UNIVERSIDAD NACIONAL DE INGENIERIA

FACULTAD DE INGENIERIA MECANICA

EVALUACION DEL GRANALLADO EN HOJAS DE MUELLE TIPO BALLESTA PARA USO AUTOMOTRIZ

INFORME DE SUFICIENCIA

PARA OPTAR EL TITULO PROFESIONAL DE: INGENIERO MECANICO

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PROMOCION 2003-II

LIMA-PERU

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A:

Dios Todopoderoso, a mis padres Gladys y José, y a mi hermana, quienes son lo más apreciado en mi vida.

SIMBOLOS

A	área
a,b	distancia entre agujero para perno central y uno de los extremos de la hoja de muelle donde se está aplicando carga externa
A_1, A_3, A_{Cm}	temperaturas críticas
c	distancia a la fibra neutra
e	espesor del material
E	módulo de elasticidad
F	fuerza
f	frecuencia natural de la hoja de muelle
f	deflexión
g	aceleración de la gravedad
HL	altura libre
I	momento de inercia
k	constante de elasticidad
L	longitud de carga
M	momento flector
N	factor de seguridad
S	esfuerzo
S_a	componente variable del esfuerzo
S_m	esfuerzo medio
S_{max}	esfuerzo máximo
S_{min}	esfuerzo mínimo
S_n	resistencia a la fatiga
S_u	esfuerzo de rotura
S_Y	esfuerzo de fluencia
SF	factor de rigidez
α	hierro alfa
γ	hierro gamma

TABLA DE CONTENIDOS

CAPITULO VI

UTILIZACIÓN DEL PLAN DE EVALUACIÓN EN HOJAS DE MUELLE PROCESADAS CON GRANALLA SAE S 330

PROLOGO

El presente Informe de Suficiencia, a través de sus 6 capítulos, tiene como fin elaborar un Plan de Evaluación que permita correlacionar los parámetros del granallado al grado de aumento en la resistencia a la fatiga en las hojas de muelle tipo ballesta de forma semi-elíptica y de sección plana para uso automotriz.

En el primer capítulo, que es la Introducción, detallo los antecedentes, objetivos, alcances, justificaciones y limitaciones de mi trabajo.

En el segundo capítulo, explico la función que tienen los muelles dentro del sistema de suspensión de los automóviles, menciono las principales propiedades y usos de los diversos tipos de muelles para uso automotriz, dándole mayor énfasis al muelle tipo ballesta por ser él usado en mi Plan de Evaluación.

En el tercer capítulo, detallo las características dimensionales, metalográficas, químicas, de acabado superficial, de dureza y de templabilidad que debe tener la materia prima para las hojas de muelle tipo ballesta. Además, menciono el proceso productivo que utiliza Industria Peruana del Acero S.A. para la fabricación de sus muelles Elefante.

En el cuarto capítulo, explico la teoría de fatiga, alcanzando además el diagrama desarrollado por la Norma SAE HS J788 sobre la estimación de ciclos de vida por

fatiga para las hojas de muelle tipo ballesta que no tienen granallado. Adicionalmente, en este capítulo, explico los fundamentos del granallado, las variables del proceso de granallado, los equipos para el granallado y las condiciones de granallado para las hojas de muelle tipo ballesta. Evidenciándose, la importancia que tiene el granallado sobre las piezas que trabajan a fatiga, ya que este proceso de deformación superficial en frío aumenta el tiempo de vida de estas piezas.

En el quinto capítulo, elaboro el Plan de Evaluación del granallado en las hojas de muelle tipo ballesta. Para ello, explico de forma matemática o haciendo referencia a alguna Norma, el uso de las ecuaciones utilizadas en el Plan de Evaluación, especifico las características que deben tener las probetas para el ensayo de fatiga e indico la forma como se debe montar las probetas en la máquina fatigadora.

En el sexto capítulo, utilizo el Plan de Evaluación para identificar la resistencia a la fatiga que se obtiene en las hojas de muelle granalladas en diferentes posiciones de la faja transportadora de la granalladora (posición: derecha, centro e izquierda), ya que se ha encontrado que existen diferentes intensidades y coberturas de granallado en una posición con respecto a las otras.

Al término del capitulo sexto, se elaboran conclusiones y se dan recomendaciones, finalizando con la bibliografía y los apéndices.

Es muy importante para el suscrito reconocer y agradecer el valioso apoyo recibido por Industria Peruana del Acero S.A (empresa donde laboro), y sobre todo a su Gerente de Operaciones, el Ing. Jorge Gómez Sánchez Costa.

CAPITULO I

INTRODUCCION

1.1. ANTECEDENTES

Industria Peruana del Acero S.A (IPASA) es una empresa peruana con certificación ISO 9001, que fue fundada en el año 1952 y que tiene su planta industrial en la provincia de Chincha.

IPASA es una empresa manufacturera que se dedica a la fabricación de hojas y muelles tipo ballesta marca "Elefante", y a sabiendas de que el granallado es un tratamiento superficial en frio que mejora la resistencia de los elementos mecánicos que trabajan a fatiga, ha incorporado este tratamiento superficial dentro de su proceso de fabricación.

Dado el espíritu de constante mejoramiento continuo que existe en IPASA y a mi calidad de Jefe del Departamento de Control de Calidad de esta empresa, elaboro el presente informe para crear una metodología que permita correlacionar las condiciones del proceso de granallado al grado de aumento en la resistencia a la fatiga de las hojas de muelle tipo ballesta.

1.2. OBJETIVOS

1.2.1. Objetivo General

Elaborar un Plan de Evaluación que permita correlacionar los parámetros del granallado al grado de aumento en la resistencia a la fatiga en las hojas de muelle tipo ballesta de forma semi-elíptica y de sección plana para uso automotriz.

1.2.2. Objetivo Especifico

Identificar la calidad del granallado en las hojas de muelle tipo ballesta de forma semi-elíptica y de sección plana, cuando son procesadas en la parte central, derecha e izquierda de la faja transportadora de la máquina granalladora, a las mismas condiciones de funcionamiento de dicha máquina.

1.3. ALCANCE

- El alcance del Plan de Evaluación es sólo para hojas de muelle sueltas (no para paquete de muelle armado) tipo ballesta de uso automotriz de forma semi-elíptica y de sección plana.
- No se va indicar en el presente informe la temperatura de temple, dureza de temple, temperatura de revenido, dureza de revenido ni las condiciones del granallado utilizadas por Industria Peruana del Acero S.A por ser información de carácter reservado.

1.4. JUSTIFICACION

Según las condiciones del granallado a que han sido sometidas las piezas mecánicas y al tipo de trabajo de estas (fatiga por flexión, fatiga por torsión, etc) el aumento del tiempo de vida puede llegar hasta 6 veces con respecto a los materiales que no tienen este proceso. Dado ello, y sabiendo que las hojas de muelle tipo ballesta trabajan a fatiga por flexión, el Plan de Evaluación que se desarrolla en el presente informe va a permitir optimizar los rangos de impactación que IPASA utiliza en sus productos, aumentando así la satisfacción de sus clientes ya que ellos obtendrán un muelle con mayor durabilidad.

1.5. LIMITACIONES

Los métodos de medición y control que se utilizan en el Plan de Evaluación se limitan a las capacidades que poseen los equipos e instrumentos que actualmente utiliza IPASA.

CAPITULO 2

GENERALIDADES DE LOS MUELLES DE USO AUTOMOTRIZ

2.1. FUNCION DE LOS MUELLES

Los muelles son piezas elásticas que forman parte del sistema de suspensión de los automóviles, ubicados entre el bastidor (ver figura 2.1) y lo más próximo a las ruedas, que tienen como función absorber las desigualdades que tiene el terreno por el que se desplaza, para que el ascenso y descenso de la carrocería no afecte: el confort ni la seguridad de los pasajeros, ni la protección de la carga y ni la protección de las piezas del automóvil.

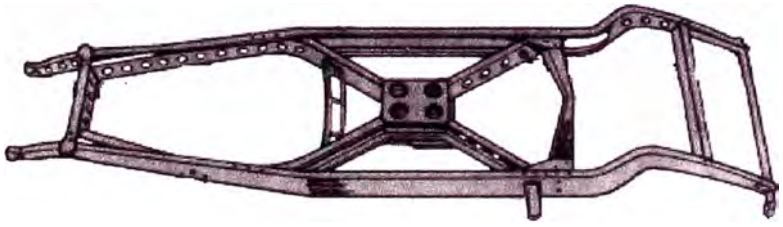


Figura 2.1: bastidor

2.2. TIPOS DE MUELLES

2.2.1. Muelles helicoidales

Los muelles helicoidales, también llamados muelles tipo resorte, consisten en una barra redonda de acero aleado enrollada en forma de espiral ascendente, generalmente de diámetro y paso constante (ver figura 2.2). Estos muelles son ideales para automóviles ligeros (donde la carga no varía de manera notable entre el vehículo vacio y cargado), en cambio en

automóviles pesados no son apropiados ya que si se fabricarían de acuerdo al peso de la carga resultarían muy rígidos cuando el vehículo marche en vacio.

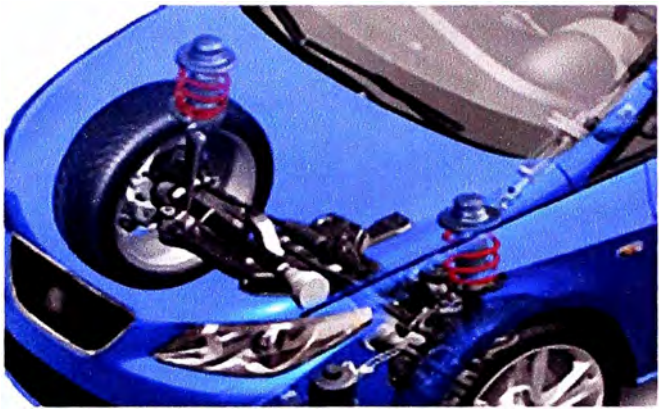


Figura 2.2: Muelle helicoidal montado en su unidad

2.2.2. Muelles Neumáticos

La ventaja principal de los muelles neumáticos es que su presión interior puede ser modificada de acuerdo a la carga, consiguiéndose con ello mantener la misma altura en el vehículo cargado y vacio, además de proporcionar casi la misma suavidad de marcha con independencia de la carga aprovechando la compresibilidad del aire interior (ver figura 2.3).

Este tipo de muelle está adquiriendo cada vez más utilización en los vehículos dotados con frenos de aire, ya que el aire comprimido está disponible en estas unidades.

Figura 2.3: Muelle neumático montado en su unidad

2.2.3. Muelles tipo barra de torsión

Las barras de torsión son barras de acero aleado de buenas propiedades elásticas, que actúan como filtro cinético entre la carrocería y las ruedas, ya que al torcerse absorben el efecto rebote de las llantas cuando estas salen de su posición de equilibrio por efecto de las irregularidades del camino (ver figura 2.4).

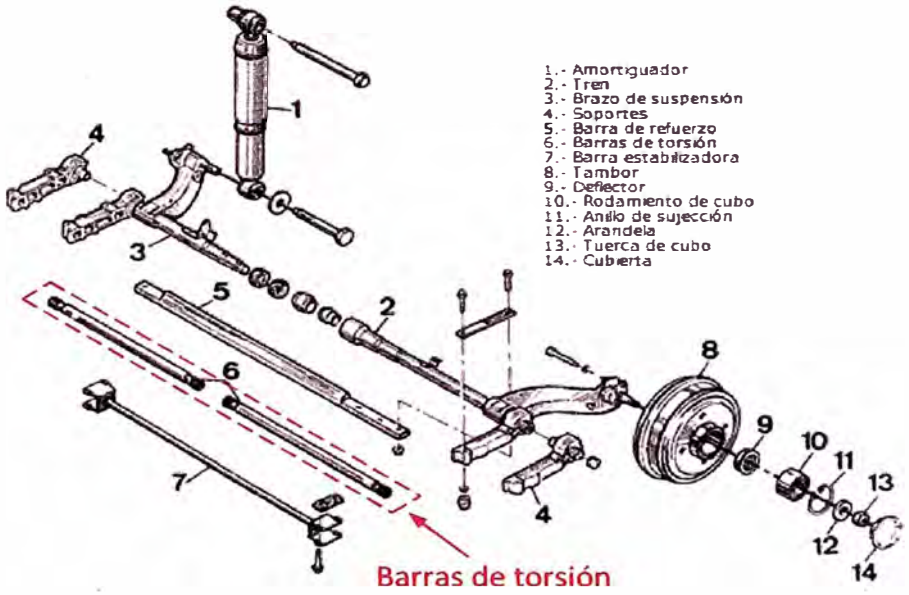
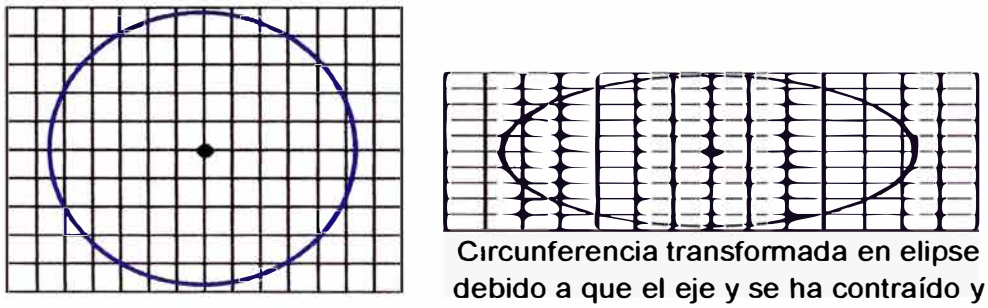


Figura 2.4: Despiece de una suspensión de brazos tirados de dos barras de torsión

2.2.4. Muelles tipo ballesta

Los muelles tipo ballesta son el conjunto de hojas de acero laminadas en caliente, de bordes redondeados, conformados y tratados térmicamente, de formas semi-elípticas, rectas o parabólicas, unidas entre sí por un perno central y alineadas mediante abrazaderas, teniendo en conjunto la función de absorber elásticamente las cargas dinámicas originadas por las irregularidades del camino. Estos muelles son utilizados en los vehículos de transporte de pasajeros y en los vehículos de transporte de cargas (ver figuras 2.8 y 2.9).

Se denomina hojas de forma semi-elíptica, a aquellas hojas de espesor constante, se incluyen también las hojas que tienen desbaste sólo en el extremo de sus puntas (ver figura 3.14), que han sido fabricadas con una curvatura correspondiente a un arco de circunferencia, ya que durante su funcionamiento adquieren la forma semi-elíptica, debido a que se contraen en la dirección de la carga y se extienden en la dirección ortogonal de la misma (ver figura 2.5).



Circunferencia en un plano cartesiano no deformado

Circunferencia transformada en elipse debido a que el eje y se ha contraído y a que el eje x se ha expandido

Figura 2.5: Transformación de una circunferencia en elipse por deformación ortogonal del plano cartesiano

Las hojas de forma parabólica son fabricadas con una curvatura de arco de circunferencia, a excepción de su parte central la cual es plana, a la vez poseen espesor variable, encontrándose el mayor espesor en su parte central, por lo cual al soportar cargas correspondientes a su diseño adquieren la forma de una parábola (ver figura 2.6). Y se denominan hojas rectas, a aquellas que se fabrican con un arco de circunferencia de radio infinito. Vale la pena indicar que los últimos modelos de automóviles que utilizan muelles tipo ballesta, en su mayoría están utilizando los muelles parabólicos.

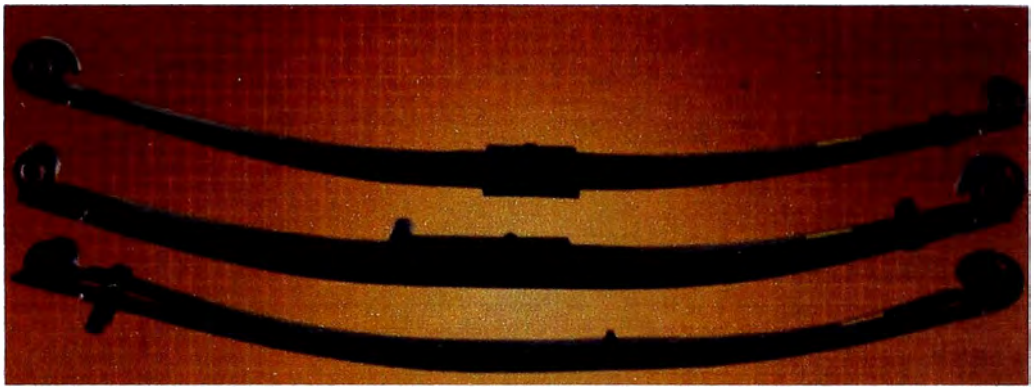


Figura 2.6: Fotografía de muelles parabólicos

Dentro del paquete de muelle la hoja exterior más grande es conocida como "hoja madre" u hoja principal u hoja primera, y a partir de ella se alinean las demás hojas, las cuales se identifican según su posición respecto a la hoja madre, como: hoja segunda, hoja tercera, etc.

El paquete de muelle, se une al bastidor a través de los extremos de la hoja primera (ver figuras 2.7 y 2.8), y se une a su asiento en el eje del vehículo a través de unos pernos en U (ver figura 2.8).

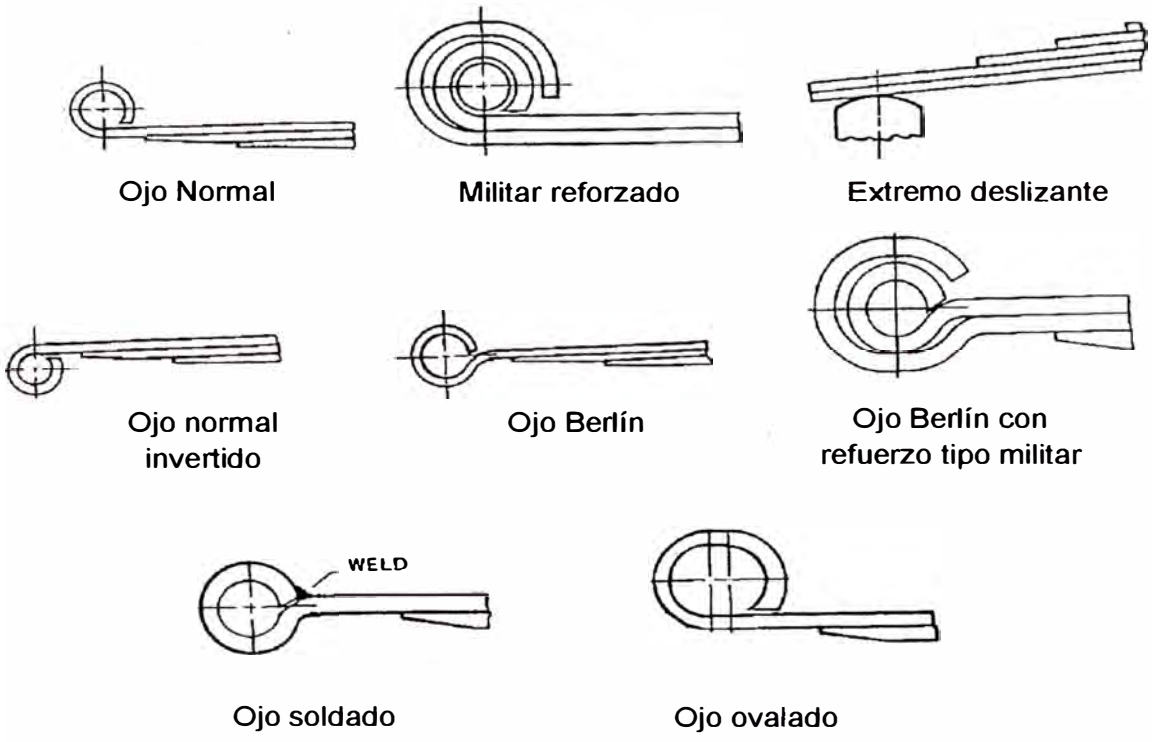


Figura 2.7: Tipo de extremos en hoja primera

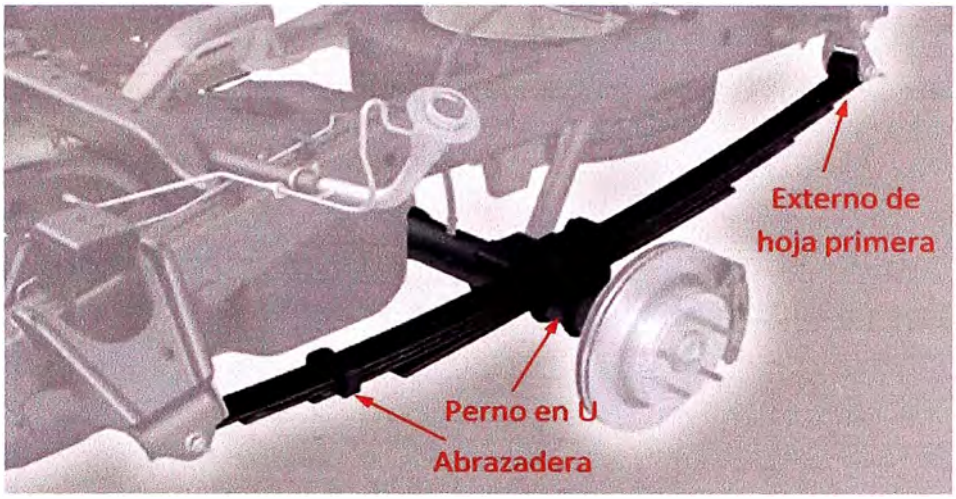


Figura 2.8: Muelle tipo ballesta montado en su unidad

Con respecto al agujero para perno central, las hojas de muelle se pueden clasificar como simétricas, siempre y cuando al pasar un plano imaginario paralelo a la sección axial por el centro del agujero en mención, las partes de las hojas de muelle son iguales, o asimétricas cuando no se cumple la condición mencionada.

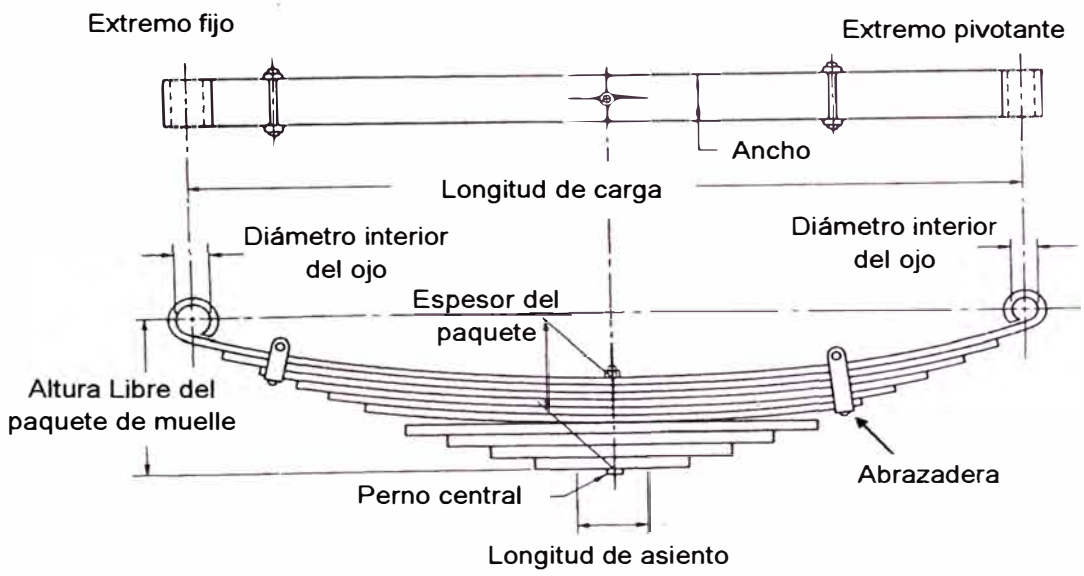


Figura 2.9: Muelle tipo ballesta de forma semi-elíptica

La sección de las hojas de mulle son variables, pudiendo ser: planas, acanaladas o de extremo parabólico (ver figura 2.9). IPASA, comercializa sólo hojas de muelle de sección plana.

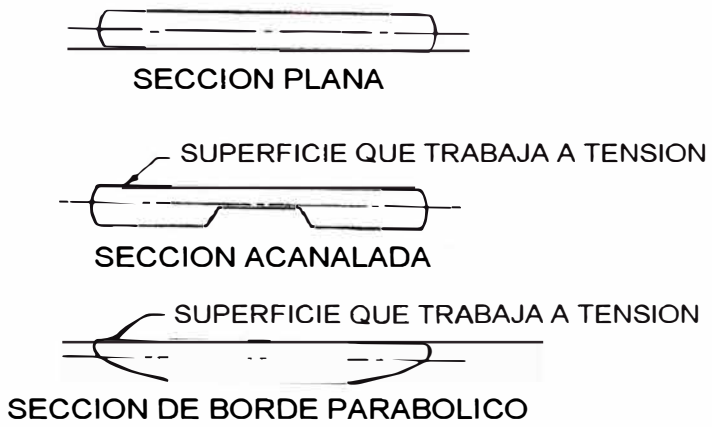


Figura 2.10: Secciones de hojas de muelle tipo ballesta

IPASA fabrica hojas y muelles tipo ballesta de forma semi-elíptica y de forma recta. En el caso de hojas semi-elípticas, existe una gran diversidad, debiéndose ello a variaciones en el largo, espesor y ancho del material; así como de la forma de las puntas (extremos), tal es así, que IPASA fabrica productos de 70 diferentes tipos de punta.(ver apéndice A).

