 1388 | **2530** | 4586 |
| − 7.8 | **18** | 64.4 | 216 | **420** | 788 | 616 | **1140** | 2084 | 1004 | **1840** | 3344 | 1393 | **2540** | 4604 |
| − 6.7 | **20** | 68.0 | 221 | **430** | 806 | 621 | **1150** | 2102 | 1010 | **1850** | 3362 | 1399 | **2550** | 4622 |
| − 5.6 | **22** | 71.6 | 227 | **440** | 824 | 627 | **1160** | 2120 | 1016 | **1860** | 3380 | 1404 | **2560** | 4640 |
| − 4.4 | **24** | 75.2 | 232 | **450** | 842 | 632 | **1170** | 2138 | 1021 | **1870** | 3398 | 1410 | **2570** | 4658 |
| − 3.3 | **26** | 78.8 | 238 | **460** | 860 | 638 | **1180** | 2156 | 1027 | **1880** | 3416 | 1416 | **2580** | 4676 |
| − 2.2 | **28** | 82.4 | 243 | **470** | 878 | 643 | **1190** | 2174 | 1032 | **1890** | 3434 | 1421 | **2590** | 4694 |
| − 1.1 | **30** | 86.0 | 249 | **480** | 896 | 649 | **1200** | 2192 | 1038 | **1900** | 3452 | 1427 | **2600** | 4712 |
| 0.0 | **32** | 89.6 | 254 | **490** | 914 | 654 | **1210** | 2210 | 1043 | **1910** | 3470 | 1432 | **2610** | 4730 |
| 1.1 | **34** | 93.2 | 260 | **500** | 932 | 660 | **1220** | 2228 | 1049 | **1920** | 3488 | 1438 | **2620** | 4748 |
| 2.2 | **36** | 96.8 | 266 | **510** | 950 | 666 | **1230** | 2246 | 1054 | **1930** | 3506 | 1443 | **2630** | 4766 |
| 3.3 | **38** | 100.4 | 271 | **520** | 968 | 671 | **1240** | 2264 | 1060 | **1940** | 3524 | 1449 | **2640** | 4784 |
| 4.4 | **40** | 104.0 | 277 | **530** | 986 | 677 | **1250** | 2282 | 1066 | **1950** | 3542 | 1454 | **2650** | 4802 |
| 5.6 | **42** | 107.6 | 282 | **540** | 1004 | 682 | **1260** | 2300 | 1071 | **1960** | 3560 | 1460 | **2660** | 4820 |
| 6.7 | **44** | 111.2 | 288 | **550** | 1022 | 688 | **1270** | 2318 | 1077 | **1970** | 3578 | 1466 | **2670** | 4838 |
| 7.8 | **46** | 114.8 | 293 | **560** | 1040 | 693 | **1280** | 2336 | 1082 | **1980** | 3596 | 1471 | **2680** | 4856 |
| 8.9 | **48** | 118.4 | 299 | **570** | 1058 | 699 | **1290** | 2354 | 1088 | **1990** | 3614 | 1477 | **2690** | 4874 |
| 10.0 | **50** | 122.0 | 304 | **580** | 1076 | 704 | **1300** | 2372 | 1093 | **2000** | 3632 | 1482 | **2700** | 4892 |
| 11.1 | **52** | 125.6 | 310 | **590** | 1094 | 710 | **1310** | 2390 | 1099 | **2010** | 3650 | 1488 | **2710** | 4910 |
| 12.2 | **54** | 129.2 | 316 | **600** | 1112 | 716 | **1320** | 2408 | 1104 | **2020** | 3668 | 1493 | **2720** | 4928 |
| 13.3 | **56** | 132.8 | 321 | **610** | 1130 | 721 | **1330** | 2426 | 1110 | **2030** | 3686 | 1499 | **2730** | 4946 |
| 14.4 | **58** | 136.4 | 327 | **620** | 1148 | 727 | **1340** | 2444 | 1116 | **2040** | 3704 | 1504 | **2740** | 4964 |
| 15.6 | **60** | 140.0 | 332 | **630** | 1166 | 732 | **1350** | 2462 | 1121 | **2050** | 3722 | 1510 | **2750** | 4982 |
| 16.7 | **62** | 143.6 | 338 | **640** | 1184 | 738 | **1360** | 2480 | 1127 | **2060** | 3740 | 1516 | **2760** | 5000 |
| 17.8 | **64** | 147.2 | 343 | **650** | 1202 | 743 | **1370** | 2498 | 1132 | **2070** | 3758 | 1521 | **2770** | 5018 |
| 18.9 | **66** | 150.8 | 349 | **660** | 1220 | 749 | **1380** | 2516 | 1138 | **2080** | 3776 | 1527 | **2780** | 5036 |
| 20.0 | **68** | 154.4 | 354 | **670** | 1238 | 754 | **1390** | 2534 | 1143 | **2090** | 3794 | 1532 | **2790** | 5054 |
| 21.1 | **70** | 158.0 | 360 | **680** | 1256 | 760 | **1400** | 2552 | 1149 | **2100** | 3812 | 1538 | **2800** | 5072 |
| 24.4 | **76** | 168.8 | 366 | **690** | 1274 | 766 | **1410** | 2570 | 1154 | **2110** | 3830 | 1543 | **2810** | 5090 |
| 25.6 | **78** | 172.4 | 371 | **700** | 1292 | 771 | **1420** | 2588 | 1160 | **2120** | 3848 | 1549 | **2820** | 5108 |
| 26.7 | **80** | 176.0 | 377 | **710** | 1310 | 777 | **1430** | 2606 | 1166 | **2130** | 3866 | 1554 | **2830** | 5126 |
| 27.8 | **82** | 179.6 | 382 | **720** | 1328 | 782 | **1440** | 2624 | 1171 | **2140** | 3884 | 1560 | **2840** | 5144 |
| 28.9 | **84** | 183.2 | 388 | **730** | 1346 | 788 | **1450** | 2642 | 1177 | **2150** | 3902 | 1566 | **2850** | 5162 |
| 30.0 | **86** | 186.8 | 393 | **740** | 1364 | 793 | **1460** | 2660 | 1182 | **2160** | 3920 | 1571 | **2860** | 5180 |
| 31.1 | **88** | 190.4 | 399 | **750** | 1382 | 799 | **1470** | 2678 | 1188 | **2170** | 3938 | 1577 | **2870** | 5198 |
| 32.2 | **90** | 194.0 | 404 | **760** | 1400 | 804 | **1480** | 2696 | 1193 | **2180** | 3956 | 1582 | **2880** | 5216 |
| 33.3 | **92** | 197.6 | 410 | **770** | 1418 | 810 | **1490** | 2714 | 1199 | **2190** | 3974 | 1588 | **2890** | 5234 |
| 34.4 | **94** | 201.2 | 416 | **780** | 1436 | 816 | **1500** | 2732 | 1204 | **2200** | 3992 | 1593 | **2900** | 5252 |
| 35.6 | **96** | 204.8 | 432 | **810** | 1490 | 821 | **1510** | 2750 | 1210 | **2210** | 4010 | 1599 | **2910** | 5270 |
| 36.7 | **98** | 208.4 | 438 | **820** | 1508 | 827 | **1520** | 2768 | 1216 | **2220** | 4028 | 1604 | **2920** | 5288 |
| 37.8 | **100** | 212.0 | 443 | **830** | 1526 | 832 | **1530** | 2786 | 1221 | **2230** | 4046 | 1610 | **2930** | 5306 |
| 43 | **110** | 230 | 449 | **840** | 1544 | 838 | **1540** | 2804 | 1227 | **2240** | 4064 | 1616 | **2940** | 5324 |
| 49 | **120** | 248 | 454 | **850** | 1562 | 843 | **1550** | 2822 | 1232 | **2250** | 4082 | 1621 | **2950** | 5342 |