Según la Norma SAE HS J 788 los muelles tipo ballesta deben tener las siguientes propiedades mecánicas:

- Esfuerzo de Tracción : 1300 - 1700 MPa
- Esfuerzo de Fluencia (0.2% Offest) : 1170 -1550 MPa
- Elongación : 7% Min.
- Reducción de área : 25% Min.
- Módulo de elasticidad : 200000 MPa
- Dureza Brinell : 388-461 HBN

CAPITULO 3

MATERIA PRIMA Y PROCESO DE FABRICACIÓN DE LAS HOJAS DE MUELLE TIPO BALLESTA

3.1. MATERIA PRIMA

Para la fabricación de hojas de muelle tipo ballesta se pueden utilizar los siguientes aceros: SAE 9260, SAE 4068, SAE 4161, SAE 6150, SAE 8660, SAE 5160, SAE 51B60, SAE 5160H y SAE 50B60, los cuales deben ser laminados en caliente en forma de barras macizas con bordes redondeados.

De toda esa gama de posibilidades, la Norma SAE HS J788 (Abril de 1980) recomienda utilizar los siguientes aceros según el espesor de la hoja de muelle tipo ballesta a fabricar:

Espesores	Acero
Hasta 8 mm	SAE5160
Hasta 16 mm	SAE5160H
Hasta 37.5 mm	SAE51B60

Es por ello que IPASA utiliza el acero SAE 5160H para la fabricación de los muelles Elefante.

3.1.1. Composición Química

La composición química de los aceros para muelles de calidad SAE 5160H debe cumplir con las especificaciones dadas en la Norma SAE J1268 May 95, es decir:

	%C	%Mn	%Si	%Cr	%S	%P
Mín	0.55	0.65	0.15	0.60	-	-
Máx	0.65	1.10	0.35	1.00	0.025	0.025

3.1.2. Características Metalográficas

3.1.2.1. Descarburización Superficial

La descarburización superficial es la pérdida de carbono en la periferia del acero, debido a altas temperaturas bajo la acción de gases como: oxigeno, hidrógeno, anhídrido carbónico, etc. Como la descarburización está presente inevitablemente en el proceso de fabricación del acero y a que esta disminuye la resistencia a la fatiga del acero, se ha establecido tolerancias para la descarburización dependiendo del espesor del material y de la utilización del mismo.

Tal es así, que en IPASA la descarburización superficial de la materia prima para las hojas de muelle tipo ballesta no debe exceder de 0.20 mm de profundidad para materiales cuyo espesor es menor a 12.5 mm, y no debe exceder de 0.25 mm de profundidad para materiales de espesor igual o mayor a 12.5 mm. Las profundidades de descarburización mencionadas son del tipo 2 de acuerdo al estándar SAE J419 Dec 83(ver apéndice B).

3.1.2.2. Nivel de Inclusiones No Metálicas

Las inclusiones no metálicas, son elementos extraños y perjudiciales ya que reducen las características y propiedades del acero. Pueden provenir de las escorias, de los refractarios o de las materias producidas durante la oxidación y desoxidación en el proceso de fabricación del acero.

Entre los principales tipos de inclusiones no metálicas tenemos:

- Los silicatos, que son las inclusiones que más reducen las características del acero, siendo de forma alargada.
- Los óxidos, que son inclusiones muy duras y frágiles, que durante la forja y la laminación se rompen en forma de rosarios.

Debido a que es inevitable la presencia de las inclusiones no metálicas, IPASA ha establecido que para su materia prima sea aceptable como máximo inclusión de 5 para óxidos y de 4 para silicatos, siendo la forma de medir la establecida en el método A de la Norma ASTM E45-87 (ver apéndice C).

3.1.2.3. Tamaño de Grano

Cuando el metal pasa del estado líquido al estado sólido se inicia la cristalización, es decir, comienzan a formarse los cristales, los cuales después de la solidificación adquieren una forma exterior irregular, denominándoseles a estos cristales: granos.

La determinación del tamaño de grano es importante ya que influye en las propiedades mecánicas, conforme más fino sea el grano, el acero tendrá principalmente mayor ductilidad y tenacidad.

En IPASA, el tamaño de grano para la materia prima de las hojas de muelle debe estar en el rango de 5 a 8, según la Norma ASTM E112-88 (ver apéndice D).

El tamaño de grano que se hace mención es al correspondiente al tamaño de grano austenítico.

3.1.2.4. Segregaciones Bandeadas

Las segregaciones bandeadas son variaciones estructurales en forma de bandas ya sea periódicamente o intermitentemente, que se originan a consecuencias de la heterogeneidad química inicial producida durante la solidificación del lingote y a la deformación producida por la laminación y la forja. Como las segregaciones bandeadas son perjudiciales para las propiedades mecánicas, la microestructura de la materia prima para las hojas de muelle no debe evidenciarlas a un aumento de 100x.

3.1.2.5. Constituyentes metalográficos

Dependiendo del ordenamiento de los átomos de fierro y carbono, un mismo acero puede tener diferentes constituyentes, y la variación de estos constituyentes origina cambios en las propiedades mecánicas del acero, a pesar de mantenerse la misma composición química.

Existen diversos constituyentes metalográficos, los cuales menciono a continuación:

- Ferrita: La ferrita es hierro alfa (α), ver figura 3.19, es decir, hierro casi puro, que cristaliza en el sistema cubico de cuerpo centrado. Es el más blando de todos los constituyentes del acero (90 Brinell), además de ser muy dúctil y maleable.

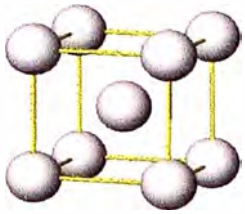


Figura 3.1: Cristal Cúbico de Cuerpo Centrado

- Cementita: La cementita es carburo de hierro, (CFe_3) que contiene 6.67% de carbono y 93.3% de hierro. Es el constituyente más duro y frágil de los aceros al carbono, su dureza es superior a 68 HRc y cristaliza en forma ortorrómbica. Es magnética a la temperatura ambiente, pero pierde su magnetismo a 218ºC. Por lo general, la cementita tiene forma de láminas paralelas (como cuando forma parte de la perlita) o tiene forma globular.

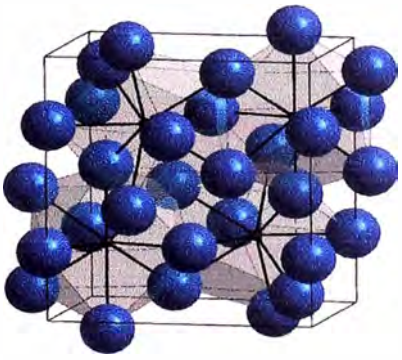


Figura 3.2: Cristal Ortorrómbico

- Perlita: Es el constituyente eutectoide (ver figuras 3.3 y 3.19) formado por capas alternadas de ferrita y cementita. Es de composición química constante de aproximadamente 13.5% de CFe_3 y 86.5% de Fe (0.8% de C y 99.2% de Fe). La perlita por lo general aparece en el enfriamiento lento de la austenita o por transformación isotérmica de la austenita en la zona de los 650º a 725º C.

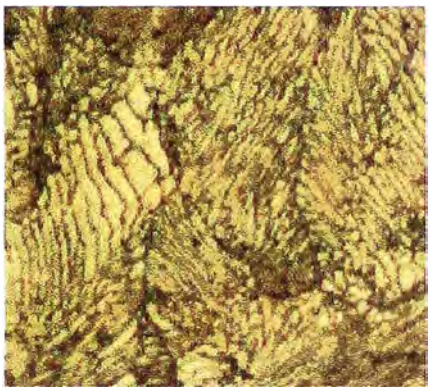


Figura 3.3: Microfotografía de Perlita laminar a 1000x

- Austenita: Es una solución sólida de carbono o carburo de hierro en hierro gamma (γ), la cual cristaliza en el sistema cúbico de cara centrada (ver figura 3.4). Es de composición variable pudiendo contener desde 0 hasta 1.7% de carbono. Todos los aceros se encuentran formados por cristales de austenita cuando se calientan a una temperatura superior a las críticas A_{C3} y A_{Cm} (ver figura 3.19).

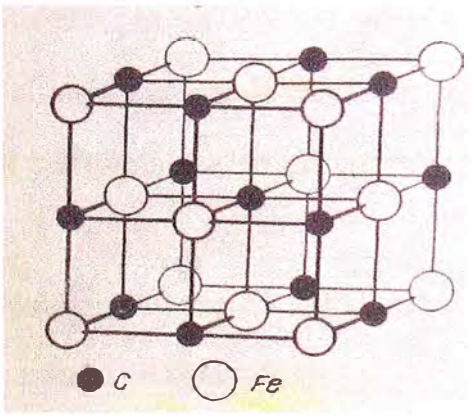


Figura 3.4: Cristal Cúbico de Cara Centrada

- Martensita: Es el constituyente típico de los aceros templados. Está formada por una solución sólida sobresaturada de carbono o carburo de hierro alfa, y se obtiene por enfriamiento rápido de los aceros desde altas temperaturas. Su contenido de carbono suele variar generalmente desde pequeñas trazas hasta 1% de carbono,

sus propiedades físicas varían con su composición, y después de la cementita y de los carburos es el constituyente más duro de los aceros. Presenta un aspecto marcadamente acicular, formando agujas en zigzag. La martensita cristaliza en el sistema tretagonal (ver figuras 3.5 y 3.6).

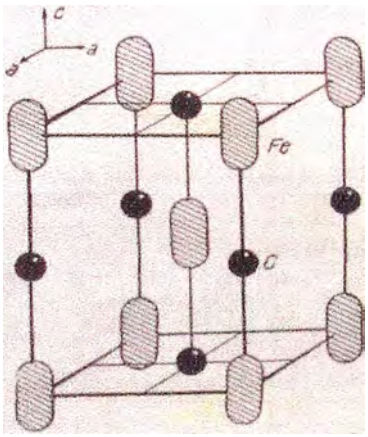


Figura 3.5: Cristal tretagonal

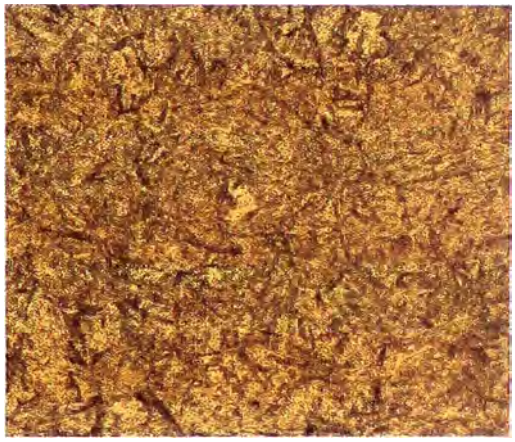


Figura 3.6: Microfotografía de estructura Martensítica a 500x

Adicionalmente existen otros constituyentes como la troostita, sorbita y bainita, a los cuales no se le da mayor detalle por no ser constituyentes normales ni deseables tanto en las hojas de muelle como en su materia prima.

La estructura metalográfica de la materia prima de las hojas de muelle debe ser: ferrita y perlita (ver figura 3.7).

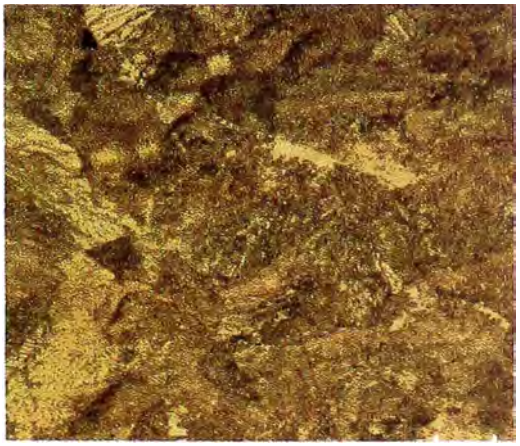


Figura 3.7: Microfotografía de estructura Ferrita y Perlita a 1000x

3.1.3. Características Dimensionales

3.1.3.1. Ancho y espesor

Las especificaciones de ancho y espesor se dan en el apéndice E, el cual es un extracto de la Norma SAE J1123 Nov.92.

3.1.3.2. Radio de Bordes

Los radios en los bordes de la barras deben estar entre el 65% y el 85% del espesor de la barra, según Norma SAE J1123A Nov.92.

3.1.3.3. Combadura lateral

La combadura lateral máxima es de 3 mm por metro o de 15 mm por 5 metros de longitud, dentro de una porción arbitraria, tal y como lo establece la Norma JIS G4801 1984.

3.1.4. Dureza

La dureza Brinell con identador de 10mm de diámetro y 3,000 kgf de carga, no debe superar los 302 HBN, tal y como lo establece la Norma JIS G4801 1984.

3.1.5. Acabado Superficial

La superficie de la barra debe estar libre de oxidación severa y de costras procedentes de la laminación, además no debe presentar marcas de herramientas en la dirección transversal (cualquier orientación mayor de 15° del eje longitudinal) o dentro de los 6.2 mm de

los bordes que superen los 0.25mm de profundidad, según especificaciones dadas por el fabricante norteamericano de muelles EATON.

Vale la pena mencionar, que todo defecto superficial es causal de disminución en la resistencia a la fatiga.

3.1.6. Templabilidad

La templabilidad es la capacidad del acero de adquirir dureza durante el temple y distribuir la misma en forma homogénea desde la superficie hasta su núcleo. Esta propiedad depende principalmente de la composición química, y es muy importante para materiales de gran espesor tratados térmicamente.

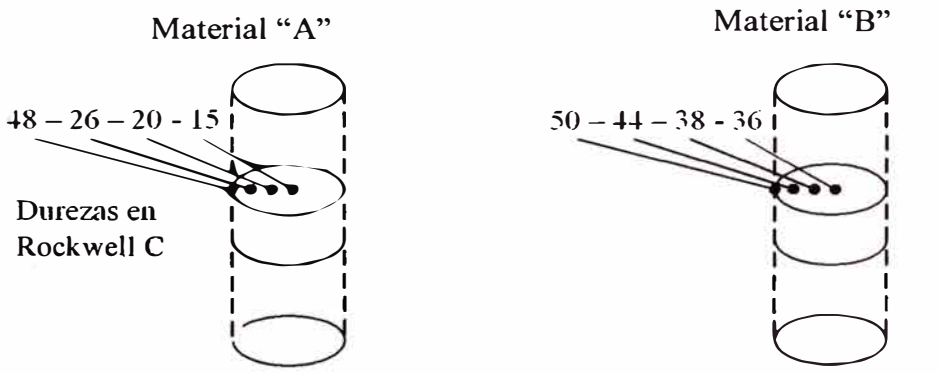


Figura 3.8: Barras redondas con diferente templabilidad

En la figura anterior, se muestran 2 barras dimensionalmente idénticas de 100 mm de diámetro, de diferentes materiales pero templadas a las mismas condiciones, el material "A" después de temple tiene una dureza desde la superficie al núcleo de 48 a 15 HRc, en cambio el material "B", tiene una variación de dureza menor ya que va desde 50HRc hasta 36 HRc, por tanto, este último material tiene mejor templabilidad.

El método más usado para determinar la templabilidad del acero es el ensayo Jominy, el cual se debe efectuar según las directrices dadas por la

Norma SAE J406 Feb95 (ver apéndice F). Adicionalmente, para cada tipo de acero la Norma SAE ha desarrollado unas bandas de templabilidad, asignando la denominación H a los aceros cuyas durezas obtenidas en el ensayo Jominy se encuentren dentro de las bandas citadas anteriormente.

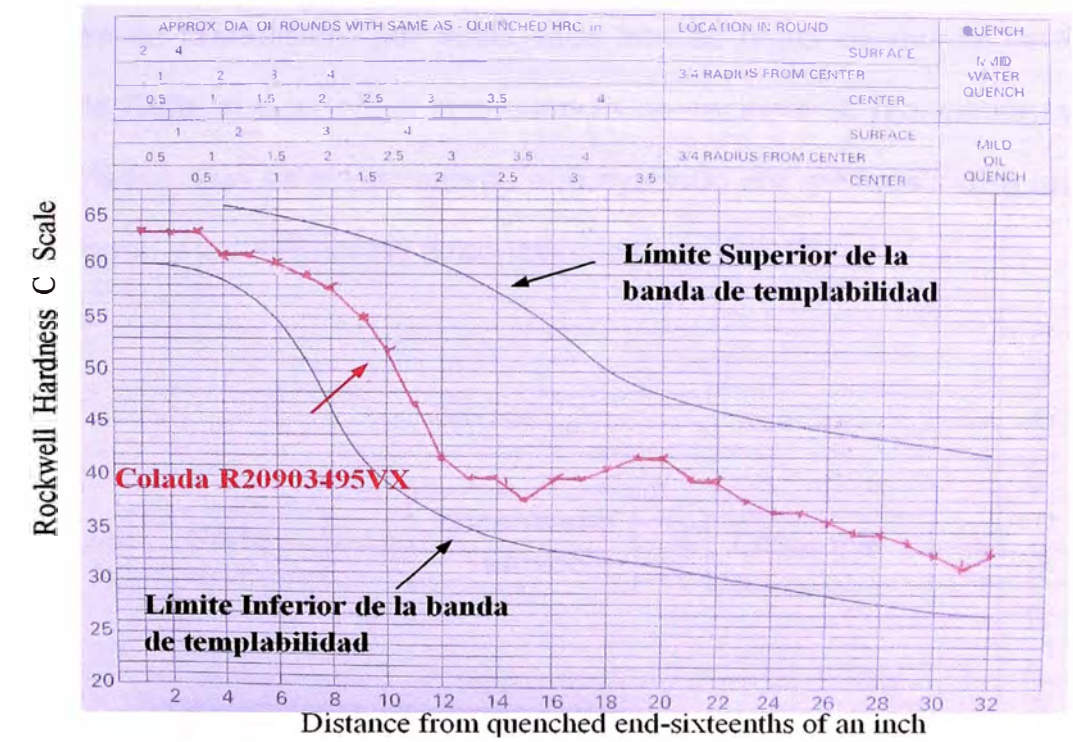


Figura 3.9: Banda de templabilidad del acero SAE 5160H

La figura anterior es un extracto de la Norma SAE J1268 MAY95, al cual se le ha adicionado los resultados del ensayo Jominy de la colada R20903495VX del fabricante Jiangyin Xing Cheng, en él se puede apreciar que el material analizado cumple con la Norma al estar la curva Jominy dentro de las bandas de templabilidad, por tanto este acero es SAE 5160H, si algún punto de la curva hubiera estado por debajo de la banda de templabilidad, el acero seria solamente SAE 5160 (siempre y cuando cumpla con los requisitos de composición química).

3.2. PROCESO DE FABRICACION

IPASA ha dividido su proceso de fabricación en 3 grandes actividades: Corte, Tratamiento Térmico y Ensamble (ver figura 3.10). Como existe una gran variedad de tipos de hojas de muelle, no todas las hojas van a ser sometidas a las mismas operaciones de fabricación, por tanto, todo lote de hojas de muelle lleva consigo una Hoja de Ruta, el cual indica la secuencia operacional de fabricación; y la Hoja de Característica, que es el documento que ayudado por gráficos indica las características de forma y las exigencias dimensiónales.

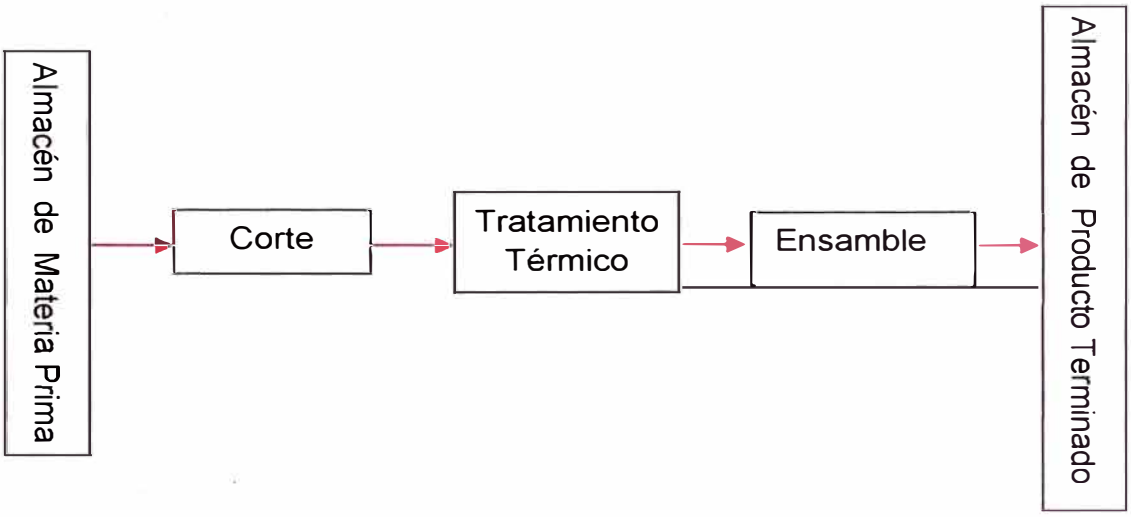


Figura 3.10: Flujograma para la elaboración de muelles Elefante

3.2.1. Corte

El Corte es la primera actividad dentro del proceso de fabricación, y está dividido en 2 partes: Corte Fase 1 y Corte Fase 2.

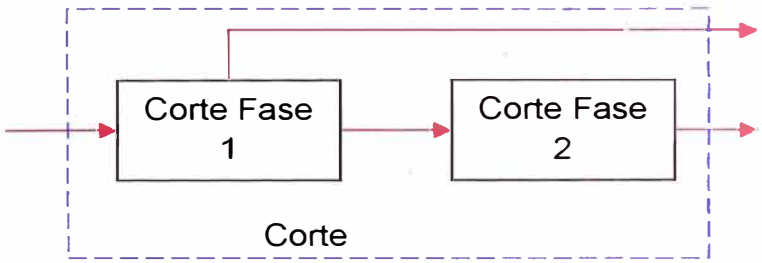


Figura 3.11: Flujograma de la Actividad de Corte

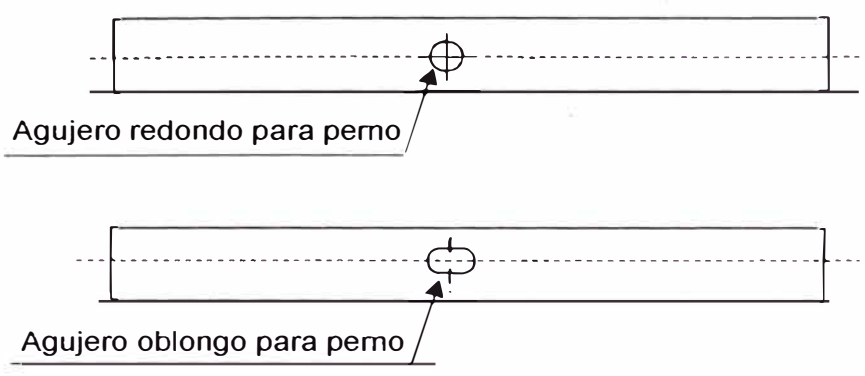
3.2.1.1. Corte Fase 1

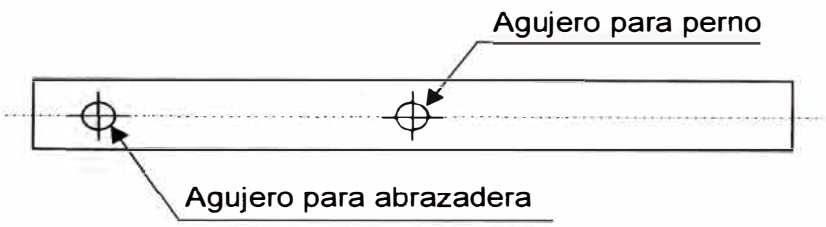
Todas las hojas de muelle pasan por Corte Fase 1, en esta fase a través de prensas se cortan las barras de acero SAE 5160H a la longitud requerida y se punzonan los agujeros cuyo diámetro son mayores al espesor del material de la hoja.

Figura 3.12: Fotografía de las Operaciones de Corte y Punzonado

➢ Entregable de la Operación de Corte de Barras

➢ Entregables de la Operación de Punzonado





3.2.1.2. Corte Fase 2

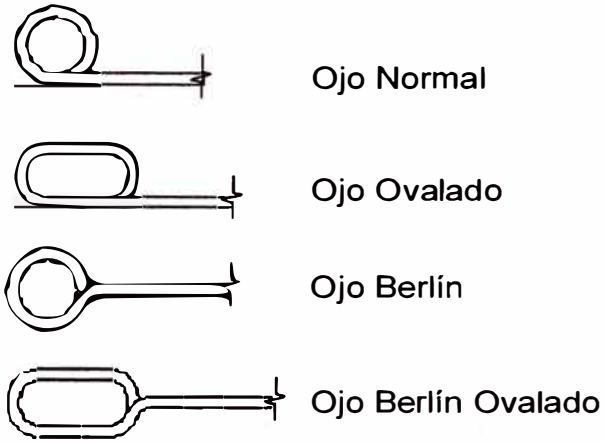
Abarca todos las operaciones de fabricación que deben tener las hojas de muelle antes de ser sometidas al Tratamiento Térmico y que no han sido realizadas en Corte Fase 1, las operaciones son: formado de ojo, formado de doblez, desbaste, sesgado, corte lateral, avellanado, formado de nervadura, cepillado, formado de oblea, taladrado y punzonado en caliente.