# Conversions for Fahrenheit (Continued)

| °C | | °F | °C | | °F | °C | | °F | °C | | °F | °C | | °F |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 54 | **130** | 266 | 460 | **860** | 1580 | 849 | **1560** | 2840 | 1238 | **2260** | 4100 | 1627 | **2960** | 5360 |
| 60 | **140** | 284 | 466 | **870** | 1598 | 854 | **1570** | 2858 | 1243 | **2270** | 4118 | 1632 | **2970** | 5278 |
| 66 | **150** | 302 | 471 | **880** | 1616 | 860 | **1580** | 2876 | 1249 | **2280** | 4136 | 1638 | **2980** | 5396 |
| 71 | **160** | 320 | 477 | **890** | 1634 | 866 | **1590** | 2894 | 1254 | **2290** | 4154 | 1643 | **2990** | 5414 |
| 77 | **170** | 338 | 482 | **900** | 1652 | 871 | **1600** | 2912 | 1260 | **2300** | 4172 | 1649 | **3000** | 5432 |
| 82 | **180** | 356 | 488 | **910** | 1670 | 877 | **1610** | 2930 | 1266 | **2310** | 4190 | | | |
| 88 | **190** | 374 | 493 | **920** | 1688 | 882 | **1620** | 2948 | 1271 | **2320** | 4208 | | | |
| 93 | **200** | 392 | 499 | **930** | 1706 | 888 | **1630** | 2966 | 1277 | **2330** | 4226 | | | |
| 99 | **210** | 410 | 504 | **940** | 1724 | 893 | **1640** | 2984 | 1282 | **2340** | 4244 | | | |
| 100 | **212** | 414 | 510 | **950** | 1742 | 899 | **1650** | 3002 | 1288 | **2350** | 4262 | | | |
| 104 | **220** | 428 | 516 | **960** | 1760 | 904 | **1660** | 3020 | 1293 | **2360** | 4280 | | | |
| 110 | **230** | 446 | 521 | **970** | 1778 | 910 | **1670** | 3038 | 1299 | **2370** | 4298 | | | |
| 116 | **240** | 464 | 527 | **980** | 1796 | 916 | **1680** | 3056 | 1304 | **2380** | 4316 | | | |
| 121 | **250** | 482 | 532 | **990** | 1814 | 921 | **1690** | 3074 | 1310 | **2390** | 4334 | | | |
| 127 | **260** | 500 | 538 | **1000** | 1832 | 927 | **1700** | 3092 | 1316 | **2400** | 4352 | | | |