No todas las hojas de muelle pasan por Corte Fase 2, y las hojas procesadas en esta Fase no son sometidas a todas las operaciones, ya que ello depende de las características de forma y dimensionales que se desean obtener en cada lote de hojas de muelle.

- Formado de ojo

Figura 3.13: Fotografía del Formado de ojo

Entregables:

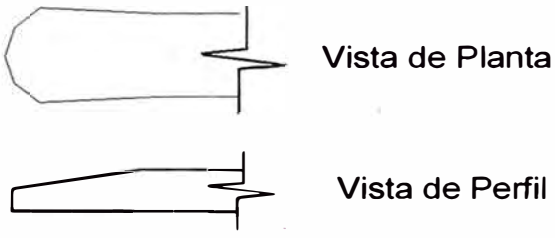


- Desbaste

Figura 3.14: Fotografía de la Operación de Desbaste

Entregable:

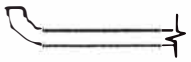
Punta desbastada



- Formado de doblez

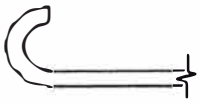
Figura 3.15: Fotografía de la Operación de Formado de Doblez

Entregables:



Doblez Normal 1/4

Doblez Normal Mediano



Doblez Normal 3/4

Doblez Envolvente

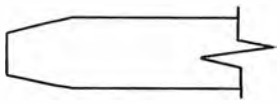
Doblez Berlín 3/4

Doblez Berlín Envolvente

- Sesgado

Figura 3.16: Fotografía de la Operación de Sesgado

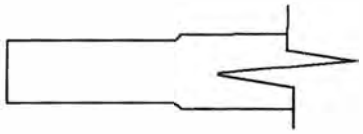
Entregable:



- Corte Lateral

Figura 3.17: Fotografía de la Operación de Corte Lateral

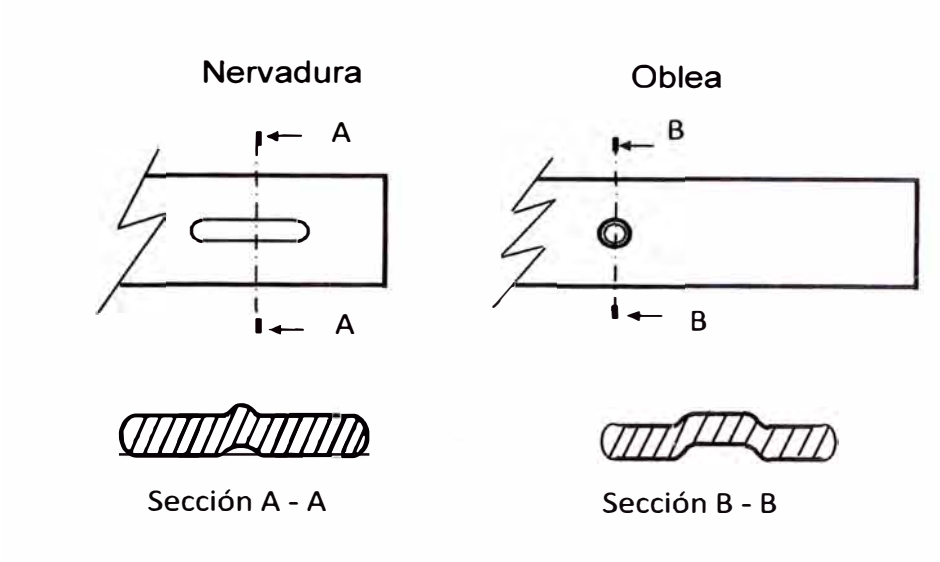
Entregable:



- Formado de Nervadura u oblea

Figura 3.18: Fotografía de Prensa donde se hacen las operaciones de nervadura y oblea

Entregable:



3.2.2. Tratamiento Térmico

Todas las hojas de muelle son sometidas a tratamiento térmico, el cual consta de temple y revenido.

3.2.2.1. Temple

El temple es un tratamiento térmico que tiene por objeto endurecer y aumentar la resistencia de los aceros: calentándolos a una temperatura determinada, manteniéndolos a esa temperatura por cierto tiempo y luego enfriándolos bruscamente sin llegar al fisuramiento.

Como las condiciones de temple para los muelles Elefante son parte del Know How de IPASA y a que las Normas Internacionales no hacen referencia acerca de las condiciones de temple para los muelles tipo ballesta, voy a ser referencia sólo a las recomendaciones dadas por los autores de los libros de tratamiento térmico:

- Calentamiento: El calentamiento es la primera fase del temple, siendo la velocidad de calentamiento un parámetro muy importante a controlar en materiales de gran espesor, ya que una gran diferencia de temperatura entre el núcleo y la superficie pueden

producir fuertes tensiones internas ocasionadoras de grietas y fisuras.

En el calentamiento lo que se desea es modificar la estructura metalográfica inicial, para ello, los aceros hipoeutectotides (aceros con porcentaje de carbono inferior a 0.8) son calentados a una temperatura ligeramente mayor a la crítica superior para obtener una estructura completamente austenítica; y los aceros hipereutectoides (aceros con porcentaje de carbono superior a 0.8) son calentados a una temperatura entre la crítica inferior y la crítica superior para obtener una estructura compuesta por austenita y cementita. Vale la pena indicar que el acero SAE 5160H, es un acero hipoeutectoide ya que su porcentaje de carbono esta entre: 0.55 – 0.65%, por tanto, en el calentamiento de este acero se tiene como objetivo tener una estructura final completamente austenítica.

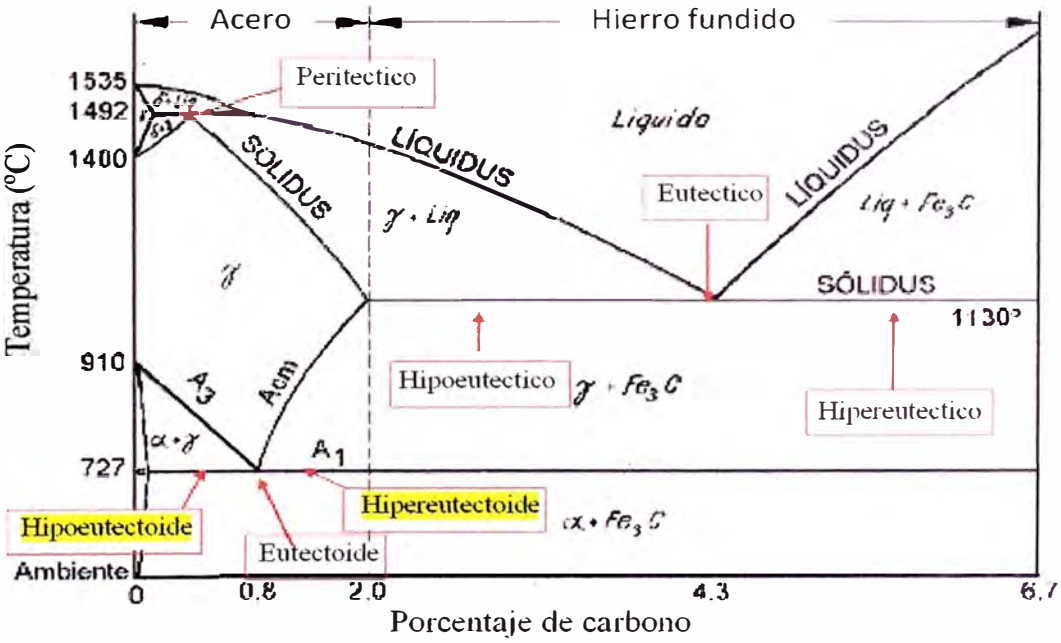


Figura 3.19: Diagrama de equilibrio hierro-carbono

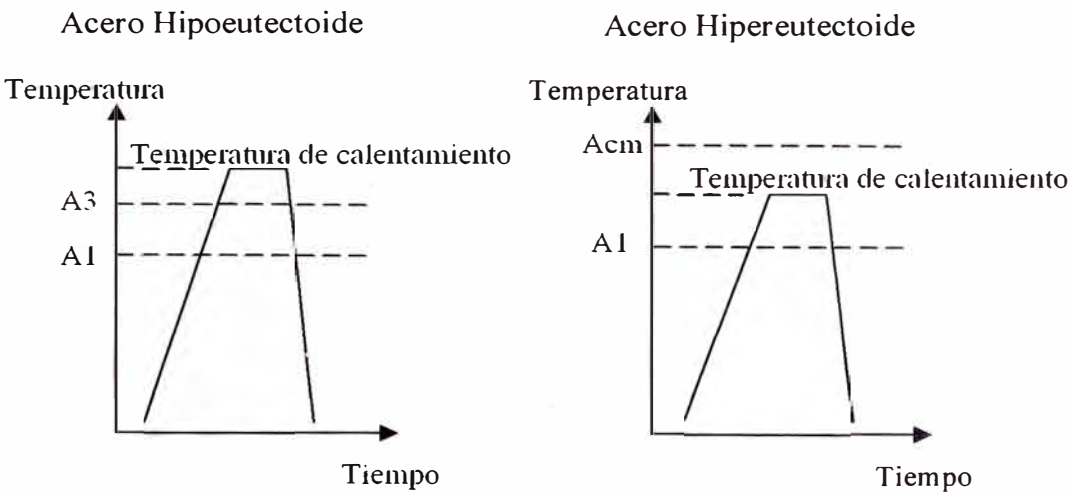


Figura 3.20: Esquema de Temple de aceros

- Tiempo de permanencia a la temperatura de temple: El tiempo de permanecía sirve para asegurar que toda la masa del acero este formada por cristales de austenita (para aceros hipoeutectoides) y que la estructura sea homogénea. El tiempo de permanencia depende de: la masa del acero, de la velocidad de calentamiento, de la clase del acero, y del estado inicial y final del material.

  En general, el tiempo de permanencia oscila entre media hora y una hora por pulgada de espesor del material.

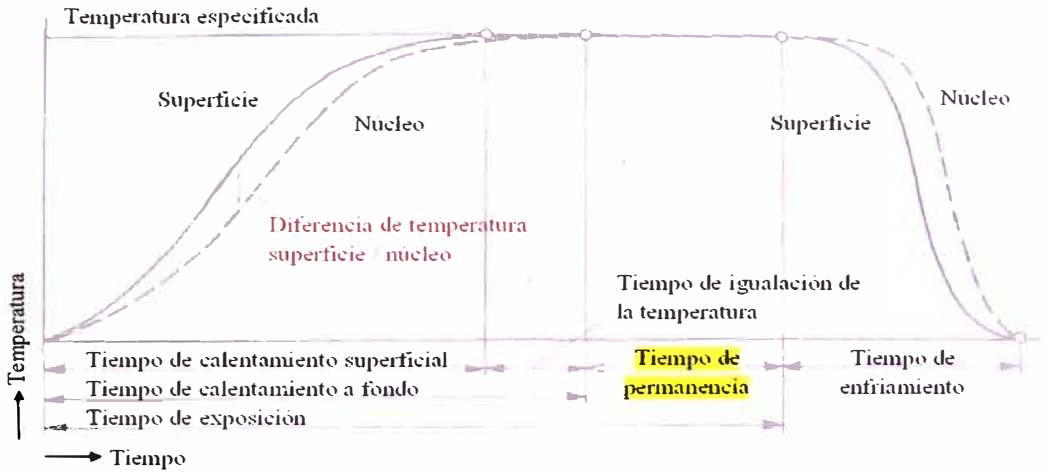


Figura 3.21: Diagrama de Calentamiento para el temple

Velocidad de enfriamiento: Para que exista un buen temple, la velocidad de enfriamiento tiene que ser mayor a la velocidad crítica de temple sin provocar fisuramiento en el material. La velocidad crítica de temple es la velocidad mínima que permite transformar el 100% de austenita en martensita, y que numéricamente se obtiene como la curva tangente a la nariz de la curva S en el diagrama TTT.

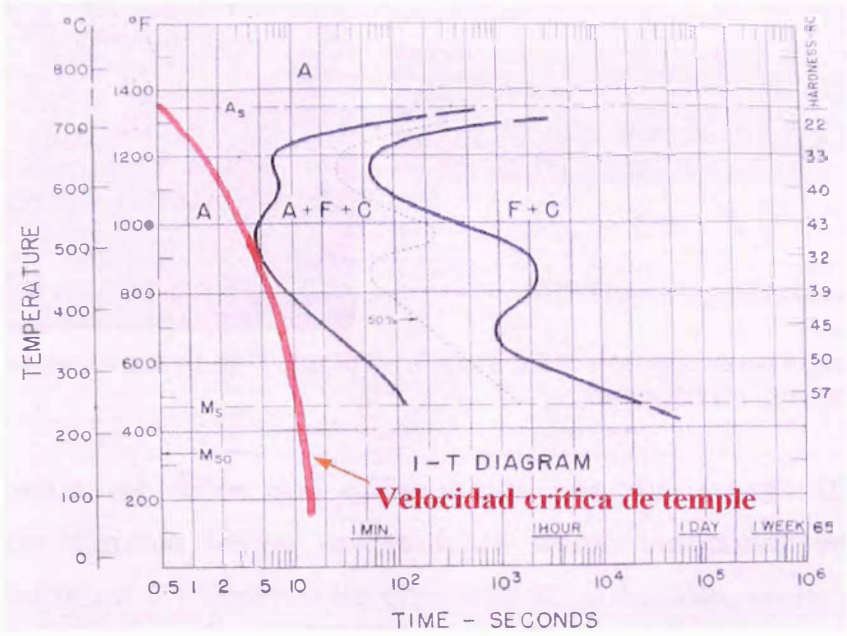


Figura 3.22: Diagrama TTT del acero SAE 5160H con curva de velocidad critica de temple

Dependiendo del tipo de acero, la velocidad de enfriamiento necesaria se obtiene en diferentes medios, como: agua, agua con sal, aceite, aire a presión, aire tranquilo, etc. Vale la pena mencionar, que para obtener un buen temple en el acero SAE 5160H este se debe enfriar en aceite.

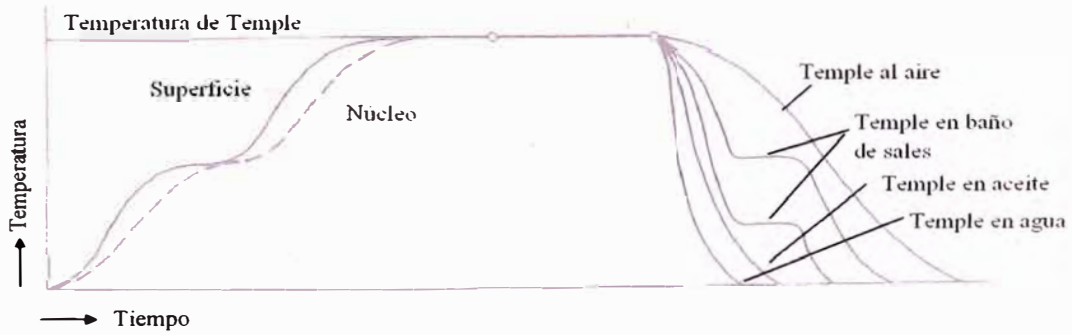


Figura 3.23: Diagrama de enfriamiento en diferentes medios de temple

Como las hojas de muelle a la temperatura de temple son maleables, estas al ser retiradas de los hornos se posicionan en unas curvadoras, las cuales al ser sumergidas en aceite le confieren a las hojas de muelle su forma característica.

Figura 3.24: Fotografía del Proceso de Temple

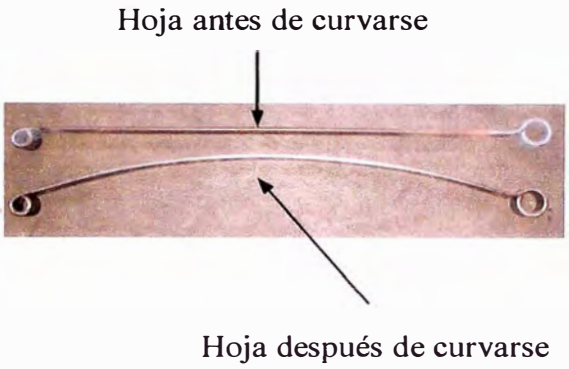


Figura 3.25: Fotografía de hoja antes y después de curvarse

En la industria, es difícil que obtengamos una estructura 100% martensítica, ya que algunas veces no se logra reunir las condiciones ideales, como: temperatura y velocidad de enfriamiento suficiente, completa homogeneidad de la austenita, ausencia de carburos y partículas sin disolver en la austenita, dado ello, en la siguiente figura se muestra una curva para aceros al carbono, donde se indica la dureza y el % de martensita mínimo para un buen temple.

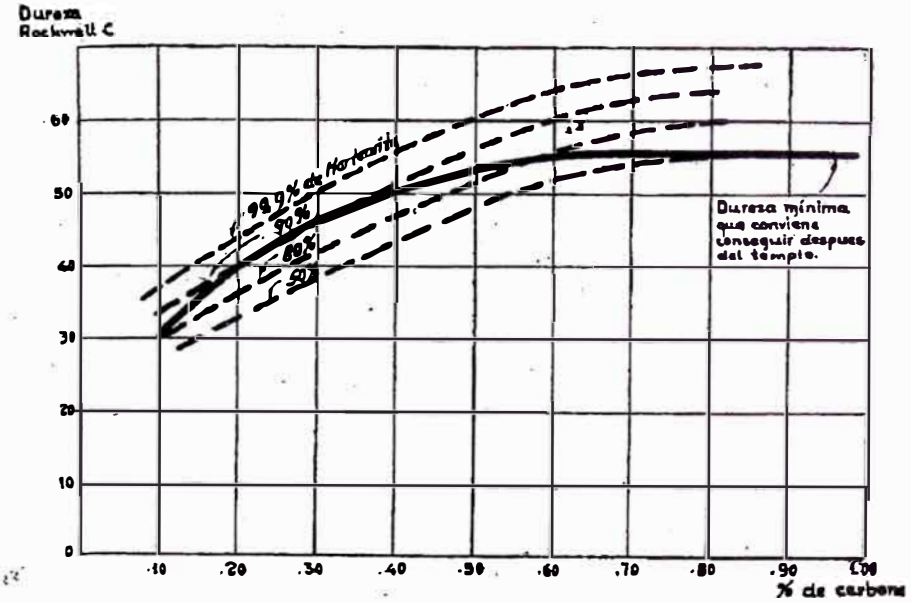


Figura 3.26: Curva de dureza mínima después del temple

3.2.2.2. Revenido

El revenido es un tratamiento térmico complementario y posterior al temple, debido a que después de este tratamiento térmico los aceros quedan demasiados duros y frágiles para los usos al que van a ser destinados, siendo por tanto el objetivo del revenido sacrificar la dureza obtenida para aumentar la tenacidad y elasticidad, además de eliminar las tensiones internas producidas en el temple.

En el revenido el acero es calentado a una temperatura más baja que la crítica inferior y posteriormente enfriado al aire, aceite o agua (según la característica del acero).

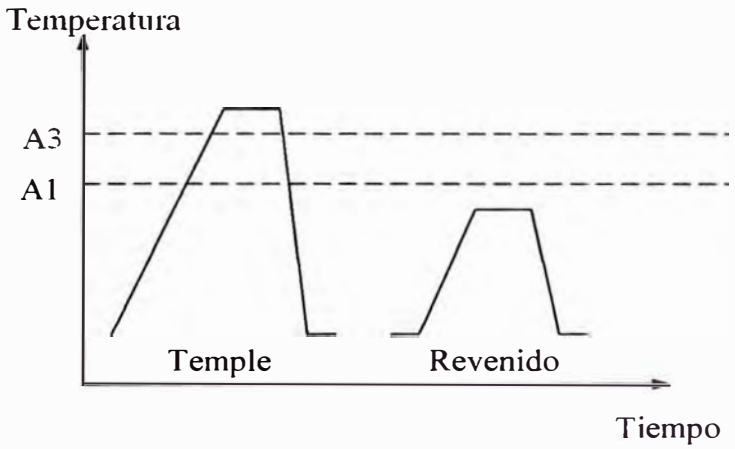


Figura 3.27: Esquema de temple y revenido en aceros hipoeutectoides

Metalográficamente, la martensita obtenida en el temple durante el revenido se engrosa y oscurece tomando el nombre de martensita revenida.

Durante la fabricación de los muelles tipo ballesta, el proceso de revenido según la Norma JIS G4801 (1984) se debe realizar a una temperatura comprendida entre 460º - 510º C y se debe obtener una dureza de 363 – 429 HB.

Figura 3.28: Fotografía del Proceso de Revenido

3.2.3. Ensamble

El Ensamble es la última actividad de fabricación en IPASA, la cual abarca todas las operaciones que se deben realizar luego del tratamiento térmico. Debido a que IPASA fabrica hojas de muelle sueltas y paquetes de muelles armados, y además de que existe una gran diversidad de hojas; no todos los productos van a pasar por todas las operaciones de la actividad denominada Ensamble.

3.2.3.1. Granallado

El granallado es un proceso que IPASA utiliza para decapar sus productos antes del proceso de pintado y sobre todo para conferir a sus productos mayor resistencia a la fatiga. IPASA para este proceso utiliza la granalla SAE S 330 y realiza la medición de la impactación del granallado utilizando las probetas Almen A, según lo especificado en la Norma SAE J442 Jan95 (ver apéndice I). Para mayor detalle sobre la teoría y efectos del granallado ver el capítulo 4.

3.2.3.2. Armado de muelles

Esta operación consiste en unir las hojas de muelle y sus accesorios (perno central, abrazaderas, tubo espaciador y perno de la abrazadera), respetando las pinzas entre hojas y la flecha final del muelle; siendo la pinza la abertura en la posición central que existe entre una hoja y su siguiente antes de aplicarles algún tipo de fuerza para juntarlas.

3.2.3.3. Prueba de Carga y Flexión de muelles

La prueba de carga de muelles se realiza sólo al paquete de muelle armado, el cual consiste en aplicar una carga vertical en la posición del perno central, y a través de la medición de la fuerza (F) y de la deformación del muelle en el sentido vertical (f), se obtiene la constante de elasticidad (k), a través de la siguiente fórmula: $k = F / f$.

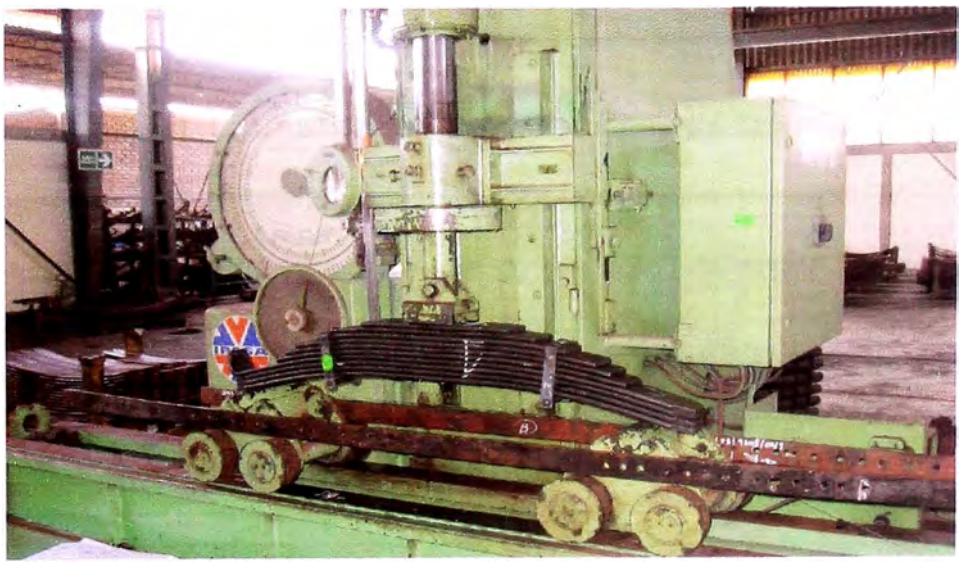


Figura 3.29: Fotografía de la Prueba de Carga

3.2.3.4. Rimado

El rimado es una operación que consiste en dar al diámetro interior de los ojos la tolerancia dimensional requerida en la Hoja de Característica del producto, la cual por lo general es de posición H7.

3.2.3.5. Esmerilado de ojos

El esmerilado es una operación que se realiza a algunos tipos de hojas, que consiste en disminuir el ancho de la hoja en la posición abarcada por el ojo del muelle, por la acción de unas piedras abrasivas.

3.2.3.6. Embocinado

El embocinado es una operación que se realiza sólo a solicitud del cliente, y consiste en colocar con la ayuda de una prensa la bocina dentro del ojo de la hoja de muelle.

3.2.3.7. Pintado

El pintado es la última operación dentro del proceso de fabricación, en IPASA las hojas sueltas se pintan primero por inmersión y luego se retocan por aspersión, en cambio los muelles se pintan sólo por aspersión y cuando ya están armados.

Dentro de la operación de pintado se encuentra la tarea del marcado, la cual es muy importante ya que en ella los productos se identifican por su código, con el logo del muelle Elefante y con la fecha de fabricación, lo cual nos permite hacer la trazabilidad del producto cada vez que sea necesario.

CAPITULO 4

GRANALLADO Y SUS EFECTOS SOBRE LA RESISTENCIA A LA FATIGA

4.1. TEORIA DE FATIGA

La fatiga es el fenómeno de fallo presente en materiales sometidos a cargas dinámicas cíclicas, cuyo principal peligro es que la rotura puede ocurrir a una fuerza menor que la resistencia de tracción o menor al límite elástico para una carga estática, de forma imprevista, causando roturas catastróficas. Es un fenómeno muy importante, ya que es la primera causa de rotura de los materiales metálicos (aproximadamente el 90%), aunque también está presente en polímeros y en cerámicos.

La rotura por fatiga se inicia con una minúscula fisura en la superficie o en puntos cercanos a ella, donde exista imperfecciones en los cristales como: penetración de óxidos en los contornos de los granos, inclusiones no metálicas, etc; o en discontinuidades superficiales como: ralladura o marca de herramienta, cambio de sección, canal chavetero, etc. Debido a la acción de las cargas dinámicas, la fisura se propaga en la dirección de un plano sometido a carga de tracción, hasta que el área resistente llega a ser tan pequeña que se produce súbitamente la fractura completa.

Del párrafo anterior, se deduce que la resistencia a la fatiga de un material, se ve reducida por las imperfecciones en los cristales superficiales y por las

discontinuidades superficiales. Por tanto, la probabilidad de rotura por fatiga se disminuye evitando estas discontinuidades: realizando modificaciones en el diseño (eliminando los cambios bruscos de sección con cantos vivos por superficies redondeadas con radios de curvatura grande), mejorando el acabado superficial, etc. Además, como las fisuras nuclean y se propagan por acción de los esfuerzos de tracción, aplicando esfuerzos de compresión en las superficies que trabajan a tracción se aumenta la resistencia a la fatiga, siendo el mejor método para estos casos el granallado (ver el capítulo 4.2).

La fractura por fatiga presenta una gran diversidad de aspectos, ya que depende si esta es ocasionada por cargas axiales, por flexión, por torsión o si la sección fracturada posee o no entalladura, agujeros o canal chavetero; pero aún así, todas las fracturas poseen 2 zonas características: una de superficie mate y sedosa o aterciopelada, y otra zona de grano cristalino (forma de la fractura final instantánea). Si se examinan con atención los bordes de la fractura de fatiga, con mucha frecuencia se distinguen en los mismos estrías o pequeñas grietas que tienen su nacimiento en defectos de la sección o de la superficie externa.

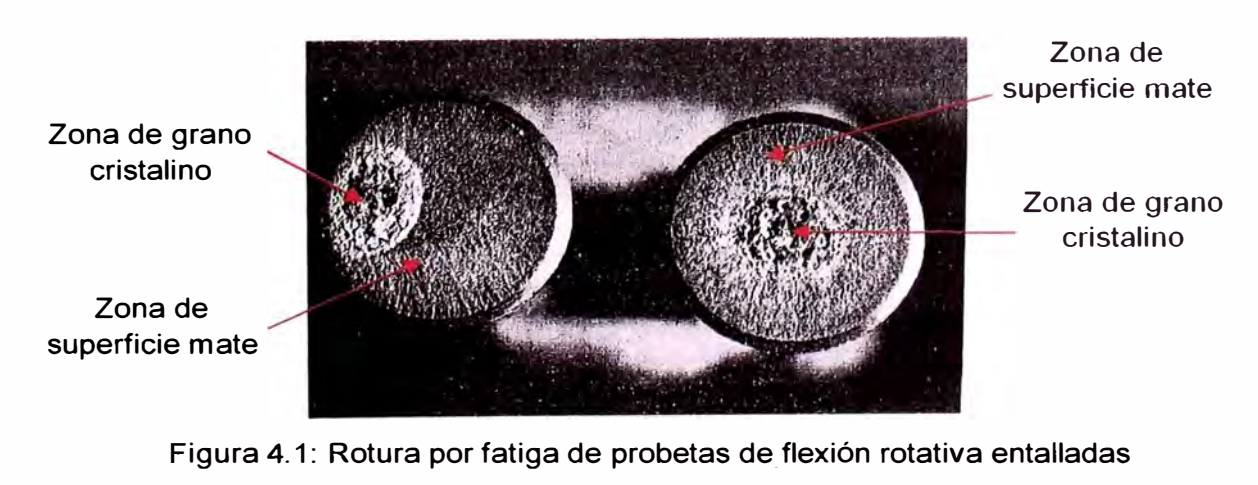


Figura 4.1: Rotura por fatiga de probetas de flexión rotativa entalladas

La variación de los esfuerzos se idealizan frecuentemente a través de modelos sinusoidales, en donde existen: un esfuerzo máximo (S_{max}), un esfuerzo mínimo (S_{min}), un esfuerzo medio (S_m) y una componente variable (S_a).

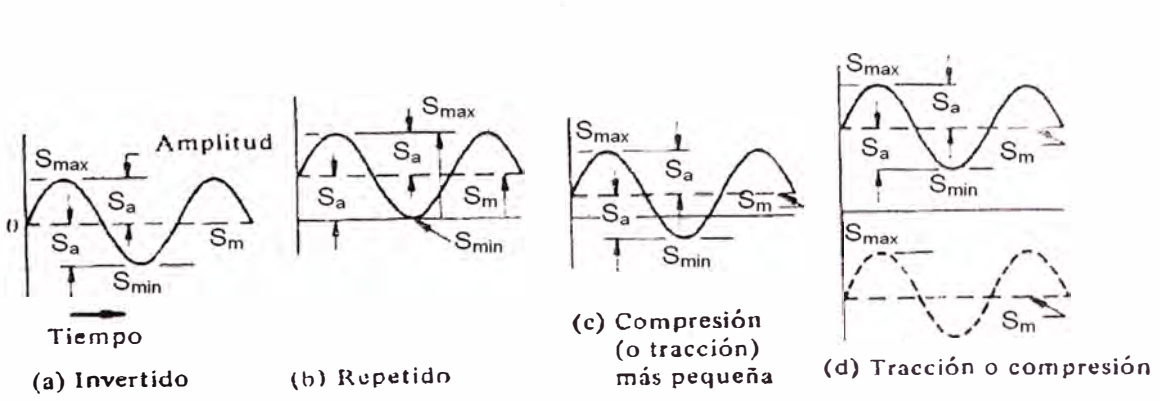


Figura 4.2: Variaciones sinusoidales del esfuerzo

El límite de fatiga, es decir, el esfuerzo máximo que se somete la pieza sin llegar a la rotura al repetirse un número indefinido de veces, se representa normalmente en escala logarítmica o semi-logarítmica, en función del número de ciclos. En rigor, todo material cristalino presenta un límite de fatiga, tal es así, que para la mayoría de los aceros dicho límite suele situarse en el entorno del millón de ciclos (para ensayos de probeta rotatoria), para tensiones internas que rondan 0,7-0,45 veces el límite elástico del material; mientras que para aquellos que se dicen sin límite de fatiga, como el aluminio, se da incluso para tensiones muy bajas (en el aluminio de 0,1-0,2 veces dicho límite), y aparece a ciclos muy elevados (en el aluminio puede alcanzar los mil millones de ciclos, en el titanio pueden ser, según aleaciones, cien millones de ciclos o incluso, excepcionalmente el billón de ciclos). Como en general no se diseñan máquinas ni elementos de manera que las máximas tensiones sean de 0,1-0,2 veces el límite elástico del material, pues en ese caso se estarían desaprovechando buena parte de las capacidades mecánicas del material, y como tampoco se suele diseñar asumiendo valores de vida por encima del millón de ciclos, en la práctica este tipo de materiales no van a poder presentar su límite de fatiga, aunque sí lo tienen.

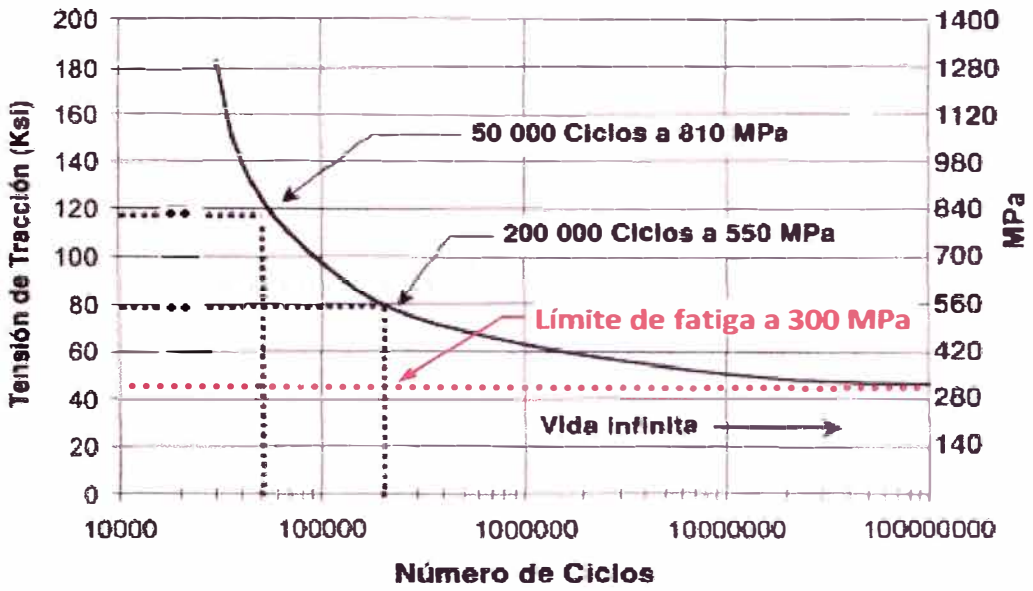


Figura 4.3: Diagrama semilogaritmico de esfuerzos vs. Número de ciclos

Existen diversas teorías que a través de aproximaciones empíricas relacionan el esfuerzo medio (S_m) y el esfuerzo variable (S_a) para obtener las condiciones de fatiga, de ellos los más importantes son: Soderberg, Goodman modificado y Gerber.

En el Método de Soderberg se traza una recta que pasa por el límite de fatiga y por la resistencia de fluencia (ver figura 4.4) admitiéndose que la recta representa un estado de esfuerzos que está del lado de un punto de fallo después de un número indefinido de alternancias de S_a , para el caso de probetas de acero pulido. De la figura 4.4, se aprecia que en el punto P existe un esfuerzo variable OV sobre un esfuerzo medio OM, sin embargo para diseño se recomienda usar un factor de seguridad N, obteniéndose la recta GD. Por tanto, en el Método Soderberg se obtiene la siguiente ecuación:

$$\frac{1}{N} = \frac{s_m}{s_y} + \frac{s_a}{s_n}.$$

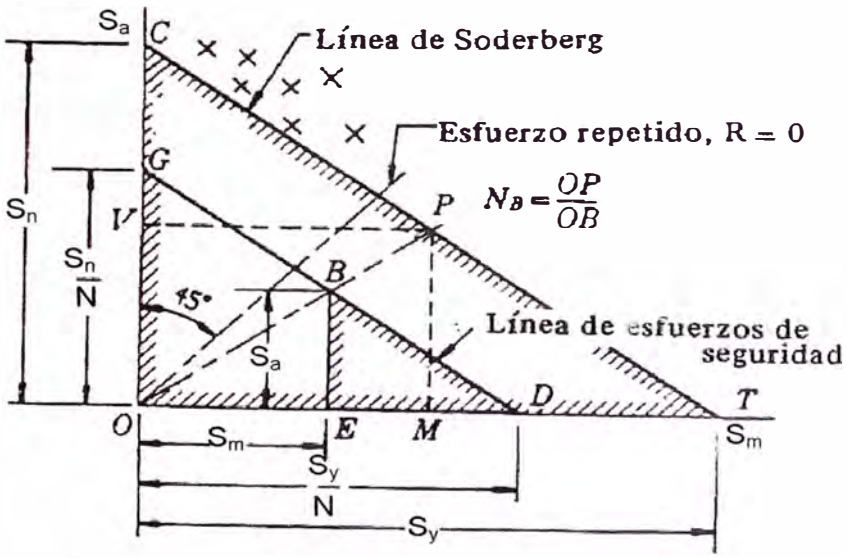


Figura 4.4: Línea de Solderberg

En la figura 4.5 se aprecia la línea de Goodman Modificada y la de Gerber, las cuales obedecen a las siguientes ecuaciones:

Línea de Goodman: $$\frac{1}{N} = \frac{S_m}{S_u} + \frac{S_a}{S_n},$$

Línea de Gerberg: $$1 = \left(\frac{S_m}{S_u}\right)^2 + \frac{S_a}{S_n}.$$

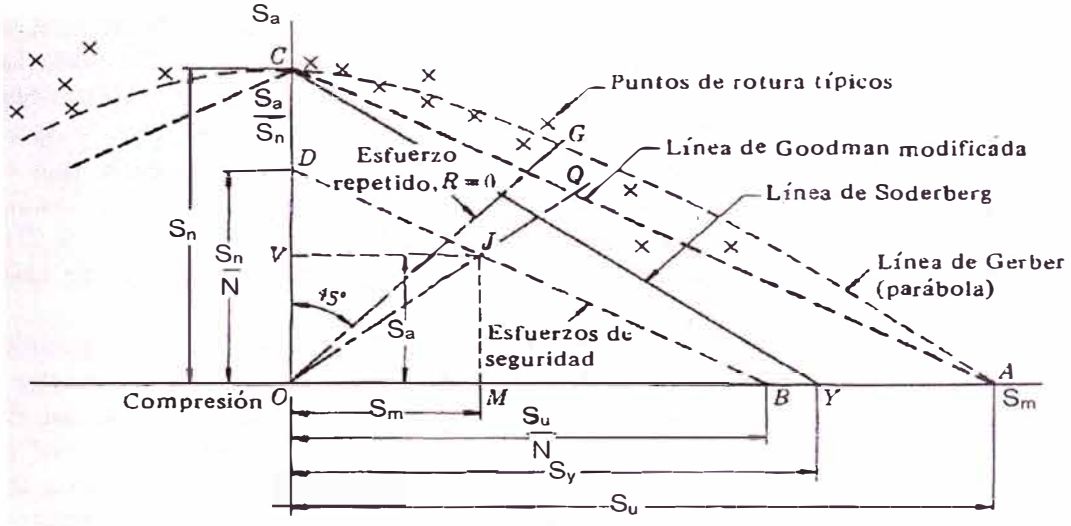
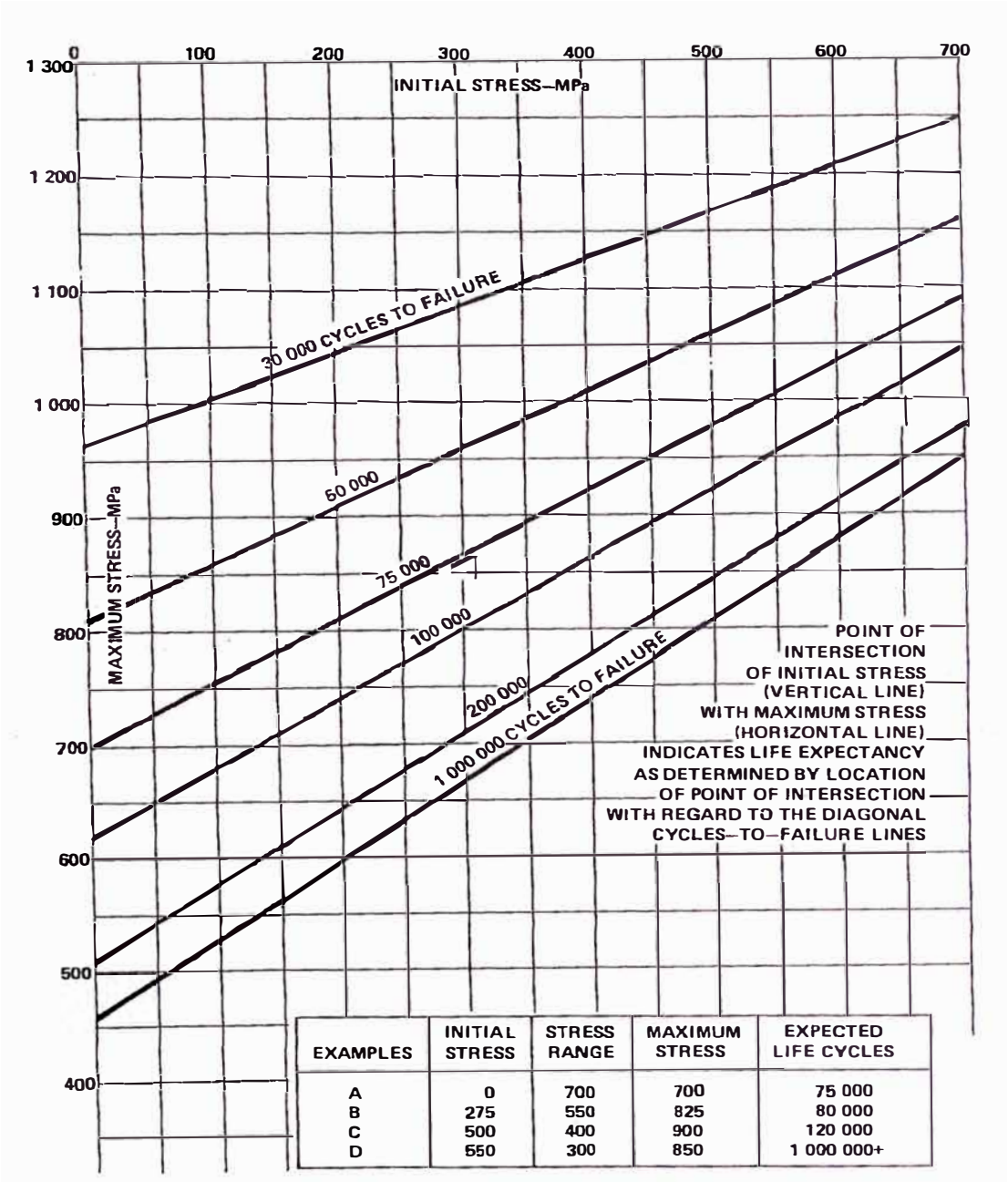


Figura 4.5 Línea de Goodman, Gerber y Soderberg

Para el caso de hojas de muelle tipo ballesta, no es necesario usar los métodos de Goodman Modificado, Gerber ni de Soderberg, ya que la Norma SAE HS J788 da un diagrama de estimación de ciclos de vida por fatiga para las hojas de muelle tipo ballesta que no tienen granallado, relacionando el esfuerzo máximo (S_{max}), el esfuerzo mínimo (S_{min}), y el número de ciclos.



EXAMPLES	INITIAL STRESS	STRESS RANGE	MAXIMUM STRESS	EXPECTED LIFE CYCLES
A	0	700	700	75 000
B	275	550	825	80 000
C	500	400	900	120 000
D	550	300	850	1 000 000+

Figura 4.6: Diagrama de ciclo de vida por fatiga para hojas de muelle sin granallar

4.2. EL GRANALLADO

4.2.1. Fundamentos del Granallado

El Granallado (o en ingles conocido como shot peening) es un procedimiento de plastificación en frío que consiste en impactar las superficies que van a trabajar a tracción, por un chorro de pequeñas esferas a velocidades de hasta 100 m/s, originando deformaciones permanentes de forma redondeadas parecidas a huellas de golpe producidas por pequeños martillos.

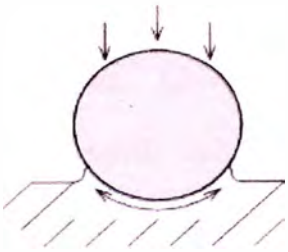


Figura 4.7: Deformación plástica en el punto de impacto

Durante el granallado se obtiene el aplastamiento de los granos metalográficos de la superficie del metal, originándose con ello dos efectos:

- Los granos se ensanchan comprimiéndose entre sí, provocando la aparición de tensiones de compresión residuales paralelas a la superficie.

Figura 4.8: Zona sometida a esfuerzos de compresión

Un perfil típico de la tensión residual producida por el granallado se representa en la siguiente figura:

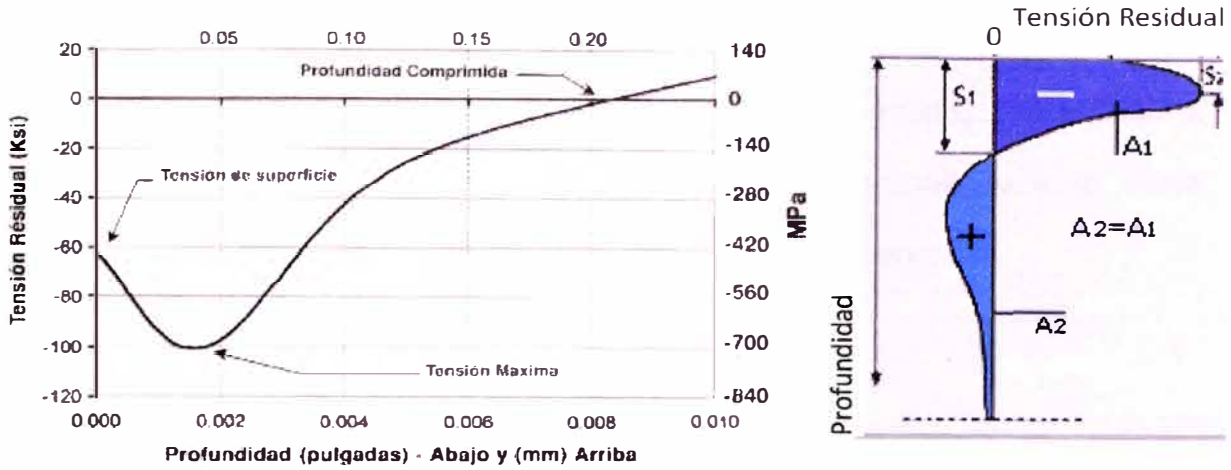


Figura 4.9: Perfil típico de tensiones residuales producidas por el granallado

- ✓ Tensión Máxima: Es el valor de la amplitud de la tensión residual de compresión máxima. Mientras más aumenta la tensión máxima, el material será más resistente a la iniciación y propagación de grietas por fatiga.
- ✓ Profundidad comprimida: Es la profundidad de la capa de compresión resistente a la propagación de grietas. La profundidad de la capa puede aumentar cuando se aumenta la energía del impacto de las granallas. Se busca una capa más profunda para una mejor resistencia a la propagación de fisuras. Por lo general, esta capa tiene una profundidad de 50 a 250 micrómetros.
- ✓ Tensión de superficie: En general su amplitud es más baja que la Tensión Máxima.

Estas tensiones de compresión anulan tensiones residuales inducidas en procesos anteriores como mecanizado, tratamiento térmico, conformación plástica, etc. Y además se oponen a todo esfuerzo de tensión a tracción a

las que son sometidas en una utilización posterior. Un ejemplo de ello se muestra en la figura 4.10, la cual presenta una barra en flexión sobre tres puntos, en donde la diagonal de línea punteada representa la tensión producida por la fuerza exterior, la curva de rayas mixtas representa la tensión residual de compresión producido por el granallado y la curva restante representa la acción resultante de las dos primeras.

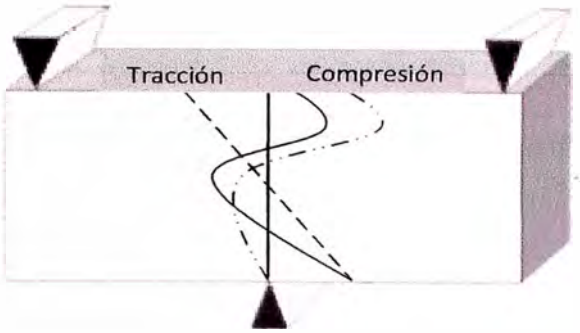


Figura 4.10: Tensión resultante sobre una barra granallada sometida a carga por flexión

- Como efecto secundario, al ensancharse los granos se cubren los espacios intergranulares (reduciéndolos considerablemente) y con ello se disminuye la velocidad de la corrosión galvánica.

Como las grietas no se inician ni se propagan en un volumen sometido a compresión, y a que la mayor parte de roturas por fatiga y corrosión bajo tensión tienen su origen en la superficie o en la cercanía de la misma, las tensiones residuales de compresión introducidas por el granallado aumentan sensiblemente la duración de vida de las piezas metálicas.