# Abbreviations

| | |
|---|---|
| ANSI | American National Standards Institute |
| ASP | Arc Spraying — See Glossary |
| BTU | British Thermal Units — See Glossary |
| CGA | Compressed Gas Association |
| FLSP | Flame Spraying — See Glossary |
| g/min | grams per minute |
| kPa | kilopascal, a unit of force equal to 1000 N/m$^2$ |
| lb/h | pounds per hour |
| MPS | Methylacetylene-Propadiene Stabilized gas fuel |
| NFPA | National Fire Protection Association |
| NIOSH | National Institute for Occupational Safety and Health |
| OSHA | Occupational Safety and Health Administration |
| psi | pounds per square inch |
| psig | pounds per square inch — gage pressure |
| PSP | Plasma Spraying — See Glossary |
| RMS | Root Mean Square |
| SAE | Society of Automotive Engineers |
| scfh | Standard Cubic Feet per Hour |
| sfpm | Surface Feet per Minute — See Glossary |
| TBC | Thermal Barrier Coatings — See 5.6 |
| THSP | Thermal Spraying — See Glossary |
| VPD | Vacuum Plasma Deposition — See Glossary |

# Glossary

A mixture of generic and popular terminology has been adopted by the thermal spraying industry. The compilation presented here includes (1) Standard Terms and Definitions (* starred items) from AWS A3.0 adapted for use in Thermal Spraying, and (2) terms and definitions judged to be of significant value in the understanding and application of the various processes.

## A

**abrasive.** Material such as sand, crushed chilled cast iron, crushed steel grit, aluminum oxide, silicon carbide, flint, garnet, or crushed slag used for cleaning or surface roughening.

**abrasive blasting.** See preferred term **blasting.**

**absorb.** To take in and engulf wholly.

***absorptive lens (eye protection).** A filter lens designed to attenuate the effects of glare and reflected and stray light. See **filter plate.**

**acoustical room.** A soundproof enclosure, containing thermal spraying and sometimes related auxiliary equipment. Its design and construction prevent any unacceptable process noises from interfering with normal work in the environment surrounding the enclosure.

**adhesion.** A binding force that holds together molecules of substances whose surfaces are in contact or near proximity.

**adhesive strength.** The magnitude of attractive forces, generally physical in character, between a coating and substrate. Two principle interactions that contribute to the adhesion are van der Waals forces and permanent dipole bonds.

**adsorb.** To take in on the surface.

***air cap.** A device for forming, shaping and directing an air flow pattern for the atomization of wire or ceramic rod.

**air cooler.** See preferred term **workpiece cooler.**

***air feed.** A thermal spraying process variation in which an air stream carries the powdered surfacing material through the gun and into the heat source.

**air filter.** Mechanism for cleaning air of contaminants such as water, oil, and solid matter.

**alumina.** A chemical compound (aluminum oxide); a ceramic used in powder or rod form in thermal spraying operations. May also be a blasting medium.

**anchoring.** A supplemental method of locking the thermal spray deposit to the substrate by screw heads, studs, or similar means.

**anode.** The electrode maintained at a positive electrical potential. In typical plasma thermal spraying gun designs, this is the front electrode, constructed as a hollow nozzle and usually fabricated from copper. In electric arc thermal spraying guns, one feed wire is the positive electrode.

**apparent density ratio.** The ratio of the measured density of an object to the absolute density of a perfectly solid material of the same composition, usually expressed as a percentage.

**arc.** A luminous discharge of electrical current crossing the gap between two electrodes.

**arc chamber.** The confined space within the plasma thermal spraying gun enclosing the anode and cathode, in which the arc is struck.

***arc force.** The axial force developed by an arc plasma.

**arc gas.** The gas introduced into the arc chamber and ionized by the arc to form a plasma.

**arc gas - primary.** See preferred term **primary gas.**

**arc gas - secondary.** See preferred term **secondary gas.**

***arc plasma.** A gas that has been heated by an electric arc to at least a partially ionized condition, enabling it to conduct an electric current.

***arc spraying (ASP).** A thermal spraying process using an arc between two consumable electrodes of surfacing materials as a heat source and a compressed gas to atomize and propel the surfacing material to the substrate.

***atomization.** (1) The division of molten material at the end of the wire or rod into fine particles. (2) The process used in the manufacture of powder.

**auxiliary cooler.** A device used to direct compressed air to prevent overheating of the thermal spraying deposit or the substrate.

## B

***backfire.** The momentary recession of the flame into the spray gun, followed by immediate reappearance or complete extinction of the flame.

**base material.** See preferred term **substrate.**

**base metal.** See preferred term **substrate.**

**berry formation.** See preferred term **nozzle accumulation.**

***blasting.** A method of cleaning or surface roughening by a forcibly projected stream of sharp angular abrasive.

**body stress.** Residual stresses within an individual sprayed particle.

***bond.** See **mechanical bond** and **metallic bond.**

**bond cap or bond bar.** The test specimen on which a spray coating is applied for the purpose of determining adhesive-cohesive strength.