Por tanto, el granallado es un procedimiento que se debe aplicar a todas las piezas que trabajan a fatiga como: muelles tipo ballesta, muelles

helicoidales, barras de torsión, ejes, engranajes cónicos, piezas de frenos, levas, árboles de levas, resortes de embrague, álabes de compresor, bielas, cigüeñales, componentes de cajas de engranajes, ruedas dentadas, barrenos de minería, herramientas de corte, vástagos de pistón, barras de empuje, bujes, anillos de sincronización, ruedas de turbina, álabes de turbina, resortes de válvulas, válvulas, bujes, etc.

En resumen, el granallado aumenta la resistencia a la fatiga, produce un aumento de la resistencia a la corrosión, y además como efecto secundario a la impactación limpia la superficie de las piezas.

4.2.2. Variables del proceso del granallado

Las variables más importantes dentro del proceso de granallado son: la granalla, la velocidad de la granalla y el ángulo de proyección de las granallas.

- Granalla: Las granallas son las partículas que impactan a gran velocidad en la superficie de las piezas a granallar, las granallas son de diferentes materiales, tamaños y durezas.

  a) Respecto a los materiales tenemos:

  - ✓ Granalla de acero fundido (cast stell shot): Esta granalla tiene una buena relación de dureza y capacidad de resistencia a la rotura, siendo su costo menor al de granalla de alambre cortado. Esta granalla se encuentra normalizadas a través del SAE J827 Jul94, SAE J2175 Jun91 y SAE J444 May 93 (ver apéndice G).

- ✓ Granalla de alambre cortado (cut wire shot): Esta granalla proviene del corte de un alambre de acero al carbono o acero inoxidable, en donde su longitud es igual a su diámetro y sus bordes son redondeados. Es la granalla que más aceptación está teniendo actualmente en el mundo, debido a que tiene una excelente dureza con muy bajo nivel de rotura, lo que implica un bajo consumo y sobre todo permite obtener un nivel de granulometría constante en un porcentaje elevado de partículas. Estas granallas se encuentran normalizadas a través del SAE J441 Jun93(ver apéndice H).
- ✓ Granalla de fundición de hierro esférico y nodular: Comprende a las granallas de fundición gris, blanca y maleable. Se utilizan en aquellos casos donde se requiera efectuar un trabajo de granallado de bajo costo inicial, a pesar que tienen una vida útil muy inferior a las granallas de acero debido a su mayor fragilidad. En el caso del granallado, la rotura adquiere una gran importancia ya que es imprescindible que el impacto sobre la superficie lo realice una partícula esférica, lo que se torna difícil de controlar utilizando un abrasivo con alta velocidad de fractura. En cuanto a las granallas de fundición nodular, estas se utilizan en escala muy limitada pues debido a su baja dureza las intensidades logradas son pobres y además dejan residuos de grafito en las piezas granalladas.
- ✓ Micro-esferas de vidrio (glass bead) o cerámica: Se utilizan para el conformado de chapas delgadas, ya que se obtienen bajos niveles de intensidad de granallado. Ideal para chapas

de acero inoxidable o materiales no ferrosos que no deben ser contaminados con abrasivos de acero al carbono.

b) Respecto a la dureza de la granalla, se tiene que tener en cuenta que esta debe ser superior a la dureza del material a granallar, pero sin llegar a ser muy duro ya que con ello aumenta su fragilidad (es decir, aumenta su porcentaje de rotura).

c) El tamaño de la granalla es un factor importante, ya que influye directamente en la energía de deformación de la superficie durante el impacto. Mientras la velocidad y el tiempo de exposición se mantengan constantes, todo incremento del tamaño de la granalla implica un incremento en la intensidad del proceso y una menor cobertura. Siempre se debe seleccionar el menor tamaño de granalla que produzca la intensidad deseada, logrando de esa forma la mayor rapidez del proceso y la mejor cobertura en la superficie.

- Velocidad de la granalla: Es una variable muy importante de controlar, ya que desde el punto de vista energético, al aumentar la velocidad de la granalla, aumenta su energía cinética y por tanto aumenta la intensidad del granallado; pero también el incremento de velocidad produce un mayor porcentaje de fracturas de granallas lo que impide el crecimiento teórico de la intensidad.

- Angulo de proyección: es el ángulo formado entre la superficie y la dirección del flujo de partículas. Al reducirse el ángulo de proyección disminuye la intensidad del granallado, en aquellos casos en los

cuales el ángulo (por necesidades prácticas) debe ser inferior a los 90º, debe incrementarse el tamaño de la granalla y/o la velocidad para mantener el valor de intensidad.

La combinación de estas variables (granalla, velocidad de la granalla y ángulo de proyección de las granallas) nos permite obtener las condiciones de la operación del granallado, la cual se puede cuantificar y controlar midiendo la intensidad y la cobertura del granallado:

- Intensidad del granallado: Es directamente proporcional a la profundidad de la capa comprimida del material granallado, es decir, a mayor intensidad de granallado mayor es la resistencia a la iniciación y propagación de grietas.

  El método usado para medir la intensidad del granallado es la Prueba Almen, el cual fue inventado por Jhon Almen en el laboratorio de Investigación de General Motors (ver figura 4.12). La prueba consiste en montar y asegurar en un soporte (bloque Almen) de acero carburado o endurecido, una lámina plana de acero SAE 1070 rolado en frio, de dureza entre 44 y 50 HRc y de las dimensiones dadas en la figura 4.11, para granallarlo por una sola cara, siendo la medida de la flecha obtenida el valor de la intensidad del granallado.

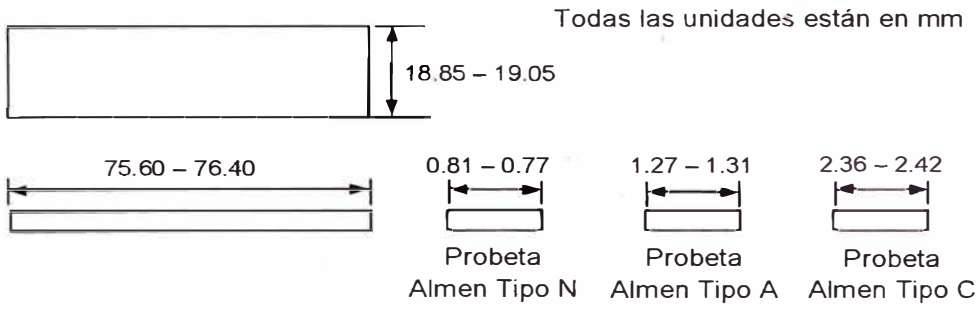


Figura 4.11: Probetas Almen

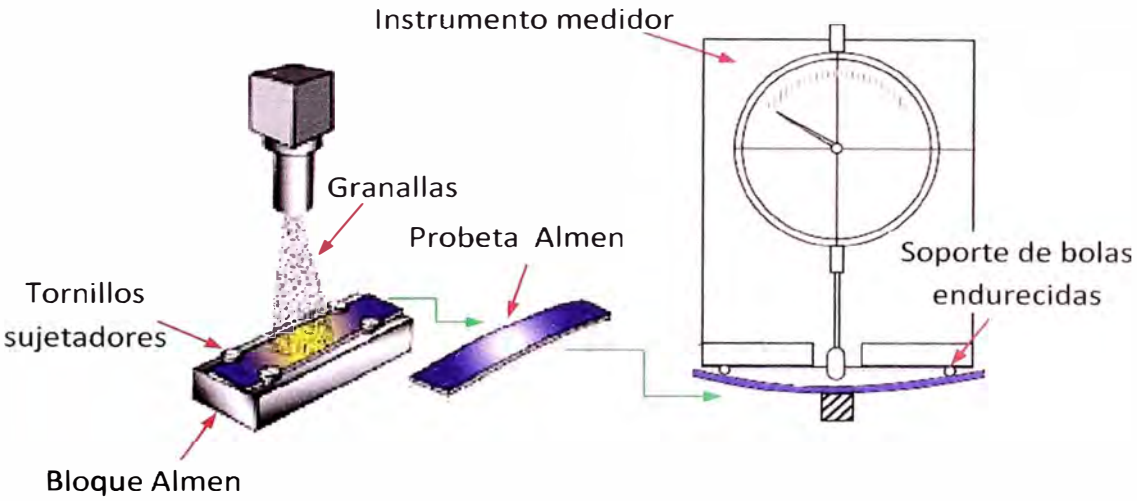


Figura 4.12: Ensayo Almen

Para mayor detalle ver el apéndice I (Norma SAE J442 Jan95).

- Cobertura del granallado: Es una medida que nos indica el porcentaje del área que ha sido impactada por las partículas esféricas. Para que el granallado sea considerado bueno, la cobertura tiene que ser elevada ya que de lo contrario no se obtiene el aumento de la resistencia a la fatiga deseada.

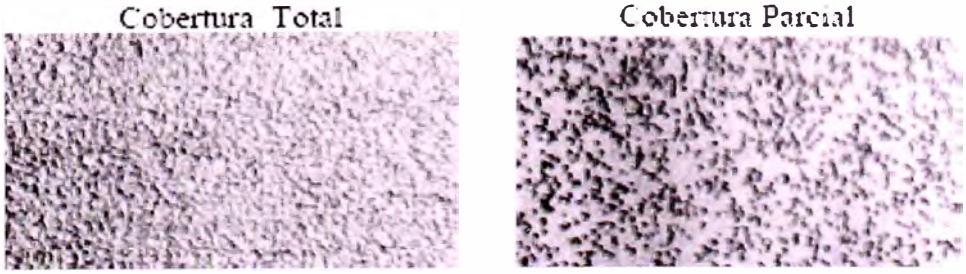


Figura 4.13: Fotografías de coberturas del granallado

Existen varios métodos para medir el factor de cobertura, pero uno de los más utilizados consiste en lo siguiente:

- ✓ Realizar en la probeta a granallar un pulido espejo.
- ✓ Someter a dicha superficie al flujo de granallas en condiciones predeterminadas.
- ✓ Retirar la probeta y proyectar la superficie expuesta en un comparador con 50 aumentos.
- ✓ Sobre dicha proyección y en un papel transparente trazar las marcas producidas por los impactos (bien diferenciadas de las zonas pulidas).
- ✓ Medir la superficie de la zona impactada. La relación entre esta superficie y la total, expresado en porcentaje, es el factor de cobertura obtenido.

4.2.3. Equipos para el granallado

Existen varios tipos de máquinas granalladoras, las cuales son seleccionadas dependiendo del tipo de material, tamaño y forma de las partes a granallar, así como del acabado superficial que se desea obtener.

Los equipos de granallado poseen 6 sistemas básicos:

a) Sistema de aceleración de la granalla: Existen 2 formas de acelerar la granalla

- ➢ Granallado por aire comprimido: Este sistema es de muy bajo rendimiento, por lo cual es más adecuado para trabajos pequeños donde no son necesarios caudales altos. Es un sistema flexible, pues el transporte de la granalla puede realizarse en dirección horizontal y mediante cañerías de goma. Estas características le

permiten ser utilizados en la preparación de superficies de estructuras armadas reemplazando a las herramientas manuales.

- Granallado por turbina centrífuga: Es el sistema más económico e ideal para las líneas de producción continuas (figura 4.14). En este sistema las granallas son ingresadas a la turbina a través del tubo de alimentación, en el distribuidor son desviadas y pre-aceleradas, en la caja de control son dirigidas hacia los alabes o paletas y en estas son aceleradas y disparadas hacia las superficies a granallar.

  En este sistema el ángulo de proyección se puede cambiar fácilmente girando la caja de control.

  El número de turbinas montadas en una máquina queda determinado por la forma y tamaño de las piezas a granallar.

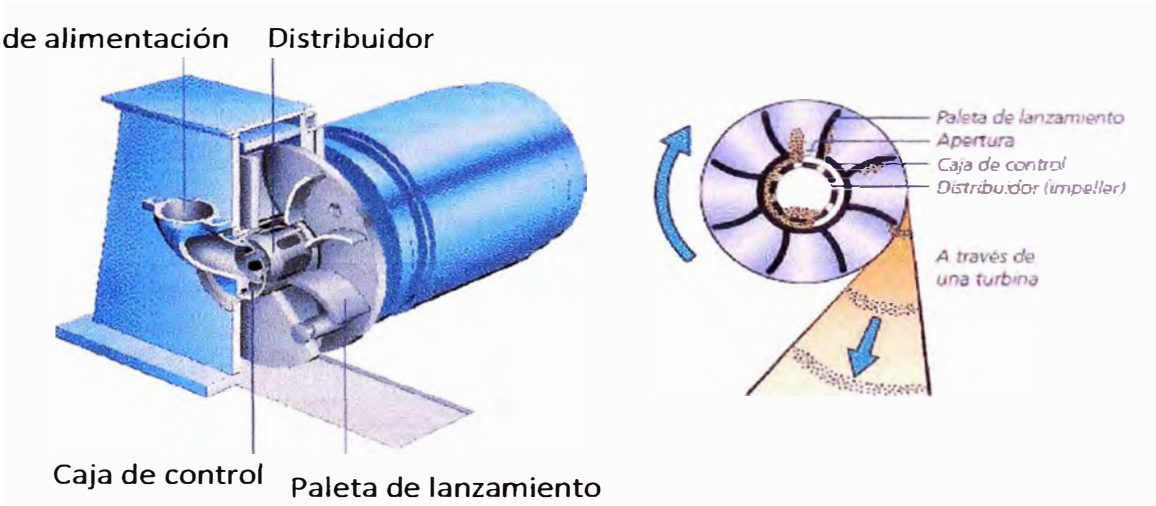


Figura 4.14: Turbina centrifuga

b) Sistema de circulación y limpieza de la granalla: Esta es la parte del equipo que se encarga de recircular y limpiar la granalla para lograr un funcionamiento continuo. En los equipos de granallado convencionales, la granalla luego de chocar contra la pieza, cae en

una tolva de recolección para posteriormente ser llevada por gravedad o por un sin fin a un elevador de cangilones. El elevador lleva la granalla, cascarillas, óxidos y otros contaminantes a un separador por flujo de aire ubicado en la parte superior de la máquina, y a través de zarandas y chapas deflectoras elimina las partículas contaminantes, polvos y granallas pequeñas que dejan de ser efectivas en el granallado. La granalla limpia cae en una tolva superior, para que posteriormente alimente a la turbina por gravedad. Un alimentador electrónico añade granalla nueva para reemplazar la eliminada, de forma que se consigue una mezcla operatoria constante.

c) Sistema colector de polvos: El polvo generado durante el granallado es retirado del flujo de granalla circulante y de la cabina de granallado por un colector de polvos. El colector de polvos más usado es el de cartuchos de papel, que además de retirar el polvo de la máquina mantiene las áreas adyacentes a la misma limpia de polvos.

d) Cabina: La cabina durante el granallado contiene polvo y abrasivo en suspensión. La ventilación que genera el aspirador de polvo dentro del gabinete asegura que la presión del aire dentro de ésta sea menor que la presión ambiental, de modo que el polvo no se escape a las áreas de trabajo adyacentes. Las aberturas para la entrada y salida de las piezas están equipadas con sellos para evitar que el abrasivo se escape de la máquina. Las cabinas están construidas en acero de bajo carbono y revestidas interiormente con materiales resistentes a la abrasión, que pueden ser goma, componentes sintéticos, o placas de fundición de aleaciones especiales. En áreas que pueden ser

alcanzadas por flujo directo de granalla es recomendable utilizar placas de fundición que tienen un rendimiento muy superior a los demás materiales.

e) Sistema de movimiento o sostén de las piezas a granallar: La necesidad de granallar desde destornilladores, block de automotores, caños, chapas, rieles, y hasta vagones de ferrocarril nos da una idea de la gran variedad de sistemas de movimiento o sostén de las piezas a granallar que hay.

- Granalladoras de tambor: Son usadas principalmente para resortes de válvulas, grapas y otras piezas pequeñas que se puedan trabajar a granel.

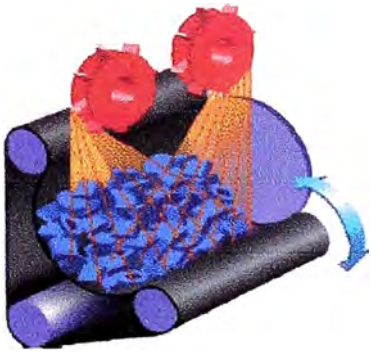


Figura 4.15: Granalladora de tambor

- Granalladoras continuas: Estas granalladoras requieren poco espacio y no necesitan almacenamiento intermedio de piezas. Estos tipos de granalladoras son utilizadas por ejemplo para muelles tipo ballesta y tipo helicoidal.

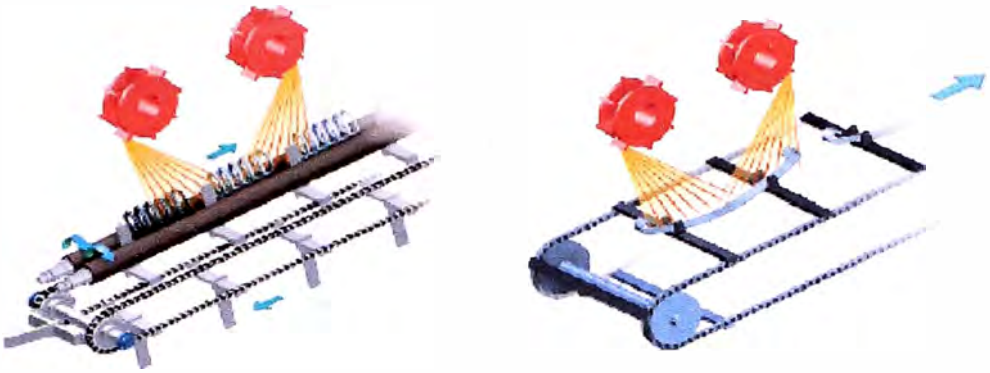


Figura 4.16: Granalladoras continuas

- Granalladoras de piezas colgadas: Son usadas en piezas grandes o en piezas de geometría complicada.

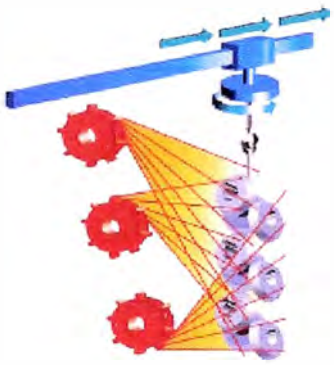


Figura 4.17: Granalladora de pieza colgadas

- Granalladoras con manipulador: Satisfacen los requerimientos de producción más exigentes, gracias a su gran rendimiento de granallado. Incluso superficies interiores con difícil acceso se granallan satisfactoriamente.

Figura 4.18: Granalladoras con manipulador

- Granalladoras rotativas: En estas granalladoras las piezas giran en tablas satélites montadas en una placa giratoria. Son usadas por ejemplo en engranajes rectos, engranajes conicos, ejes de engranajes y piezas similares.

Figura 4.19: Granalladora rotativa

f) Controles e instrumentación: Es el sistema que provee los comandos e indicaciones para arranque y parada de los mecanismos, elevadores, colector de polvos, turbinas, y sistemas de manejo de las piezas; amperímetros y cuenta-horas para los motores de turbinas, todos ubicados en una consola central.

4.2.4. Condiciones de granallado para hojas de muelle tipo ballesta

El proceso de granallado se debe realizar en una máquina de turbina centrífuga con movimiento de piezas continuas.

La Norma SAE HS J788 recomienda para el granallado de hojas de muelle tipo ballesta, lo siguiente:

- Granallas de alambre cortado de códigos CW-23 a CW-41 (ver apéndice H) o las granallas de acero fundido de códigos S-230 a S-390 (ver apéndice G).

  Una intensidad de granallado de 10A a 20A para muelles de carga ligera y mediana, y 6C a 14C para muelles de carga pesada. La designación 10A a 20A, significa una intensidad de granallado de 10

a 20 milésimas de pulgadas (0.25 a 0.50 mm) en el ensayo Almen A. Y la designación 6C a 14C significa una intensidad de granallado de 6 a 14 milésimas de pulgada (0.15 a 0.36 mm) en el ensayo Almen C.

- Una cobertura de por lo menos 90%.

4.3. EFECTOS DEL GRANALLADO SOBRE LA RESISTENCIA A LA FATIGA

Como se explicó en el capítulo 4.2, el granallado aumenta la resistencia de vida por fatiga, estando el aumento influenciado por la impactación y por la cobertura del granallado, así como del tipo de trabajo que tiene la pieza.

Tal es así, que por ejemplo: para engranajes de acero SAE 1020 se logra un aumento a la resistencia de fatiga de 2.7 veces, para piñón de acero NE-9420 se puede obtener un aumento hasta de 4.2 veces, para hojas de muelle tipo ballesta el aumento puede llegar hasta 6 veces y para las barras de torsión el aumento puede ser de hasta 6 veces.

En la figura 4.20, se muestra como varía la resistencia a la fatiga de un muelle tipo ballesta de acero AISI 9260 de 40 a 45 HRc de dureza y de ¼" de espesor.

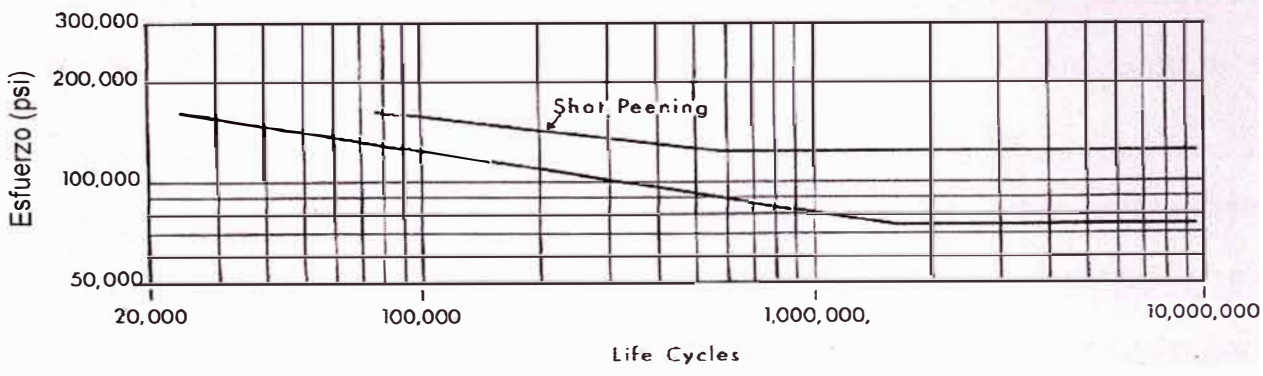


Figura 4.20: Influencia del granallado en la resistencia a la fatiga de la hoja de muelle tipo ballesta de acero AISI 9260

CAPITULO 5

PLAN DE EVALUACION DEL GRANALLADO DE HOJAS DE MUELLE TIPO BALLESTA

Las empresas manufactureras de muelle, realizan los ensayos de fatiga a sus productos tomando como muestras paquetes armados de muelle, en este informe los ensayos se van a realizar a hojas sueltas ya que con ello se disminuye costos de ensayo y se analiza mejor los efectos del granallado.

5.1. CARACTERISTICAS DE LAS PROBETAS

La materia prima de las probetas deben cumplir las exigencias citadas en el capitulo 3.1, tanto en composición química, descarburización superficial, tamaño de grano, nivel de inclusiones no metálicas, estructura metalográfica, segregaciones bandeadas, dimensiones, templabilidad y acabado superficial.

Las probetas deben tener ojos en sus extremos para que puedan ser sujetadas en la maquina fatigadora. No se debe ampollar las hojas durante el calentamiento para el formado de ojos.

Las probetas deben ser templadas y revenidas sin producirles ampollamiento, obteniéndose una estructura final de martensita revenida y una dureza de 363 – 429 HB (según Norma JIS G 4801) o de 388 - 461 HB (según SAE HS J788).

Las probetas deben ser granalladas sólo en la cara que trabaja a tracción.

5.2. CALCULO DE LOS PARAMETROS PARA ENSAYO DE FATIGA

Para elaborar el Plan de evaluación del granallado, debemos definir lo siguiente:

5.2.1 Esfuerzo

El esfuerzo es la fuerza interna aplicada por unidad de área. Cuando un cuerpo esta sometido a fuerzas de tracción, es decir, cuando existen 2 fuerzas en sentido opuesto que tienden a alargar el material, matemáticamente el esfuerzo se define como:

$$S = F / A \quad \ldots\ldots (1)$$

De igual forma, cuando un cuerpo esta sometido a fuerzas de compresión, es decir, cuando existen 2 fuerzas en el mismo sentido que tienden a comprimir el material, se utiliza la misma ecuación dada en el caso de tracción para calcular el esfuerzo.