***bond coat.** A preliminary (or prime coat) of material that improves adherence of the subsequent spray deposit.

***bonding force.** The force that holds two atoms together; it results from a decrease in energy as two atoms are brought closer to one another.

***bond line.** The cross section of the interface between a thermal spraying deposit and substrate, or between adhesive and adherent in an adhesive bonded joint.

**bond strength.** The force required to pull a coating free of a substrate, usually expressed in psi (kPa).

**BTU - British Thermal Unit,** a unit of measure for heat (equal to 1055J).

***buildup.** A surfacing variation in which surfacing metal is deposited to achieve the required dimensions.

***burnoff rate.** A nonstandard term for **melting rate.**

## C

**cap.** See preferred term **nozzle** or **air cap.**

**carbide.** A chemical compound formed between carbon and a metal or metals; examples are tungsten carbide, tantalum carbide, titanium carbide, chromium carbide.

***carburizing flame** — A nonstandard term for **reducing flame.**

***carrier gas.** The gas used to carry powdered material from the powder feeder or hopper to the gun.

**cast.** The twist warp or curvature of a metal wire.

**cathode.** The electrode maintained at a negative electric potential. In a plasma gun it is usually the rear electrode, conically shaped, and fabricated from tungsten or thoriated tungsten.

**ceramic rod flame spray gun.** A flame spraying device wherein an oxyfuel gas flame provides the heat, and the surfacing material to be sprayed is in ceramic rod form.

***ceramic rod flame spraying.** A thermal spraying process variation in which the material to be sprayed is in ceramic rod form. See **flame spraying** (FLSP).

**ceramic rod speed.** The length of ceramic rod sprayed in a unit of time.

**cermet.** A physical mixture of ceramics and metals; examples are alumina plus nickel and zirconia plus nickel.

***cladding.** A surfacing variation that deposits or applies surfacing material, usually to improve corrosion or heat resistance.

***clad metal.** A laminar composite consisting of a metal, with a metal of different chemical composition applied to one or two sides.

**clad powder.** See preferred term **powder clad.**

**coalesce.** To grow or come together; fuse; unite.

**coating.** (1) The act of building a deposit on a substrate, (2) the spray deposit.

***coating density.** A nonstandard term for **spray deposit density ratio.**

**coating strength.** (1) A measure of the cohesive bond within a coating, as opposed to coating-to-substrate bond (adhesive strength), (2) the tensile strength of a coating, usually expressed in psi (kPa).

**coating stress.** The stresses in a coating resulting from rapid cooling of molten material or semimolten particles as they impact the substrate. Coating stresses are a combination of body and textural stresses.

**coefficient of thermal expansion.** The ratio of the change in length per degree rise in temperature to the length at a standard temperature such as 68°F (20°C).

**cohesive strength.** See **coating strength.**

***collaring.** Adding a shoulder to a shaft or similar component as a protective confining wall for the thermal spray deposit.

**combination aftercooler/dryer.** A deliquescent desiccant dryer with an integral aftercooler.

**companion panel.** A small tab coated concurrently with the workpiece, used for inspection.

**composite coating.** A coating consisting of two or more dissimilar spray materials which may or may not be layered.

**composite powder.** See preferred term **powder composite.**

**compressed air mask.** A force feed type of face mask with a suitable regulator worn by the thermal spraying operator to provide a fresh air supply.

***cone.** The conical part of an oxyfuel gas flame next to the orifice of the tip.

***contact tube.** A device which transfers current to a continuous electrode.

**control console.** The instrumented unit from which the gun is operated and operating variables are monitored and controlled.

**controlled atmosphere chamber.** An enclosure or cabinet either filled with an inert gas or evacuated to below atmospheric pressure in which thermal spraying can be performed to minimize, or prevent, oxidation of the coating or substrate.

**cooler.** See preferred term **workpiece cooler.**

**cord.** A plastic tube filled with powder, and extruded to form a compact, flexible layer level wound wire-like "cord."

**critical resolved shearing stress.** The shearing stress on the slip plane necessary to produce slip (threshold value).

**cubicle.** See preferred term **acoustical room.**

***cylinder.** See **gas cylinder.**

***cylinder manifold.** A multiple header for interconnection of gas or fluid sources with distribution points.

## D

***defect.** A discontinuity or discontinuities that by nature or accumulated effect (for example, total crack length) render a part or product unable to meet minimum applicable acceptance standards or specifications. This term designates rejectability. See also **discontinuity** and **flaw.**

**degrease.** To remove oil or grease from the surface of the workpiece. See **solvent degreasing.**

**deliquescent.** The process of melting or becoming liquid by absorbing moisture from the air.

**deliquescent desiccant dryer.** A pressure vessel containing a collection chamber and a drying desiccant. It has no moving parts, and normally produces a 50°F (10°C) dewpoint or lower.

**density.** The mass or quantity of matter of a substance per unit volume, expressed as pounds per cubic inch, or grams per cubic centimeter.