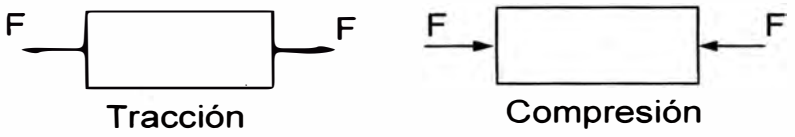


Figura 5.1: Cuerpo sometido a tracción o a compresión

Si un cuerpo trabaja a flexión, es decir, si esta sometido a una fuerza que tiende a doblarlo; a un lado del plano neutro se producen esfuerzos de tracción y al otro lado del plano neutro se producen esfuerzos de compresión (ver figura 5.2). Matemáticamente, el esfuerzo es igual a:

$$S = M \times c / I \quad (2)$$

Siendo por tanto, el máximo esfuerzo para una misma sección:

$$S = M \times e / (I \times 2) \quad (3)$$

Donde e: espesor de la hoja de muelle

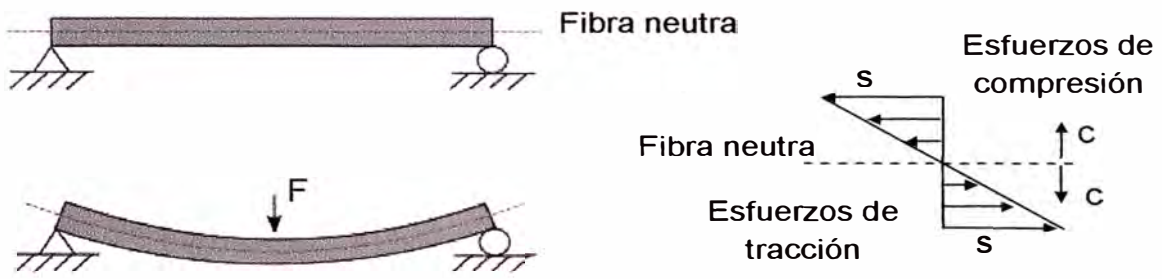


Figura 5.2: Cuerpo sometido a flexión

Como se puede apreciar en la figura 5.3, las hojas de muelle trabajan a flexión, por tanto, para hallar los esfuerzos se debe aplicar la ecuación 3.

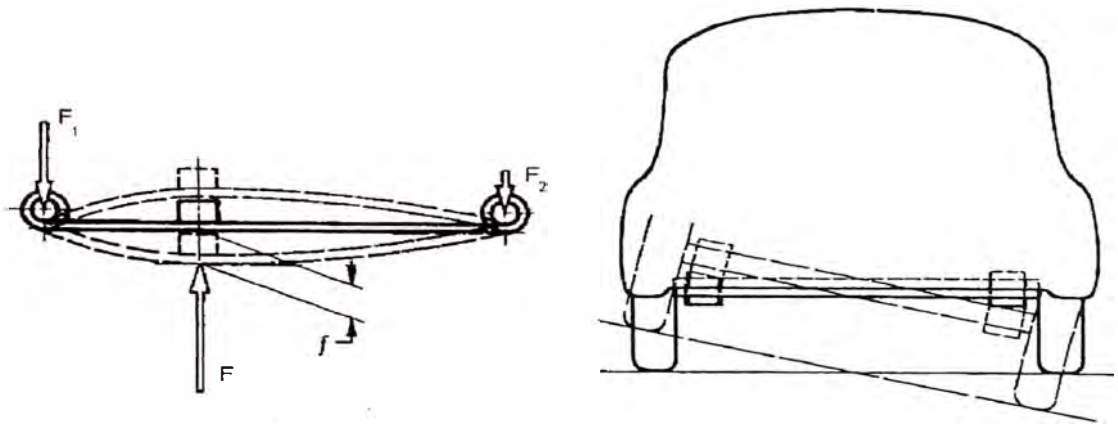


Figura 5.3: Representación de las fuerzas a que están sometidas las hojas de muelle

- Cálculo de fuerzas y de Momentos flectores en una hoja de muelle

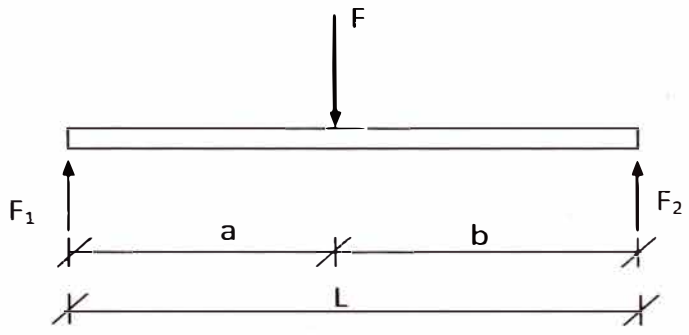


Figura 5.4: Esquema de fuerzas a las que están sometidas las hojas de muelle

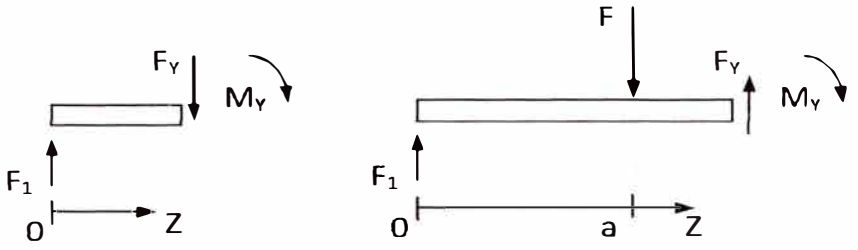
$\Sigma F = 0$

$F_1 + F_2 = F$ ..... (4)

$\Sigma M_1 = 0$

$F \times a - F_2 \times L = 0 \Rightarrow F_2 = F \times a / L$ ..... (5)

De (4) en (5) : $F_1 = F \times b / L$ ..... (6)



$Z \in [0 , a >$ Figura 5.5.a

$Z \in [a , L]$ Figura 5.5.b

Figura 5.5. Esquema de fuerzas y momentos en las hojas de muelle

De la figura 5.5 (para $Z \in [0 , a >$)

$\Sigma F = 0$

$F_Y = F_1$ ..... (7)

$\Sigma M_1 = 0$

$F_Y \times Z + M_Y = 0 \Rightarrow M_Y = - F_Y \times Z$ ..... (8)

De (7) y (6) en (8)

$M_Y = - F \times b \times Z / L$ ..... (9)

De la figura 5.6 (para $Z \in [a , L]$)

$\Sigma F = 0$

$F_1 + F_Y = F \Rightarrow F_Y = F - F_1$ ..... (10)

De (1) en (7):

$F_Y = F_2$ ..... (11)

$\Sigma M_1 = 0$

$F \times a - F_Y \times Z + M_Y = 0 \Rightarrow M_Y = F_Y \times Z - F \times a$ ..... (12)

De (11) y (6) en (12):

$$M_Y = F \times (Z-a) - F \times b \times Z / L \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (13)$$

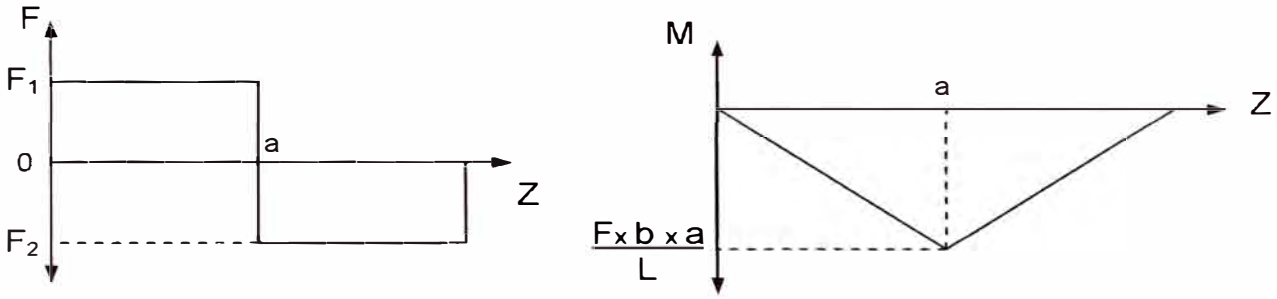


Diagrama de Fuerza

Diagrama de Momentos

Figura 5.7: Diagrama de fuerzas y momentos flectores a los que están sometidas las hojas de muelle

De la figura anterior, se deduce que el máximo momento flector al que está sometida una hoja de muelle es igual a.

$$M = F \times b \times a / L \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (14)$$

De (14) en (3) tenemos:

$$S = \frac{F \times b \times a \times e}{2 \times L \times I} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (15)$$

5.2.2 Momento de Inercia

El momento de inercia es la resistencia de un objeto a rotar entorno a un eje, matemáticamente es la suma de los productos de las masas de las partículas por el cuadrado de la distancia de cada partícula a dicho eje.

Dado que, la sección de la hoja de muelle no es completamente rectangular, ya que 2 de sus lados son ligeramente cóncavos y los otros 2 son convexos (ver figura 5.8), el momento de inercia de la hoja de mueile esta dada por la siguiente ecuación, según la Norma SAE HS J788:

$$I = 0.083333 \times \ell \times e^3 + 0.013540 \times e^4 - 1.333333 \times d \times \ell \times (0.06871 \times d^2 + (0.5 \times e - 0.4 \times d)^2) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (16)$$

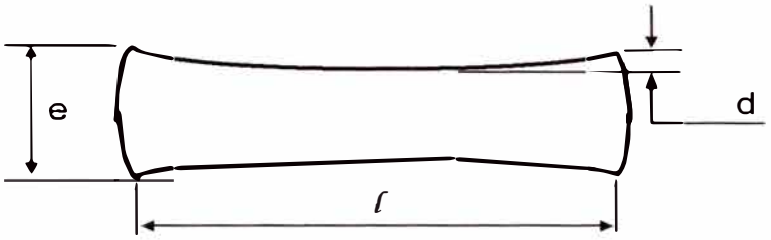


Figura 5.8: Geometría real de la sección plana para las hojas de muelle

5.2.3 Factor de Rigidez (SF)

La Norma SAE HS J788, indica que el Factor de Rigidez se obtiene experimentalmente, y establece que para los paquetes de muelles tipo ballesta varía de 1.10 a 1.50, dependiendo de la geometría de sus extremos. En IPASA a través de varios ensayos se ha identificado que el Factor de Rigidez para las hojas de muelle sueltas (no para paquete de muelle armado) es de 1.50.

5.2.4 Constante de elasticidad o constante de resorte (k)

La constante de elasticidad es un parámetro característico de los muelles, y en general de todos los resortes, que esta definido como:

$$k = F / f \quad \text{.....} \quad (17)$$

Para el caso de muelle tipo ballesta, la Norma SAE HS J788, establece la siguiente ecuación:

$$k = \frac{2 \times E \times I \times L \times SF}{b^2 \times a^2} \quad \text{.....} \quad (18)$$

5.2.5 Deflexión (f)

La deflexión es la deformación que se obtiene en las hojas de muelle cuando estas son sometidas a una fuerza vertical aplicada en la posición del

perno central. La deflexión se mide en el sentido de la aplicación de la fuerza (ver figura 3.29 y 5.3).

De (17) en (18) tenemos:

$$f = \frac{F \times b^2 \times a^2}{2 \times E \times I \times L \times SF} \quad \ldots\ldots (19)$$

De (15) en (19) tenemos:

$$f = \frac{S \times b \times a}{E \times e \times SF} \quad \ldots\ldots (20)$$

5.2.6 Máxima Deflexión

La máxima deflexión, es la mayor deformación a que se limita el paquete de muelle (a través de un tope en el chasis del vehículo), de modo que se evite la pérdida de altura del paquete de muelle y se asegure una vida útil adecuada considerando de que el muelle trabaja a fatiga.

En IPASA, se considera que el esfuerzo correspondiente a la máxima deflexión es 0.84 veces el esfuerzo de fluencia medio dado por la Norma SAE HS J788 (ver 2.2.4 del presente informe), es decir:

S = 0.84 x (1170 + 1550) / 2 = 1142.4 MPa

Remplazando E, SF y este valor de S en la ecuación (20), tenemos:

$$f_{max} = \frac{b \times a}{263 \times e} \quad \ldots\ldots (21)$$

5.2.7 Frecuencia natural (f)

La frecuencia natural (en revoluciones por minuto) de las hojas de muelle esta dado por la siguiente ecuación, según la Norma SAE HS J788:

$$f = \frac{1}{2 \times \pi} \times \sqrt{\frac{g}{f_{final} \times 0.001}} \times 60 \quad \ldots\ldots (22)$$

5.2.8 Altura Libre (HL)

La altura libre o flecha, es la mayor distancia del centro de los ojos al lado que trabaja a tracción. Si la hoja en vez de ojos tuviera extremos sesgados, con corte lateral, desbastados o cuadrados, la altura libre seria la mayor distancia ente la línea imaginaria que pasa por los 2 extremos y el lado que trabaja a tracción.

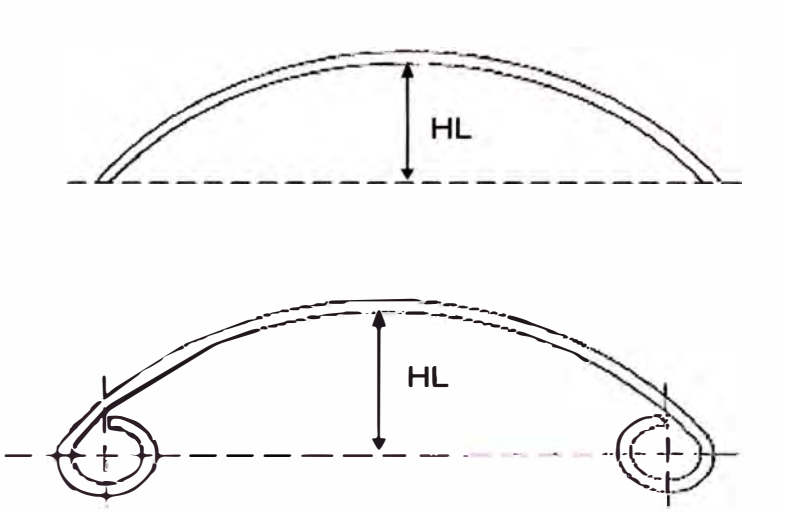


Figura 5.9: Medición de la Altura Libre

Cuando la hoja de muelle está bajo la acción de alguna fuerza, esta se deflecta, disminuyendo por tanto su altura libre.

$$HL = HL_{\text{sin fuerza}} - f \quad \ldots\ldots (23)$$

5.2.9 Carrera

En el ensayo de fatiga la carrera esta dada por la siguiente ecuación:

$$\text{Carrera} = f_{\text{final}} - f_{\text{inicial}} \quad \ldots\ldots (24)$$

5.2.10 Esfuerzos para las condiciones de fatiga

De la figura 4.6, la cual es un extracto de la Norma SAE HS J788, se deducen las siguientes relaciones entre S_{max} y S_{min} para diferentes condiciones de fatiga:

Para 30,000 ciclos de vida: $S_{max} = 966 + 0.4057 \times S_{min}$ ..... (25)

Para 50,000 ciclos de vida: $S_{max} = 810 + 0.486 \times S_{min}$ ..... (26)

Para 75,000 ciclos de vida: $S_{max} = 700 + 0.49 \times S_{min}$ ..... (27)

Para 100,000 ciclos de vida: $S_{max} = 620 + 0.605 \times S_{min}$ ..... (28)

Para 200,000 ciclos de vida: $S_{max} = 509 + 0.67 \times S_{min}$ ..... (29)

Para 1'000,000 ciclos de vida: $S_{max} = 459 + 0.702 \times S_{min}$ ..... (30)

Donde, S_{max} es obtenido cuando la hoja de muelle llega a la deflexión final, y S_{min} cuando la hoja de muelle llega a la deflexión inicial.

5.3. MAQUINA FATIGADORA

Ver figura 5.10.

5.3.1. Partes Principales

5.3.1.1. Excéntrica

La excéntrica es una volante que en dirección radial tiene un canal con forma de cola de Milano, sobre la cual se desfasa el sistema biela-embolo con respecto al centro de giro. El valor de este desfase es numéricamente igual a la mitad de la carrera.

5.3.1.2. Sistema Biela - Embolo

El sistema biela-embolo tiene como función transformar el movimiento rotacional en lineal ascendente-descendente. La longitud del embolo es regulable y con ello se define la altura libre inicial de la hoja de muelle a ensayar.

5.3.1.3. Torretas de sujeción

Las torretas de sujeción tienen como función sujetar las hojas de muelle a ciclar a través de sus ojos. La distancia entre torretas se regula dependiendo de la longitud de la hoja a ensayar y se fijan a la estructura a través de pernos. Existen 2 torretas, una que tiene un sujetador basculante y otro que tiene un sujetador fijo.

5.3.1.4. Sistema de Apagado Automático

El sistema de apagado automático, consta de un switch que durante el ensayo se encuentra en contacto con la parte inferior del sujetador fijo, pero al romperse la hoja de muelle un resorte comprimido eleva el sujetador en mención, ocasionando que el switch deje de tener contacto con el sujetador, cortando así la corriente eléctrica de alimentación.

5.3.1.5. Contador de ciclos

El contador de ciclos registra la cantidad de ciclos que dura la hoja de muelle durante el ensayo de fatiga.

5.3.1.6. Accesorios

Adicionalmente a las bocinas y pernos de sujeción que se instalan en los ojos de las hojas de mulle, existen 2 planchas de sujeción que se ponen a la altura del agujero para perno central, las cuales se fijan a través de 4 pernos, estos pernos deben tener el torque de trabajo según su grado, diámetro y tipo de rosca, ya que si el torque es bajo, la hoja rompería rápidamente (antes de fatigarse) por el agujero.

5.3.2. Características de la Máquina fatigadora de IPASA

En IPASA, la máquina fatigadora tiene las siguientes características:

Marca	: Hoesch
Modelo	: 8 – 0048
Número de ciclos por minuto	: 100
Motor eléctrico	: 10 HP y 1450 rpm
Longitud máxima de la ballesta a ensayar	: 1530 mm

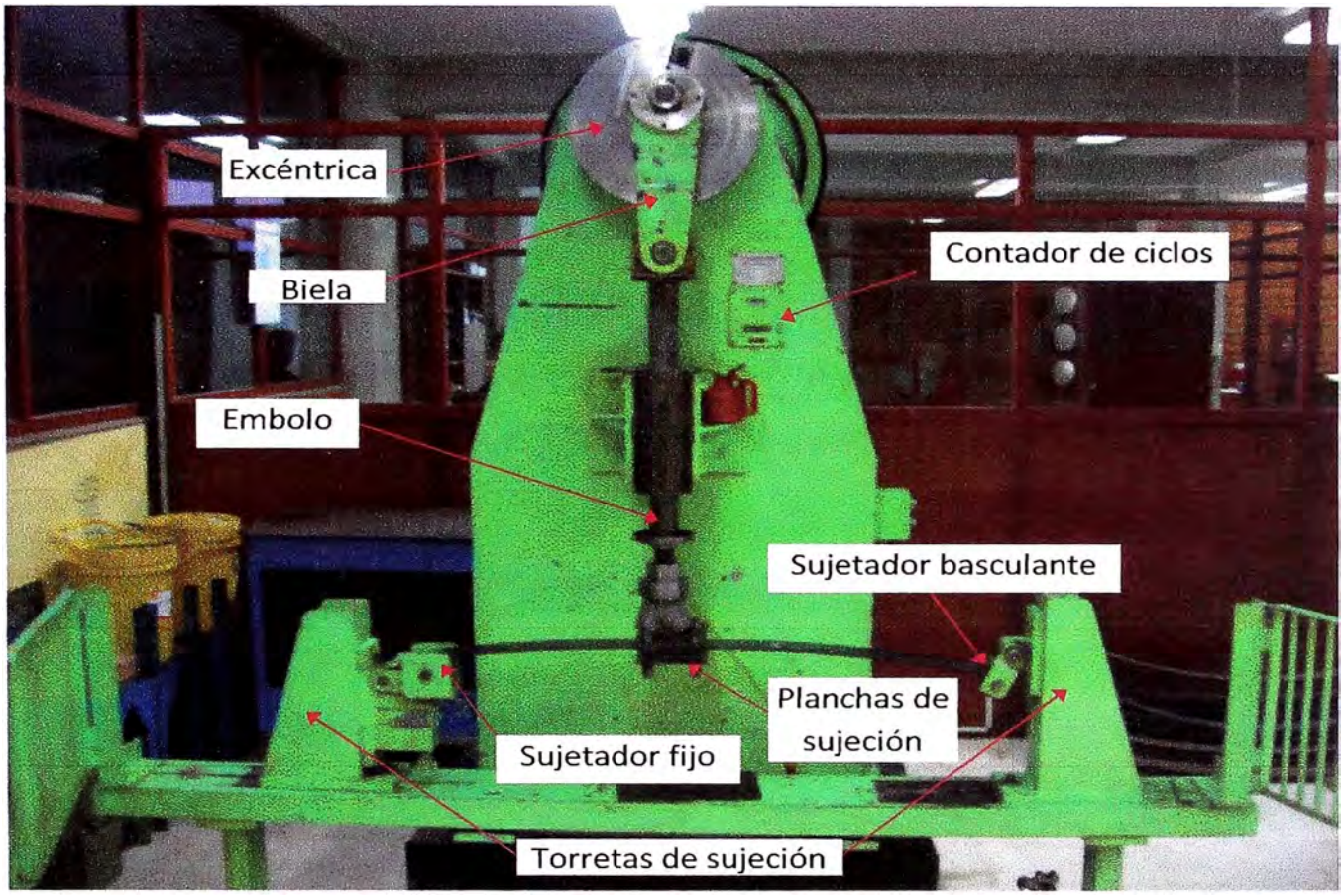


Figura 5.10: Máquina Fatigadora

5.3.3. Instalación de las probetas

Para instalar las hojas de muelle a ensayar se deben seguir los siguientes pasos:

Regular la excentricidad del sistema biela-embolo al centro de giro de la volante, usando el tornillo regulador que se encuentra dentro del canal de cola de Milano. Al término de esta operación, ajustar pernos y tuercas de sujeción.

Montar las planchas de sujeción en la probeta, dándole a los pernos el torque de trabajo correspondiente.

- Girar manualmente la volante hasta que el embolo se encuentre en el Punto Muerto Superior (PMS)
- Montar la probeta en las torretas de sujeción, usando las bocinas y pernos correspondientes.
- Medir la altura libre de la probeta.
- Modificar de ser necesario la longitud del embolo, girando el extremo del mismo. Cuando la altura libre sea igual a la altura libre inicial correspondiente al ensayo, ajustar las tuercas de sujeción del embolo.
- Verificar que el switch este en contacto con el sujetador fijo.
- Poner el contador en 0
- Poner en funcionamiento la máquina fatigadora.

5.4. PLAN DE EVALUACIÓN

i. Seleccionar como materia prima de las probetas, aquella que cumpla lo descrito en el capítulo 5.1.

ii. Escoger el modelo de hoja de muelle a ensayar, teniendo en cuenta que debe tener ojos en sus 2 extremos y que su longitud debe ser menor a 1530 mm.

iii. Controlar el proceso de calentamiento para el formado de ojos, para que no exista ampolladuras.

iv. Controlar la temperatura y dureza de temple

v. Controlar la temperatura y dureza de revenido.

vi. De todas las probetas fabricadas, 2 no deben ser granalladas.

vii. Granallar las probetas restantes por la cara que trabaja a tracción, controlando la impactación y la cobertura. Se debe utilizar las granallas indicadas en el capítulo 4.2.4.

viii. Medir las características dimensionales que se muestran en la figura 5.8.

ix. Cuando la hoja este en posición recta, medir la longitud entre centros de ojos (L) para las hojas simétricas; y para el caso de hojas asimétricas, medir la distancia entre el centro del ojo y el centro del agujero para perno, tanto para el lado corto como para el lado largo.

x. Medir la flecha (altura libre) de la hoja de muelle.

xi. Calcular el momento de inercia con la ecuación (16) y con los datos obtenidos en el paso viii.

xii. Calcular la constante de elasticidad (k) usando la ecuación (18) para un E = 200,000 MPa y un SF = 1.5. Dividir el resultado entre 9.8 para convertir N/mm a kgf/mm.

xiii. Confirmar el valor obtenido en el punto xii, mediante la prueba de Carga y Flexión a la hoja de muelle (ver 3.2.3.3).

xiv. Escoger si el ensayo va a ser para 30,000 – 50,000 – 75,000 1000,000 – 200,000 o 1'000,000 de ciclos de vida a la fatiga.

xv. Escoger la deflexión inicial (f_i)

xvi. Calcular la fuerza inicial usando la deflexión inicial, la constante de elasticidad obtenida en el punto xiii y la ecuación (17).

xvii. Calcular el esfuerzo inicial usando el valor obtenido en el paso xvi y la ecuación (15). No olvidar de multiplicar la fuerza por 9.8 para convertirlo de kgf a Newton.

xviii. Calcular el esfuerzo final, usando la ecuación (25) al (30), según la decisión tomada en el paso xiv.

xix. Calcular la fuerza final, usando el valor obtenido en el paso xviii y la ecuación (15). El valor obtenido, dividirlo entre 9.8 para convertirlo de Newton a kgf.

xx. Calcular la deflexión final, usando el valor del paso xix y la ecuación (17)

xxi. Comprobar las deflexiones, aplicándole las fuerzas final e inicial a la hoja de muelle en la Balanza de Carga y Flexión.

xxii. Calcular la frecuencia del ciclado usando el valor obtenido en el paso xxi y la ecuación (22). Si esta frecuencia esta dentro del rango de 0.9 a 1.1 veces la frecuencia de ciclado de la máquina o de sus múltiplos, cambiar la deflexión inicial (xv) o las condiciones de ciclos de vida mínima (xiv), recalculando por tanto los demás valores.

xxiii. Calcular la altura libre inicial y final usando la ecuación (23)

xxiv. Calcular la carrera usando la ecuación (24)

xxv. Instalar las probetas según lo indicado en el capitulo 5.3.3. Las probetas sin granallar deben ser las primeras en ensayarse.

xxvi. Terminado el ensayo, registrar la cantidad de ciclos resistido por la probeta.

xxvii. A través de la inspección visual, verificar si la rotura corresponde a fractura por fatiga.

xxviii. Realizar un análisis metalográfico cerca de la zona de rotura, referente a: tamaño de grano, estructura metalográfica, descarburización superficial, inclusiones no metálicas y segregaciones bandeadas.

xxix. Elaborar informe indicando las conclusiones.