**density ratio.** See **apparent density ratio.**

***deposit.** A nonstandard term for **thermal spraying deposit.**

***deposition efficiency.** The ratio, usually expressed in percent, of the weight of spray deposit to the weight of the material sprayed.

***deposition rate.** The weight of material deposited in a unit of time.

**desiccant.** A chemical used to attract and remove moisture from air or gas.

***detonation flame spraying.** A thermal spraying process variation in which the controlled explosion of a mixture of fuel gas and oxygen is utilized to melt and propel the material to the workpiece.

**dewpoint.** Temperature at which moisture will condense from humid vapors into a liquid state.

***discontinuity.** An interruption of the typical structure of a coating, such as a lack of homogeneity in the mechanical, metallurgical, or physical characteristics of the material. A discontinuity is not necessarily a defect. See also **defect** and **flaw.**

***dovetailing.** A method of surface roughening involving angular undercutting to interlock the spray deposit.

**dwell time.** The length of time the spray material is exposed to the heat zone which produces and sustains a molten condition.

## E

**ear protection.** OSHA or other safety agency approved devices for the reduction of sound audible to the outer ear.

**edge effect.** Loosening of the adhesional bond between the spray deposit and the substrate at the workpiece edges.

**edge loss.** Spray deposit lost as overspray resulting from spraying near the edge of the workpiece.

**elastic modulus.** The ratio of stress, within the proportional limit, to the corresponding strain.

***electric arc spraying.** A nonstandard term for **arc spraying.**

***electric bonding.** A nonstandard term for **surfacing.**

**electrode.** A component for the electrical circuit through which current is conducted to the arc. See **anode** and **cathode.**

**enclosure.** See preferred term **acoustical room.**

**endothermic compounds.** Beads and tablets which absorb moisture from the air and are consumed in the process. The action is termed deliquescence. Beads used are inorganic with absorption capability to reduce dewpoints 42°F (5.5°C) at an inlet temperature of 100°F (38°C), and 27°F (−2.8°C) at an inlet temperature of 70°F (21°C). Beads or tablets utilized are of two types: potassium carbonate and sodium chloride.

***exhaust booth.** A mechanically ventilated, semi-enclosed area in which air flow across the work area is used to remove fumes, gases, and solid particles.

**eye protection.** Proper helmets, face masks, or goggles which are required to be used to protect the eyes from ultraviolet and infrared radiation during thermal spraying operations.

## F

***face shield (eye protection).** A device positioned in front of the eyes and over all or a portion of the face to protect the eyes and face. See also **hand shield** and **helmet.**

***feed rate.** A nonstandard term for **spray rate.**

***filter glass.** A nonstandard term for **filter plate.**

***filter lens (eye protection).** A round filter plate.

***filter plate (eye protection).** An optical material that protects the eyes against excessive ultraviolet, infrared, and visible radiation.

***fines.** A material finer than a particular mesh size under consideration.

***flame spraying (FLSP).** A thermal spraying process in which an oxyfuel gas flame is the source of heat for melting the surfacing material. Compressed gas may or may not be used for atomizing and propelling the surfacing material to the substrate.

***flashback.** A recession of the flame into or back of the mixing chamber of the thermal spraying gun.

***flashback arrester.** A device to limit damage from a flashback by preventing propagation of the flame front beyond the location of the arrester.

***flaw.** An undesirable discontinuity. See **defect.**

**flow meter.** A device for indicating the rate of gas flow in a system.

**fretting.** Surface damage resulting from relative motion between surfaces in contact under pressure.

***fuel gases.** Gases such as acetylene, natural gas, hydrogen, propane, stabilized methylacetylene propadiene, and other fuels, and hydrocarbons, usually used with oxygen for heating.

**furnace fusing.** The melting together of the spray deposit and the substrate which results in coalescence. The furnace offers the advantages of controlled heating, cooling, and protective atmosphere.

***fused spray deposit.** A self-fluxing spray deposit which is subsequently heated to coalescence within itself and with the substrate.

***fusion.** The melting together of filler metal and base metal (substrate), which results in coalescence.

**fusion temperature.** In thermal spraying, during the fusing of self-fluxing coatings, the narrow temperature range within which the coating surface exhibits a glassy or highly reflective appearance.

## G

**galvanic corrosion.** Corrosion caused by spontaneous current between two dissimilar conductors in an electrolyte or between two dissimilar conductors in dissimilar electrolytes. If the two dissimilar metals are in contact, the reaction is referred to as **couple action.**

***gas cylinder.** A portable container used for transportation and storage of a compressed gas.

***gas pocket.** A nonstandard term for **porosity.**

***gas regulator.** A device for controlling the delivery of gas at some substantially constant pressure.

***gradated coating.** A thermal spraying deposit composed of mixed materials in successive layers which progressively change in composition from the constituent material of the substrate to the surface of the sprayed deposit. Also referred to as graduated or graded coating.

**gravity feed.** A process by which powder is fed into a thermal spraying gun by gravity.

***grit.** See preferred term **abrasive.**

**grit blasting.** See preferred term **blasting.**

**grit size.** The particle size and distribution of abrasive blasting grains. Usually expressed by Society of Automotive Engineers numbers, such as SAE G25.