CAPITULO 6

UTILIZACION DEL PLAN DE EVALUACION EN HOJAS DE MUELLE PROCESADAS CON GRANALLA SAE S 330

6.1. MATERIA PRIMA (EN CUMPLIMIENTO AL 5.4.1)

Se ha escogido como materia prima, el material 70x9mm de la colada R31004822VX, por cumplir lo descrito en el capitulo 5.1, según el Certificado de Análisis dado por el proveedor y por los resultados de la Inspección de Recepción hechos por IPASA (ver apéndice J).

Las mediciones hechas en IPASA se obtuvieron con los siguientes equipos o instrumentos de medición:

- Microscopio Metalografico Invertido, Marca Nikon, Modelo Eclipse 100, de aumentos: 50x, 100x, 200x, 500x y 1000x; el cual tiene una cámara digital Nikon instalada en su trinocular y trabaja con el software metalográfico NIS ELEMENT V3.0, este software entre otras aplicaciones mide tamaño de grano, hace mediciones longitudinales y de área. Antes de usar el software este fue calibrado con respecto a su stage micrometer patrón, cuyo certificado se muestra en el apéndice K.
- Analizador de Carbono y Azufre, Marca Leco, Modelo CS 230. El cual tiene para una muestra de 1 gramo un rango de 4 ppm – 3.5% para carbono y 4ppm – 0.4% para azufre, y una resolución tanto para carbono y azufre de 0.1 ppm. Este equipo antes de ser usado fue calibrado con respecto a sus patrones, cuyos certificados se adjuntan en el apéndice K.

- Cinta métrica de 3 metros de rango y 1 mm de división mínima, calibrador vernier de 150mm de rango y 0.02 mm de división mínima, y micrómetro de exteriores de 0 – 25 mm de rango y 0.01 mm de división mínima, los cuales están dentro de su vigencia de verificación.

6.2. MODELO DE HOJA DE MUELLE (EN CUMPLIMIENTO AL 5.4.2)

Se seleccionó la hoja de código IPASA: HYMP-2000-01A, la cual se usa como hoja primera del muelle posterior que trabaja en el Microbús Hyundai Grace del año 1995. Se fabricaron 8 probetas para ensayar.

6.3. CONTROL DE FORMADO DE OJO, TEMPLE Y REVENIDO (EN CUMPLIMIENTO AL 5.4.3, 5.4.4 Y 5.4.5)

Las probetas fueron procesadas a una correcta temperatura tanto para el formado de ojo, el temple y el revenido, no presentándose ampolladuras en las probetas. Las hojas tuvieron las siguientes durezas después del revenido:

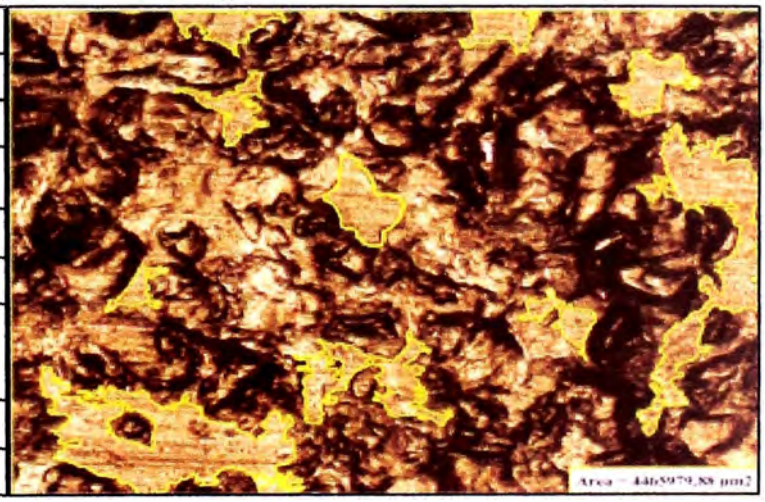
Código de probeta	Dureza (HBN)	Observación
1	415 - 415	Hojas sin shotpeening
2	415 - 440	
C1	438 - 440	Hojas con shotpeening y puestas en la parte central de la faja transportadora
C2	415 - 415	
D1	401 - 415	Hojas con shotpeening y puestas en el lado derecho de la faja transportadora
D2	415 - 415	
I1	412 - 415	Hojas con shotpeening y puestas en el lado izquierdo de la faja transportadora
I2	415 - 415	

Vale la pena indicar que no se menciona las temperaturas del formado de ojo, la temperatura del temple, la temperatura del revenido ni la dureza de temple por ser parte del know how de la empresa.

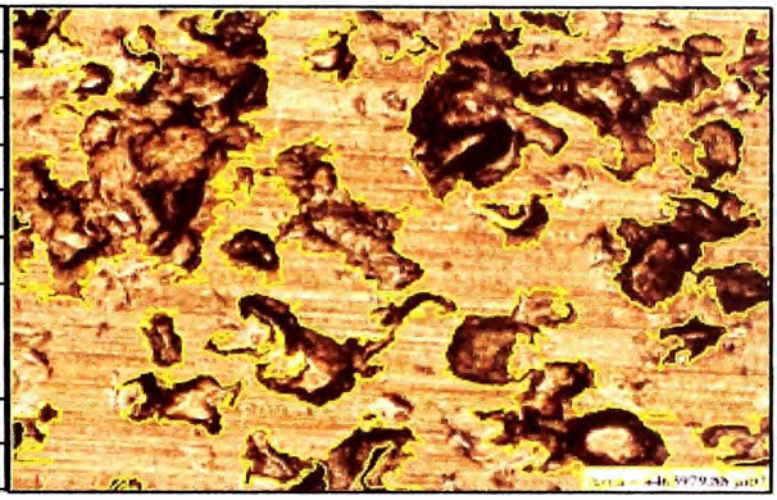
6.4. CONTROL DEL GRANALLADO DE PROBETAS (EN CUMPLIMIENTO AL 5.4.6 Y 5.4.7)

Se granallaron sólo 6 de las 8 probetas, bajo los mismos parámetros de operación de la granalladora y con la granalla SAE S330 (ver informe metalografico de recepción de IPASA, en el apéndice L), la diferencia fue que 2 probetas se pusieron en el centro de la faja transportadora de la granalladora (asignándoles a estas probetas los códigos C1 y C2), 2 en el lado derecho (asignándoles a estas probetas los códigos D1 y D2) y 2 en el lado izquierdo (asignándoles a estas probetas los códigos I1 e I2). Las 6 probetas en mención se granallaron sólo por la cara que trabaja a tracción, teniéndose los siguientes valores de impactación y cobertura:

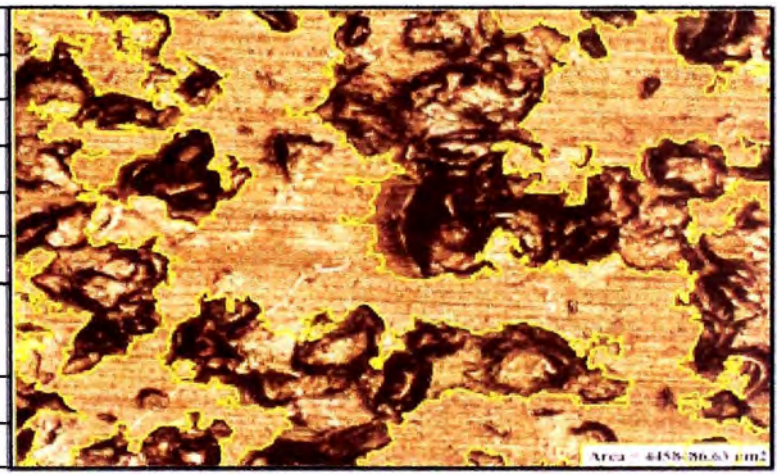
DIA	25/04/2011
HORA	02:05 pm
MAQUINA	NUEVA
VELOCIDAD DE LA FAJA	RAPIDA
IMPELENTE N°1	18 A
IMPELENTE N°2	17 A
POSICION DE LA PROBETA RESPECTO A LA FAJA	PARTE CENTRAL
IMPATACION ALMEN A	0.44 mm
COBERTURA	85%



DIA	25/04/2011
HORA	2:07 p.m.
MAQUINA	NUEVA
VELOCIDAD DE LA FAJA	RAPIDA
IMPELENTE N°1	18 A
IMPELENTE N°2	17A
POSICION DE LA PROBETA RESPECTO A LA FAJA	LADO DERECHO
IMPACTACION ALMEN A	0.22mm
COBERTURA	40%



DIA	25/04/2011
HORA	02:09 p.m.
MAQUINA	NUEVA
VELOCIDAD DE LA FAJA	RAPIDA
IMPELENTE N°1	18 A
IMPELENTE N°2	17A
POSICION DE LA PROBETA RESPECTO A LA FAJA	LADO IZQUIERDO
IMPACTACION ALMEN A	0.27mm
COBERTURA	49%

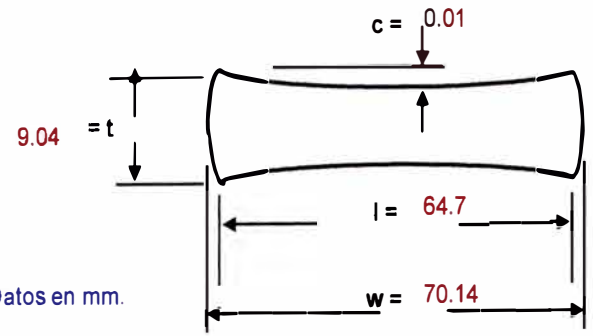


6.5. CARACTERÍSTICAS DIMENSIONALES Y CONDICIONES DEL CICLADO (EN CUMPLIMIENTO DEL 5.4.8 AL 5.4.24)

El ensayo de fatiga para todas las muestras va a ser de 30,000 ciclos de vida. Las características dimensiónales y de ciclado por probeta se muestran en los siguientes cuadros, cuyos resultados provienen de hojas de cálculo en excell.

CÁLCULO DE LAS CONDICIONES DE FATIGA PARA HOJAS DE MUELLES ASIMÉTRICOS

1.DATOS DEL PERFIL A ENSAYAR:



Nota.- Datos en mm.

Código de la Hoja:	HYMP-2000-01A	**Fecha de inicio:**	22/04/2011
Material:	70x9	**Hora de inicio:**	20:35
Orden de Compra:	156-2010		
Proveedor:	Jiangying Xing Cheng	**Fecha de término:**	23/04/2011
Dureza:	415 - 415	**Hora de término:**	02:07
Observaciones:	Hoja Sin shotpeening		
Numero de muestra :	**1**	**Número de ciclos:**	**33,225**

Cálculo del Momento de Inercia aproximado **I** :

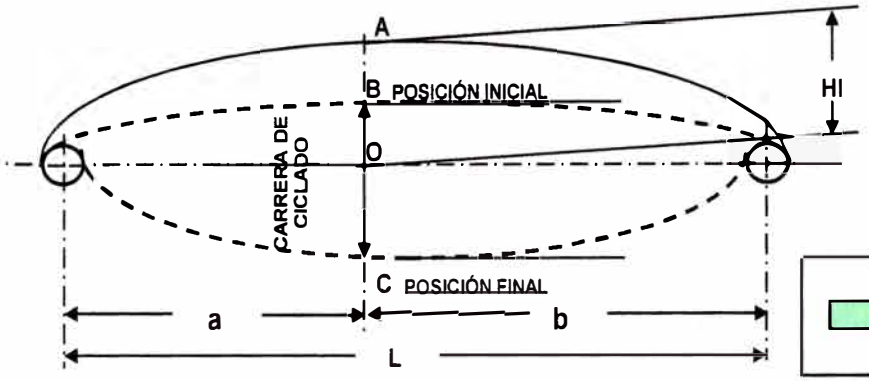
$$I = 0.083333 * l * t^3 + 0.01354 * t^4 - 1.333333 * c * l * (0.068571 * c^2 + (0.5 * t - 0.4 * c)^2) \quad mm^4$$

Luego:

I = **4068.00** **mm^4**

2. DATOS DEL PROTOTIPO A ENSAYAR:

LONG.ENTRE CENTR.	L =	1216	mm
BRAZO DE MOMENTO	(b) =	694	mm (Lado Largo)
BRAZO DE MOMENTO	(a) =	522	mm (Lado Corto)
RATE (Calculado)	k =	2.31	Kg/mm
RATE (E. Carga y Flexión)	k =	2.35	Kg/mm
ALTURA LIBRE:	HL =	130	mm
DEFLEXIÓN INICIAL:	Yi =	30	mm (valor elegido)
DEF. FINAL MÁXIMA:	$f_{máx}$ =	152	mm
FRECUENCIA DE CICLADO	=	100	rpm



Datos corregidos en la balanza durante la aplicación de la fuerza

CONDICIONES DE ENSAYO PARA 30,000 CICLOS DE VIDA DE FATIGA

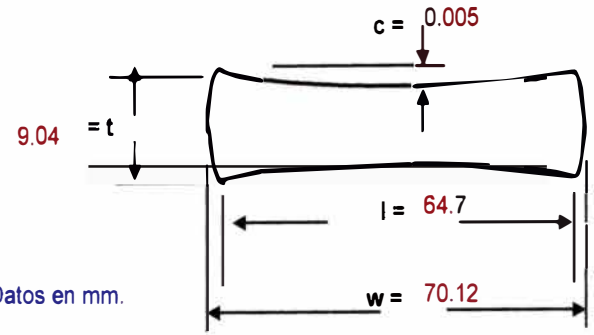
RESONANCIA	ESFUERZO FLECTOR (Mpa) INICIAL	ESFUERZO FLECTOR (Mpa) FINAL	FUERZA (Kg) INICIAL	FUERZA (Kg) FINAL	DEFLEXIÓN (mm) INICIAL	DEFLEXIÓN (mm) FINAL	ALTURA LIBRE (mm) INICIAL	ALTURA LIBRE (mm) FINAL	CARRERA (mm)	EXCENTRICA (mm)	Frec. Natural (rpm)
	228.70	1058.78	70.5	326.38	30	138.9	100	-8.9	109	54.4	80.2
No Existe, ok						138		-8		54	
						Aplicar					

CONDICIONES DE ENSAYO PARA 50,000 CICLOS DE VIDA DE FATIGA

RESONANCIA	ESFUERZO FLECTOR (Mpa) INICIAL	ESFUERZO FLECTOR (Mpa) FINAL	FUERZA (Kg) INICIAL	FUERZA (Kg) FINAL	DEFLEXIÓN (mm) INICIAL	DEFLEXIÓN (mm) FINAL	ALTURA LIBRE (mm) INICIAL	ALTURA LIBRE (mm) FINAL	CARRERA (mm)	EXCENTRICA (mm)	Frec. Natural (rpm)
	228.70	921.15	70.5	283.96	30	120.83	100	9.17	90.83	45.4	86.0
No Existe, ok						Aplicar					

CÁLCULO DE LAS CONDICIONES DE FATIGA PARA HOJAS DE MUELLES ASIMÉTRICOS

1.DATOS DEL PERFIL A ENSAYAR:



Nota.- Datos en mm.

Código de la Hoja:	HYMP-2000-01A	**Fecha de inicio:**	23/04/2011
Material:	70x9	**Hora de inicio:**	10:23
Orden de Compra:	156-2010		
Proveedor:	Jiangying Xing Cheng	**Fecha de término:**	23/04/2011
Dureza:	415 - 440	**Hora de término:**	15:28
Observaciones:	Hoja Sin shotpeening		
Numero de muestra :	**2**	**Número de ciclos:**	**30,521**

Cálculo del Momento de Inercia aproximado I :

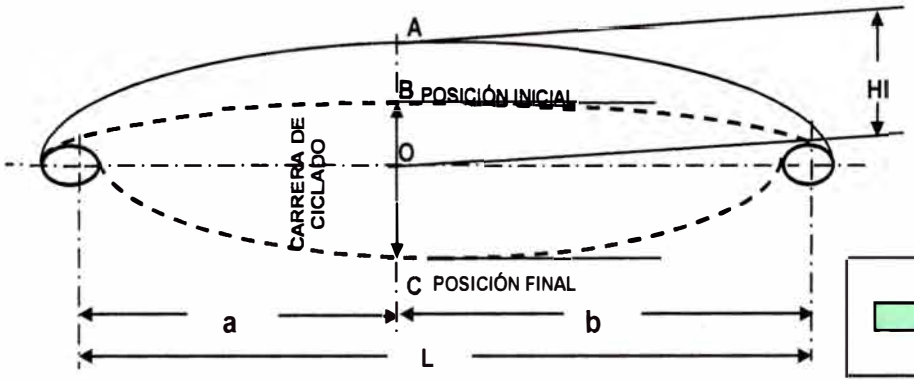
$$I = 0.083333 * l * t^3 + 0.01354 * t^4 - 1.333333 * c * l * (0.068571 * c^2 + (0.5 * t - 0.4 * c)^2) \quad mm^4$$

Luego:

$I =$ 4076.79 mm^4

2. DATOS DEL PROTOTIPO A ENSAYAR:

LONG.ENTRE CENTR.	L =	1215	mm
BRAZO DE MOMENTO	(b) =	692	mm (Lado Largo)
BRAZO DE MOMENTO	(a) =	523	mm (Lado Corto)
RATE (Calculado)	k =	2.32	Kg/mm
RATE (E. Carga y Flexión)	k =	2.40	Kg/mm
ALTURA LIBRE:	HL =	131	mm
DEFLEXIÓN INICIAL:	Yi =	30	mm (valor elegido)
DEF. FINAL MÁXIMA:	$f_{máx}$ =	152	mm
FRECUENCIA DE CICLADO	=	100	rpm



Datos corregidos en la balanza durante la aplicación de la fuerza

CONDICIONES DE ENSAYO PARA 30,000 CICLOS DE VIDA DE FATIGA

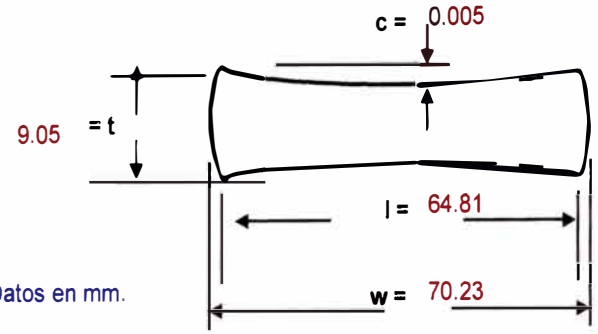
RESONANCIA	ESFUERZO FLECTOR (Mpa) INICIAL	ESFUERZO FLECTOR (Mpa) FINAL	FUERZA (Kg) INICIAL	FUERZA (Kg) FINAL	DEFLEXIÓN (mm) INICIAL	DEFLEXIÓN (mm) FINAL	ALTURA LIBRE (mm) INICIAL	ALTURA LIBRE (mm) FINAL	CARRERA (mm)	EXCENTRICA (mm)	Frec. Natural (rpm)
	233.03	1060.54	72	327.68	30	136.53	101	-5.5	106.53	53.3	80.9
No Existe, ok						136		-5		53	
						Aplicar					

CONDICIONES DE ENSAYO PARA 50,000 CICLOS DE VIDA DE FATIGA

RESONANCIA	ESFUERZO FLECTOR (Mpa) INICIAL	ESFUERZO FLECTOR (Mpa) FINAL	FUERZA (Kg) INICIAL	FUERZA (Kg) FINAL	DEFLEXIÓN (mm) INICIAL	DEFLEXIÓN (mm) FINAL	ALTURA LIBRE (mm) INICIAL	ALTURA LIBRE (mm) FINAL	CARRERA (mm)	EXCENTRICA (mm)	Frec. Natural (rpm)
	233.03	923.25	72	285.26	30	118.86	101	12.14	88.86	44.4	86.7
No Existe, ok						Aplicar					

CÁLCULO DE LAS CONDICIONES DE FATIGA PARA HOJAS DE MUELLES ASIMÉTRICOS

1.DATOS DEL PERFIL A ENSAYAR:



Nota.- Datos en mm.

Código de la Hoja:	HYMP-2000-01A	**Fecha de inicio:**	25/04/2011
Material:	70x9	**Hora de inicio:**	19:06
Orden de Compra:	156-2010		
Proveedor:	Jiangying Xing Cheng	**Fecha de término:**	26/04/2011
Dureza:	438 - 440	**Hora de término:**	05:07
Observaciones:	Hoja con shotpeening y puesta en la parte central de la faja transportadora		
Numero de muestra :	**C1**	**Número de ciclos:**	**60,020**

Cálculo del Momento de Inercia aproximado I :

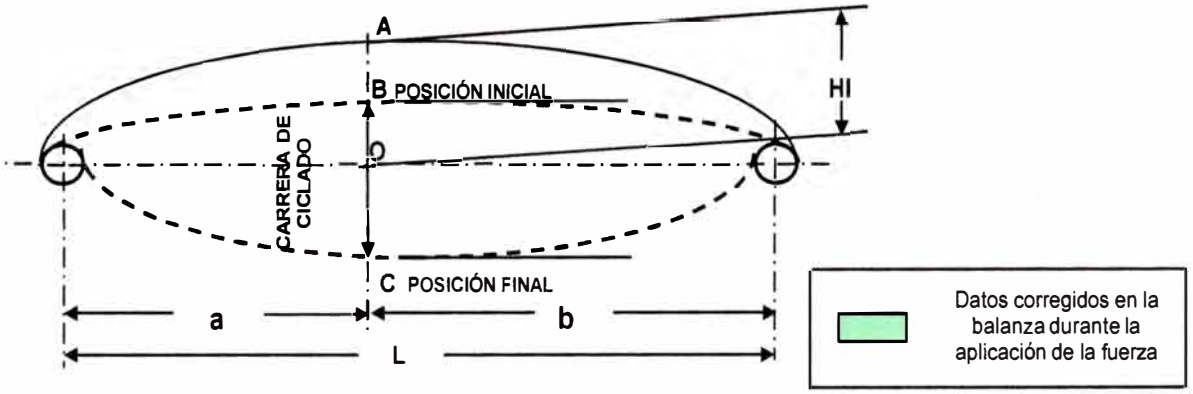
$$I = 0.083333 * l * t^3 + 0.01354 * t^4 - 1.333333 * c * l * (0.068571 * c^2 + (0.5 * t - 0.4 * c)^2) \quad mm^4$$

Luego:

$I =$ 4097.24 mm^4

2. DATOS DEL PROTOTIPO A ENSAYAR:

LONG.ENTRE CENTR.	L =	1213	mm
BRAZO DE MOMENTO	(b) =	692	mm (Lado Largo)
BRAZO DE MOMENTO	(a) =	521	mm (Lado Corto)
RATE (Calculado)	k =	2.34	Kg/mm
RATE (E. Carga y Flexión)	k =	2.40	Kg/mm
ALTURA LIBRE:	HL =	130	mm
DEFLEXIÓN INICIAL:	Yi =	30	mm (valor elegido)
DEF. FINAL MÁXIMA:	$f_{máx}$ =	151	mm
FRECUENCIA DE CICLADO	=	100	rpm



CONDICIONES DE ENSAYO PARA 30,000 CICLOS DE VIDA DE FATIGA

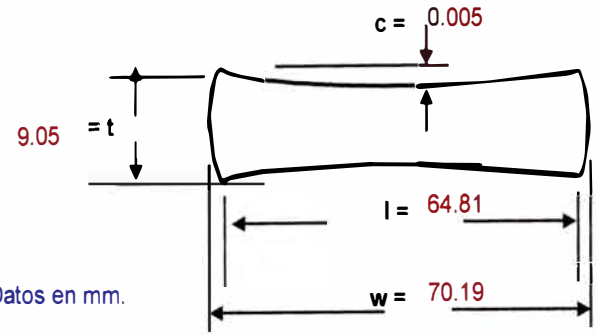
RESONANCIA	ESFUERZO FLECTOR (Mpa) INICIAL	ESFUERZO FLECTOR (Mpa) FINAL	FUERZA (Kg) INICIAL	FUERZA (Kg) FINAL	DEFLEXIÓN (mm) INICIAL	DEFLEXIÓN (mm) FINAL	ALTURA LIBRE (mm) INICIAL	ALTURA LIBRE (mm) FINAL	CARRERA (mm)	EXCENTRICA (mm)	Frec. Natural (rpm)
	231.62	1059.97	72	329.50	30	137.3	100	-7.3	107	53.6	80.7
No Existe, ok						138		-8		54	
						Aplicar					

CONDICIONES DE ENSAYO PARA 50,000 CICLOS DE VIDA DE FATIGA

RESONANCIA	ESFUERZO FLECTOR (Mpa) INICIAL	ESFUERZO FLECTOR (Mpa) FINAL	FUERZA (Kg) INICIAL	FUERZA (Kg) FINAL	DEFLEXIÓN (mm) INICIAL	DEFLEXIÓN (mm) FINAL	ALTURA LIBRE (mm) INICIAL	ALTURA LIBRE (mm) FINAL	CARRERA (mm)	EXCENTRICA (mm)	Frec. Natural (rpm)
	231.62	922.57	72	286.79	30	119.49	100	10.51	89.49	44.7	86.5
No Existe, ok						Aplicar					

CÁLCULO DE LAS CONDICIONES DE FATIGA PARA HOJAS DE MUELLES ASIMÉTRICOS

1.DATOS DEL PERFIL A ENSAYAR:



Nota.- Datos en mm.