***groove and rotary roughening.** A method of surface roughening in which grooves are made and the original surface is roughened and spread.

***gun.** A nonstandard term for **thermal spraying gun.**

***gun extension.** The extension tube attached in front of the thermal spraying gun to permit spraying within confined areas or deep recesses.

## H

***hand shield.** A protective device for shielding the eyes, face, and neck. A hand shield is equipped with a filter plate and is designed to be held by hand.

***hardfacing.** A surfacing variation in which surfacing metal is deposited to reduce wear.

***helmet.** A device designed to be worn on the head to protect eyes, face, and neck from arc radiation, radiated heat, spatter, or other harmful matter.

## I

***inert gas.** A gas which does not normally combine chemically with the substrate or the deposit. Typical examples are argon and helium.

**interface.** The contact surface between the spray deposit and the substrate.

***interpass temperature.** In multiple pass thermal spraying, the temperature (minimum or maximum as specified) of the deposited spray coating before a subsequent pass is started.

**ion.** An atom or group of atoms forming a molecule that carries a positive or negative charge as a result of having lost or gained one or more electrons.

***ionic bond.** A primary bond arising from the electrostatic attraction between two oppositely charged ions.

## K

***keying.** A nonstandard term for **mechanical bond.**

***knurling.** See **groove and rotary roughening, threading and knurling.**

## L

**lamella.** A thin layer, as in the overlayed particles in a thermal spray deposit.

**lamination.** See preferred term **lamella.**

***lens.** See **filter lens.**

***locked-up stress.** A nonstandard term for **residual stress.**

**low pressure plasma spray.** See preferred term **vacuum plasma deposition.**

## M

***manifold.** See **cylinder manifold.**

***mask.** A device for protecting a substrate surface from the effects of blasting or adherence of a spray deposit.

**matrix.** The major continuous substance of a thermal spraying coating as opposed to inclusions or particles of materials having dissimilar characteristics.

***mechanical bond.** The adherence of a thermal spraying deposit to a roughened surface by the mechanism of particle interlocking.

**melting rate.** The weight or length of spray wire or rod melted in a unit of time.

***metallic bond.** The principal bond that holds metals together and is formed between base metals and filler metals in all processes. This is a primary bond arising from the increased spatial extension of the valence electron wave functions when an aggregate of metal atoms is brought close together. See also **bonding force,** and **ionic bond.**

***metallizing.** See preferred term for **thermal spraying.**

***metallurgical bond.** A nonstandard term for **metallic bond.**

**molten metal flame spraying.** A thermal spraying process variation in which the metallic material to be sprayed is in the molten condition. See **flame spraying** (FLSP).

## N

**neat.** Unadulterated.

***neutral flame.** An oxyfuel gas flame in which the portion used is neither oxidizing nor reducing. See also **oxidizing flame** and **reducing flame.**

***nontransferred arc.** An arc established between the electrode and the constricting nozzle. The workpiece is not in the electrical circuit.

***nozzle.** (1) A device which directs shielding media, (2) a device that atomizes air in an arc spray gun, (3) the anode in a plasma gun, (4) the gas burning jet in a rod or wire flame spray gun.

**nozzle accumulation.** Surfacing material deposited on the inner surface and on the exit end of the nozzle.

## O

**open circuit voltage.** The potential difference applied between the anode and cathode prior to initiating the arc.

**overspray.** The excess spray material that is not deposited on the part being sprayed.

**oxide.** A chemical compound, the combination of oxygen with a metal forming a ceramic; examples — aluminum oxide, zirconium oxide.

***oxidizing flame.** An oxyfuel gas flame having an oxidizing effect (excess oxygen).

***oxyfuel gas spraying.** A nonstandard term for **flame spraying.**

## P

**parameter.** A measurable factor relating to several variables; loosely used to mean a spraying variable, spraying condition, spray rate, spray distance, angle, gas pressure, gas flow, etc.

***parent metal.** A nonstandard term for **substrate.**

**particle size.** The average diameter of a given powder or grit granule.

**particle size distribution.** Classification of powdered materials as determined by various testing methods defining the particle sizes and quantities in a given sample.

**particle size range.** See preferred term **particle size distribution.**

**pass.** A single progression of the thermal spray device across the surface of the substrate.

**physical bond.** See preferred term **metallic bond.**

**pistol.** See preferred term **thermal spraying gun.**

***plasma.** See **arc plasma.**

**plasma forming gas.** See preferred term **arc gas.**

***plasma metallizing.** A nonstandard term for **plasma spraying.**

***plasma spraying (PSP).** A thermal spraying process in which a nontransferred arc is utilized as the source of heat that ionizes a gas which melts and propels the coating material to the workpiece.

***plenum.** See **plenum chamber.**

***plenum chamber.** The space between the inside wall of constricting nozzle and the electrode.

***porosity.** Cavity type discontinuities within a sprayed coating.

***postflow time.** The time interval from current shutoff to shutoff of shielding gas or cooling water, or both.

**postheating.** The application of heat to an assembly after a thermal spraying operation.

**powder.** Material manufactured into finely divided particles. When explicitly blended for thermal spraying, powder falls within a specific mesh range, usually finer than 120 mesh (125 microns). Fine powder is usually defined as having particles smaller than 325 mesh (44 microns).

**powder alloy.** Powder prepared from a homogeneous molten mixture of elements, and sometimes entrapped carbides or metal oxides. All of the particles have approximately the same composition.

**powder blend.** A heterogeneous mixture of two or more alloy powders.

**powder clad (wire clad).** Powder or wire wherein one alloy is encapsulated in another; a composite.

**powder composite.** Two or more independent materials, combined to form a single integrated unit. Maybe either chemically clad or mechanically agglomorated.

***powder feeder.** A device for conveying powdered materials to thermal spraying equipment.

**powder feed gas.** See preferred term **carrier gas.**

**powder feed rate.** The quantity of powder introduced into the hot, gaseous stream per unit of time.

***powder flame spraying.** A thermal spraying process variation in which the material to be sprayed is in powder form; all oxyfuel gas processes. See **flame spraying** (FLSP).

***powder metallizing.** A nonstandard term for **powder flame spraying.**

***preflow time.** The time interval between start of shielding gas flow and arc or gas ignition.

***preheat.** The heat applied to the base metal or substrate immediately before spraying.

***preheat temperature.** A specified temperature that the substrate is required to attain immediately before material deposition.

**primary gas.** The major constituent of the arc gas fed to the gun to produce the plasma; usually argon or nitrogen.

***procedure.** The detailed elements of a process or method used to produce a specific result.

***protective atmosphere.** A gas envelope or vacuum surrounding the part to be thermally sprayed, with the gas composition controlled with respect to chemical composition; dewpoint, pressure, flow rate, etc. Examples are inert gases, combusted fuel gases, hydrogen and vacuum.

**protective barriers.** Curtains or portable fireproof canvas shields, sometimes required to enclose work areas, when there is a possibility of the spray stream being misdirected, or where the glare of the arc or flame could injure unprotected eyes.

**protective clothing.** Leather or metal coated articles designed to prevent burns from ultraviolet radiation or misdirected particles.

## Q

**quench rate.** The speed at which a sprayed particle cools upon striking the surface of the substrate.

## R

***rate of deposition.** See **deposition rate.**

***reducing flame.** A gas flame having a reducing effect (excess fuel gas).

**refrigerated dryer.** The application of a refrigeration cycle to physically lower the dewpoint.

**regenerative dryer.** A double column apparatus containing a drying medium for moisture absorption, which is automatically regenerated.

***regulator.** See **gas regulator.**

**relative density.** See preferred term **apparent density ratio.**

***residual stress.** Stress remaining in a structure or member as a result of thermal or mechanical treatment or both. See **coating stress.**

**resonance time.** See preferred term **dwell time.**

**root mean square** (RMS). A method of defining the average roughness of a surface. It is the square root of the sum of all individual measurements divided by the number of measurements.

$$\text{RMS} = \sqrt{a^2 + b^2 + c^2 + d^2 + e^2 + \text{----}}$$

***rotary roughening.** A method of surface roughening in which are revolving roughening tool is pressed against the surface being prepared, while either the work or the tool, or both, move.

***rough threading.** A method of surface roughening which consists of cutting threads with the sides and tops of the threads jagged and torn.

## S

**saturated air.** To reach 100 psi (690 kPa) air at 100% humidity, it is necessary to compress approximately 8 cu ft (0.23 m$^3$) of free air, with its inherent moisture, into one cubic foot (0.028 m$^3$), since atmospheric humidity is usually more than 12.5% at ambient. All undried compressed air systems at 100 psi (690 kPa) and ambient temperatures are at 100% relative humidity.

**screen.** One of a set of sieves, designated by the size of the openings, used to classify and sort powder to particle size.

***seal coat.** Material applied to infiltrate and close the pores of a thermal spraying deposit.

**secondary gas.** The minor or second constituent of the arc gas fed to the gun to produce plasma.

**self-bonding materials.** Those materials that exhibit the characteristics of forming a metallurgical bond with the substrate in the as-sprayed condition.

***self-fluxing alloys.** Surfacing materials that "wet" the substrate and coalesce when heated to their melting point, without the addition of an externally applied flux. These alloys contain boron or silicon, or both, as fluxing agents.

***shadow mask.** A protective device that partially shields an area of the work, thus permitting some overspray to produce a feathering at the coating edge.

***shear stress.** The stress on the slip plane produced by external loads tending to slide adjacent planes with respect to each other in the direction parallel to the planes.

***shielding gas.** Protective gas used to prevent or minimize atmospheric contamination. Also see **protective atmosphere.**

***shrinkage stress.** A nonstandard term for **residual stress.**

**sieve.** See preferred term **screen.**

***sieve analysis.** A method of determining particle size distribution, usually expressed as the weight percentage retained upon each of a series of standard screens of decreasing mesh size. Also see **particle size distribution.**

**slick up.** Point at which a self-fluxing alloy begins to shine during the fusing operation.

**solvent degreasing.** The removal of oil, grease, and other soluble contaminants from the surface of the workpiece by immersion in suitable cleaners.

**spalling.** The flaking or separation of a sprayed coating.

**splat.** A single thin flattened sprayed particle.

**splat cooling.** Extremely rapid, high rate of cooling, the effects of which can be observed in thermal spraying deposits leading to the formation of metastable phases and an amorphous microstructure.

**spray.** A moving mass of dispersed liquid droplets or heat softened particles.

**spray angle.** The angle of particle impingement, measured from the surface of the substrate to the axis of the spraying nozzle.

**spray booth.** See preferred term **exhaust booth.**

***spray deposit.** See **thermal spraying deposit.**

***spray deposit density ratio.** The ratio of the density of the spray deposit to the theoretical density of the surfacing material. Usually expressed as percent of theoretical density.

**spray distance.** The distance maintained between the thermal spraying gun nozzle tip and the surface of the workpiece during spraying.

***spray rate.** The rate at which surfacing material passes through the gun.

***spraying sequence.** The order in which different layers of similar or different materials are applied in a planned relationship, such as overlapped, superimposed, or at given angles.

**stabilizing gas.** The arc gas, ionized to form the plasma, is usually introduced into the arc chamber tangentially. The relatively cold gas chills the outer surface of the arc stream, tending to constrict the plasma, raise its temperature, and force it out of the anode (nozzle) in a steady, relatively unfluctuating stream.

**step mounting.** The intentional overlapping of several workpieces in order that one protects or masks its neighbor during the blasting or spraying process.

**sublime.** To volatilize from the solid state to a gas.

***substrate.** Any material to which a thermal spraying deposit is applied.

**superfines.** Extra small, minute powder particles, usually less than five microns in size.

**superheat.** The difference between the higher actual temperature at the evaporator outlet and the lower theoretical temperature of the refrigerant at pressure.

**surface feet per minute** (SFPM). Linear velocity of the thermal spray gun as it traverses the length of the workpiece. Also, the circumferential velocity of the substrate.

***surface preparation.** The operations necessary to produce a desired or specified surface condition.

***surface roughening.** A group of methods for producing irregularities on a surface. See also **dovetailing, groove and rotary roughening, rotary roughening, rough threading,** and **threading and knurling.**

***surfacing.** The application by thermal spraying of a layer or layers of material to a surface to obtain desired properties or dimensions, as opposed to making a joint.

***surfacing material.** The material that is applied to a substrate during surfacing.

***surfacing metal.** The metal that is applied to a substrate during surfacing.

## T

**textural stress.** The accumulated stress within an entire coating.

***thermal spraying** (THSP). A group of processes in which finely divided metallic or nonmetallic surfacing materials are deposited in a molten or semimolten condition on a substrate to form a spray deposit. The surfacing material may be in the form of powder, rod, cord, or wire. See also **arc spraying, flame spraying,** and **plasma spraying.**

**thermal spraying deposit.** The coating or layer of surfacing material applied by a thermal spraying process.

***thermal spraying gun.** A device for heating, feeding, and directing the flow of a surfacing material.

***thermal stress.** Stress resulting from nonuniform temperature distribution.

***threading and knurling.** A method of surface roughening in which spiral threads are prepared, followed by upsetting with a knurling tool.

**tons of refrigeration.** A rate of heat exchange equal to 12,000 BTU/h.

**torch.** A device used for fusing sprayed coatings; it mixes and controls the flow of gases.

**torch fusing.** The use of a torch to heat and melt a fusable spraying deposit to produce coalescense.

***travel angle.** The angle that the gun makes with a reference line perpendicular to the axis of the deposit in the plane of its axis. This angle can be used to define the position of thermal spraying torches and thermal spraying guns.

**traverse speed.** The linear velocity at which the thermal spraying gun traverses across the workpiece during the spraying operation.

## U

**undercoat.** A deposited coat of material which acts as a substrate for a subsequent thermal spraying deposit. See **bond coat.**

**undercutting.** A step in the sequence of surface preparation involving the removal of substrate material.

## V

**vacuum plasma deposition** (VPD). A thermal spraying process variation utilizing a plasma gun confined to a solid enclosure. The enclosure is evacuated and the spraying performed under low pressure, usually below 10 Torr.

***van der Waals force.** A secondary force arising from the fluctuating dipole nature of an atom with all occupied electron shells filled.

## W

***water wash.** The forcing of exhaust air and fumes from a spraying booth through water so that the vented air is free of thermal sprayed particles or fumes.

***wire feed speed.** The rate of speed at which the wire is consumed.

***wire flame spraying.** A thermal spraying process variation in which the surfacing material is in wire form. See **flame spraying** (FLSP).

**wire metallizing.** See preferred term **wire flame spraying.**

***wire straightener.** A device used for controlling the cast of coiled wire to enable it to be easily fed into the gun.

**workpiece.** The object or surface to be coated. See preferred term **substrate.**

**workpiece cooler.** See Auxiliary cooler.

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