Código de la Hoja:	HYMP-2000-01A	**Fecha de inicio:**	26/04/2011
Material:	70x9	**Hora de inicio:**	11:50
Orden de Compra:	156-2010		
Proveedor:	Jiangying Xing Cheng	**Fecha de término:**	27/04/2011
Dureza:	415 - 415	**Hora de término:**	00:18
Observaciones:	Hoja con shotpeening y puesta en la parte central de la faja transportadora		
Numero de muestra :	**C2**	**Número de ciclos:**	**74,751**

Cálculo del Momento de Inercia aproximado **I** :

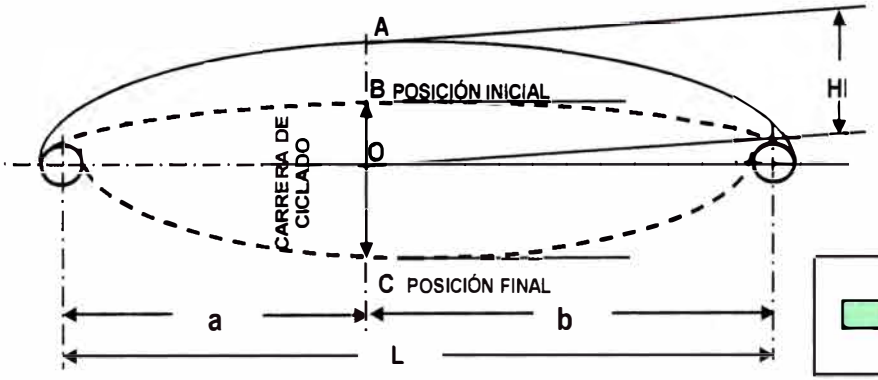
$$I = 0.083333 * l * t^3 + 0.01354 * t^4 - 1.333333 * c * l * (0.068571 * c^2 + (0.5 * t - 0.4 * c)^2) \quad mm^4$$

Luego:

I = **4097.24** **mm^4**

2. DATOS DEL PROTOTIPO A ENSAYAR:

LONG.ENTRE CENTR.	L =	1213	mm
BRAZO DE MOMENTO	(b) =	692	mm (Lado Largo)
BRAZO DE MOMENTO	(a) =	521	mm (Lado Corto)
RATE (Calculado)	k =	2.34	Kg/mm
RATE (E. Carga y Flexión)	k =	2.40	Kg/mm
ALTURA LIBRE:	HL =	131	mm
DEFLEXIÓN INICIAL:	Yi =	30	mm (valor elegido)
DEF. FINAL MÁXIMA:	$f_{máx}$ =	151	mm
FRECUENCIA DE CICLADO	=	100	rpm



Datos corregidos en la balanza durante la aplicación de la fuerza

CONDICIONES DE ENSAYO PARA 30,000 CICLOS DE VIDA DE FATIGA

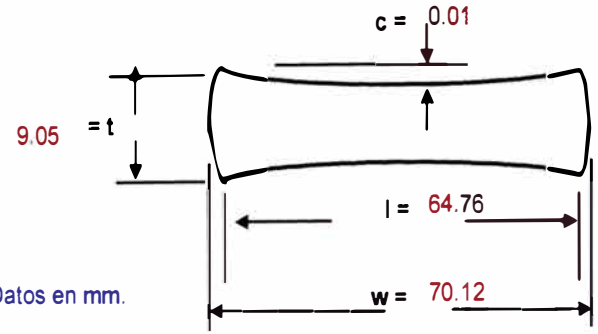
RESONANCIA	ESFUERZO FLECTOR (Mpa) INICIAL	ESFUERZO FLECTOR (Mpa) FINAL	FUERZA (Kg) INICIAL	FUERZA (Kg) FINAL	DEFLEXIÓN (mm) INICIAL	DEFLEXIÓN (mm) FINAL	ALTURA LIBRE (mm) INICIAL	ALTURA LIBRE (mm) FINAL	CARRERA (mm)	EXCENTRICA (mm)	Frec. Natural (rpm)
	231.62	1059.97	72	329.50	30	137.29	101	-6.29	107.29	53.6	80.7
No Existe, ok						137		-7		54	
						Aplicar					

CONDICIONES DE ENSAYO PARA 50,000 CICLOS DE VIDA DE FATIGA

RESONANCIA	ESFUERZO FLECTOR (Mpa) INICIAL	ESFUERZO FLECTOR (Mpa) FINAL	FUERZA (Kg) INICIAL	FUERZA (Kg) FINAL	DEFLEXIÓN (mm) INICIAL	DEFLEXIÓN (mm) FINAL	ALTURA LIBRE (mm) INICIAL	ALTURA LIBRE (mm) FINAL	CARRERA (mm)	EXCENTRICA (mm)	Frec. Natural (rpm)
	231.62	922.57	72	286.79	30	119.49	101	11.51	89.49	44.7	86.5
No Existe, ok						Aplicar					

CÁLCULO DE LAS CONDICIONES DE FATIGA PARA HOJAS DE MUELLES ASIMÉTRICOS

1.DATOS DEL PERFIL A ENSAYAR:



Nota.- Datos en mm.

Código de la Hoja:	HYMP-2000-01A	**Fecha de inicio:**	27/04/2011
Material:	70x9	**Hora de inicio:**	10:30
Orden de Compra:	156-2010		
Proveedor:	Jiangying Xing Cheng	**Fecha de término:**	27/04/2011
Dureza:	401 - 415	**Hora de término:**	15:31
Observaciones:	Hoja con shotpeening y puesta en el lado derecho de la faja transportadora		
Numero de muestra :	**D1**	**Número de ciclos:**	**30,026**

Cálculo del Momento de Inercia aproximado I :

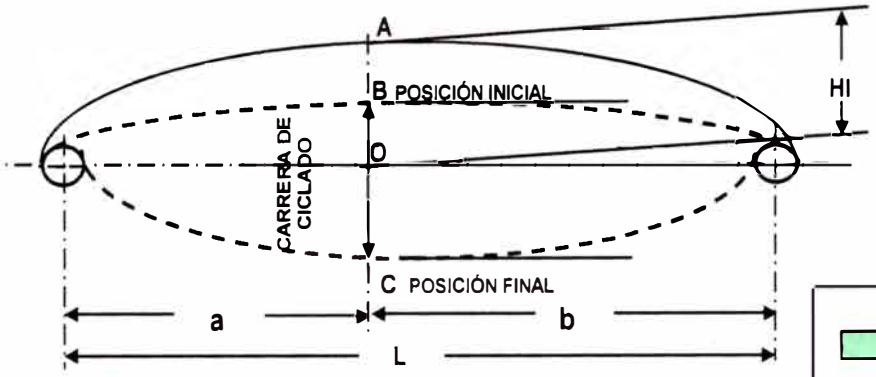
$$I = 0.083333 * l * t^3 + 0.01354 * t^4 - 1.333333 * c * l * (0.068571 * c^2 + (0.5 * t - 0.4 * c)^2) \quad mm^4$$

Luego:

$I =$ 4085.34 mm^4

2. DATOS DEL PROTOTIPO A ENSAYAR:

LONG.ENTRE CENTR.	L =	1216	mm
BRAZO DE MOMENTO	(b) =	695	mm (Lado Largo)
BRAZO DE MOMENTO	(a) =	521	mm (Lado Corto)
RATE (Calculado)	k =	2.32	Kg/mm
RATE (E. Carga y Flexión)	k =	2.40	Kg/mm
ALTURA LIBRE:	HL =	130	mm
DEFLEXIÓN INICIAL:	Yi =	30	mm (valor elegido)
DEF. FINAL MÁXIMA:	$f_{máx}$ =	152	mm
FRECUENCIA DE CICLADO	=	100	rpm



Datos corregidos en la balanza durante la aplicación de la fuerza

CONDICIONES DE ENSAYO PARA 30,000 CICLOS DE VIDA DE FATIGA

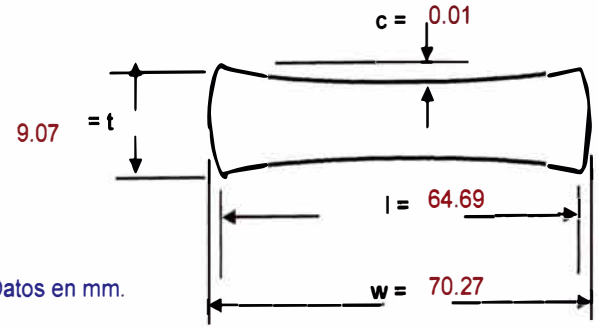
RESONANCIA	ESFUERZO FLECTOR (Mpa) INICIAL	ESFUERZO FLECTOR (Mpa) FINAL	FUERZA (Kg) INICIAL	FUERZA (Kg) FINAL	DEFLEXIÓN (mm) INICIAL	DEFLEXIÓN (mm) FINAL	ALTURA LIBRE (mm) INICIAL	ALTURA LIBRE (mm) FINAL	CARRERA (mm)	EXCENTRICA (mm)	Frec. Natural (rpm)
	232.72	1060.42	72	328.07	30	136.70	100	-6.70	107	53.3	80.9
No Existe, ok						137		-7		53.5	
						Aplicar					

CONDICIONES DE ENSAYO PARA 50,000 CICLOS DE VIDA DE FATIGA

RESONANCIA	ESFUERZO FLECTOR (Mpa) INICIAL	ESFUERZO FLECTOR (Mpa) FINAL	FUERZA (Kg) INICIAL	FUERZA (Kg) FINAL	DEFLEXION (mm) INICIAL	DEFLEXION (mm) FINAL	ALTURA LIBRE (mm) INICIAL	ALTURA LIBRE (mm) FINAL	CARRERA (mm)	EXCENTRICA (mm)	Frec. Natural (rpm)
	232.72	923.10	72	285.59	30	119.00	100	11.00	89.00	44.5	86.7
No Existe, ok						Aplicar					

CÁLCULO DE LAS CONDICIONES DE FATIGA PARA HOJAS DE MUELLES ASIMÉTRICOS

1.DATOS DEL PERFIL A ENSAYAR:



Nota.- Datos en mm.

Código de la Hoja:	HYMP-2000-01A	**Fecha de inicio:**	27/04/2011
Material:	70x9	**Hora de inicio:**	17:15
Orden de Compra:	156-2010		
Proveedor:	Jiangying Xing Cheng	**Fecha de término:**	27/04/2011
Dureza:	415 - 415	**Hora de término:**	22:26
Observaciones:	Hoja con shotpeening y puesta en el lado derecho de la faja transportadora		
Numero de muestra :	**D2**	**Número de ciclos:**	**31,125**

Cálculo del Momento de Inercia aproximado **I** :

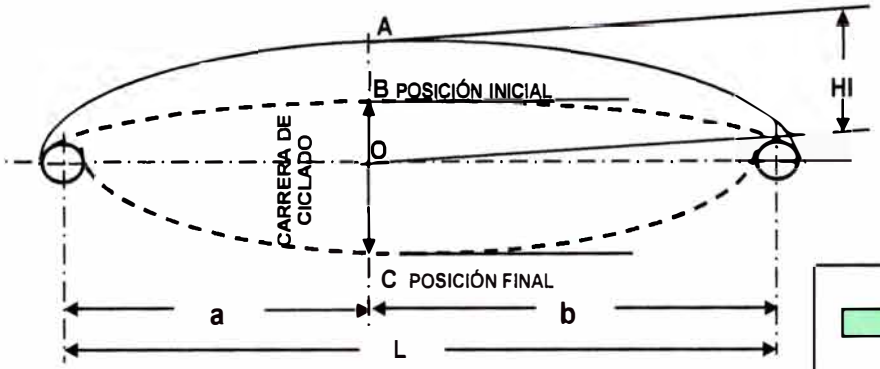
$$I = 0.083333 * l * t^3 + 0.01354 * t^4 - 1.333333 * c * l * (0.068571 * c^2 + (0.5 * t - 0.4 * c)^2) \quad mm^4$$

Luego:

I = 4108.42 mm^4

2. DATOS DEL PROTOTIPO A ENSAYAR:

LONG.ENTRE CENTR.	L =	1215	mm
BRAZO DE MOMENTO	(b) =	692	mm (Lado Largo)
BRAZO DE MOMENTO	(a) =	523	mm (Lado Corto)
RATE (Calculado)	k =	2.33	Kg/mm
RATE (E. Carga y Flexión)	k =	2.40	Kg/mm
ALTURA LIBRE:	HL =	131	mm
DEFLEXIÓN INICIAL:	Yi =	30	mm (valor elegido)
DEF. FINAL MÁXIMA:	$f_{máx}$ =	152	mm
FRECUENCIA DE CICLADO	=	100	rpm



Datos corregidos en la balanza durante la aplicación de la fuerza

CONDICIONES DE ENSAYO PARA 30,000 CICLOS DE VIDA DE FATIGA

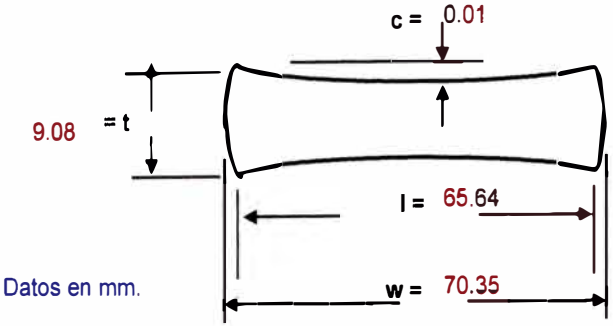
RESONANCIA	ESFUERZO FLECTOR (Mpa) INICIAL	ESFUERZO FLECTOR (Mpa) FINAL	FUERZA (Kg) INICIAL	FUERZA (Kg) FINAL	DEFLEXIÓN (mm) INICIAL	DEFLEXIÓN (mm) FINAL	ALTURA LIBRE (mm) INICIAL	ALTURA LIBRE (mm) FINAL	CARRERA (mm)	EXCENTRICA (mm)	Frec. Natural (rpm)
	232.00	1060.12	72	329.00	30	137.08	101	-6.08	107.08	53.5	80.7
No Existe, ok						137		-7		54	
						Aplicar					

CONDICIONES DE ENSAYO PARA 50,000 CICLOS DE VIDA DE FATIGA

RESONANCIA	ESFUERZO FLECTOR (Mpa) INICIAL	ESFUERZO FLECTOR (Mpa) FINAL	FUERZA (Kg) INICIAL	FUERZA (Kg) FINAL	DEFLEXIÓN (mm) INICIAL	DEFLEXIÓN (mm) FINAL	ALTURA LIBRE (mm) INICIAL	ALTURA LIBRE (mm) FINAL	CARRERA (mm)	EXCENTRICA (mm)	Frec. Natural (rpm)
	232.00	922.75	72	286.37	30	119.32	101	11.68	89.32	44.7	86.5
No Existe, ok						Aplicar					

CÁLCULO DE LAS CONDICIONES DE FATIGA PARA HOJAS DE MUELLES ASIMÉTRICOS

1.DATOS DEL PERFIL A ENSAYAR:



Nota.- Datos en mm.

Código de la Hoja:	HYMP-2000-01A	**Fecha de inicio:**	28/04/2011
Material:	70x9	**Hora de inicio:**	10:55
Orden de Compra:	156-2010		
Proveedor:	Jiangying Xing Cheng	**Fecha de término:**	28/04/2011
Dureza:	412 - 415	**Hora de término:**	15:43
Observaciones:	Hoja con shotpeening y puesta en el lado izquierdo de la faja transportadora		
Numero de muestra :	**I1**	**Número de ciclos:**	**28,820**

Cálculo del Momento de Inercia aproximado I :

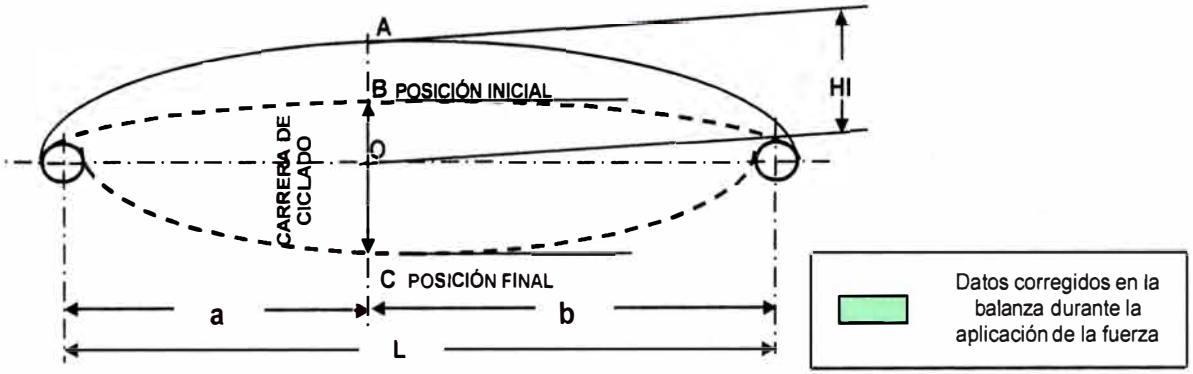
$$I = 0.083333 * l * t^3 + 0.01354 * t^4 - 1.333333 * c * l * (0.068571 * c^2 + (0.5 * t - 0.4 * c)^2) \quad mm^4$$

Luego:

$I =$ 4181.16 mm^4

2. DATOS DEL PROTOTIPO A ENSAYAR:

LONG.ENTRE CENTR.	L =	1215	mm
BRAZO DE MOMENTO	(b) =	694	mm (Lado Largo)
BRAZO DE MOMENTO	(a) =	521	mm (Lado Corto)
RATE (Calculado)	k =	2.38	Kg/mm
RATE (E. Carga y Flexión)	k =	2.40	Kg/mm
ALTURA LIBRE:	HL =	130	mm
DEFLEXIÓN INICIAL:	Yi =	30	mm (valor elegido)
DEF. FINAL MÁXIMA:	$f_{máx}$ =	151	mm
FRECUENCIA DE CICLADO	=	100	rpm



CONDICIONES DE ENSAYO PARA 30,000 CICLOS DE VIDA DE FATIGA

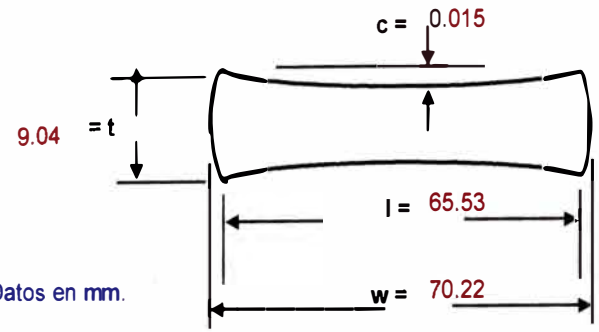
RESONANCIA	ESFUERZO FLECTOR (Mpa) INICIAL	ESFUERZO FLECTOR (Mpa) FINAL	FUERZA (Kg) INICIAL	FUERZA (Kg) FINAL	DEFLEXIÓN (mm) INICIAL	DEFLEXIÓN (mm) FINAL	ALTURA LIBRE (mm) INICIAL	ALTURA LIBRE (mm) FINAL	CARRERA (mm)	EXCENTRICA (mm)	Frec. Natural (rpm)
	228.00	1058.50	72	334.26	30	139.28	100	-9.28	109	54.6	80.1
No Existe, ok						138		-8		54	
						Aplicar					

CONDICIONES DE ENSAYO PARA 50,000 CICLOS DE VIDA DE FATIGA

RESONANCIA	ESFUERZO FLECTOR (Mpa) INICIAL	ESFUERZO FLECTOR (Mpa) FINAL	FUERZA (Kg) INICIAL	FUERZA (Kg) FINAL	DEFLEXIÓN (mm) INICIAL	DEFLEXIÓN (mm) FINAL	ALTURA LIBRE (mm) INICIAL	ALTURA LIBRE (mm) FINAL	CARRERA (mm)	EXCENTRICA (mm)	Frec. Natural (rpm)
	228.00	920.81	72	290.78	30	121.16	100	8.84	91.16	45.6	85.9
No Existe, ok						Aplicar					

CÁLCULO DE LAS CONDICIONES DE FATIGA PARA HOJAS DE MUELLES ASIMÉTRICOS

1.DATOS DEL PERFIL A ENSAYAR:



Nota.- Datos en mm.

Código de la Hoja:	HYMP-2000-01A	**Fecha de inicio:**	28/04/2011
Material:	70x9	**Hora de inicio:**	16:23
Orden de Compra:	156-2010		
Proveedor:	Jiangying Xing Cheng	**Fecha de término:**	28/04/2011
Dureza:	415 - 415	**Hora de término:**	21:43
Observaciones:	Hoja con shotpeening y puesta en el lado izquierdo de la faja transportadora		
Numero de muestra :	**I2**	**Número de ciclos:**	**31,920**

Cálculo del Momento de Inercia aproximado I :

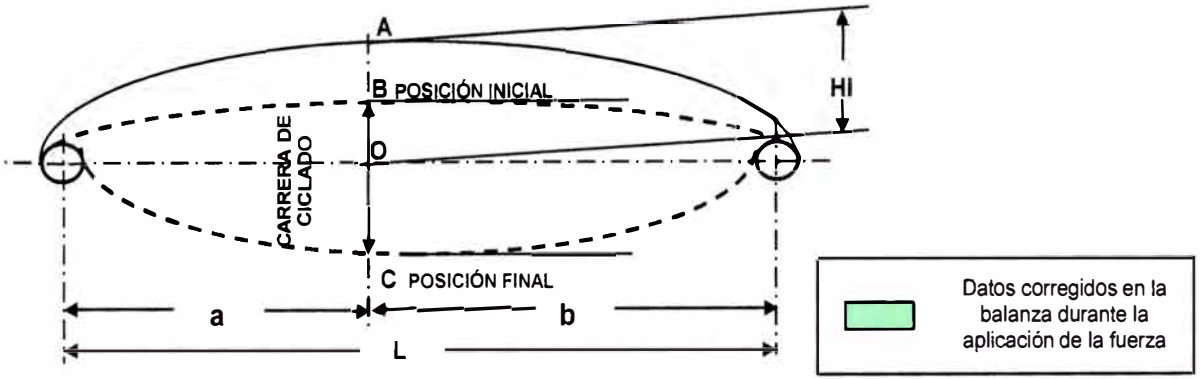
$$I = 0.083333 * l * t^3 + 0.01354 * t^4 - 1.333333 * c * l * (0.068571 * c^2 + (0.5 * t - 0.4 * c)^2) \quad mm^4$$

Luego:

$I =$ 4109.99 mm^4

2. DATOS DEL PROTOTIPO A ENSAYAR:

LONG.ENTRE CENTR.	L =	1215	mm
BRAZO DE MOMENTO	(b) =	693	mm (Lado Largo)
BRAZO DE MOMENTO	(a) =	522	mm (Lado Corto)
RATE (Calculado)	k =	2.34	Kg/mm
RATE (E. Carga y Flexión)	k =	2.40	Kg/mm
ALTURA LIBRE:	HL =	131	mm
DEFLEXIÓN INICIAL:	Yi =	30	mm (valor elegido)
DEF. FINAL MÁXIMA:	$f_{máx}$ =	152	mm
FRECUENCIA DE CICLADO	=	100	rpm



CONDICIONES DE ENSAYO PARA 30,000 CICLOS DE VIDA DE FATIGA

RESONANCIA	ESFUERZO FLECTOR (Mpa) INICIAL	ESFUERZO FLECTOR (Mpa) FINAL	FUERZA (Kg) INICIAL	FUERZA (Kg) FINAL	DEFLEXIÓN (mm) INICIAL	DEFLEXIÓN (mm) FINAL	ALTURA LIBRE (mm) INICIAL	ALTURA LIBRE (mm) FINAL	CARRERA (mm)	EXCENTRICA (mm)	Frec. Natural (rpm)
	231.04	1059.73	72	330.25	30	137.60	101	-6.60	107.60	53.8	80.6
No Existe, ok						136		-5		53	
						Aplicar					

CONDICIONES DE ENSAYO PARA 50,000 CICLOS DE VIDA DE FATIGA

RESONANCIA	ESFUERZO FLECTOR (Mpa) INICIAL	ESFUERZO FLECTOR (Mpa) FINAL	FUERZA (Kg) INICIAL	FUERZA (Kg) FINAL	DEFLEXIÓN (mm) INICIAL	DEFLEXIÓN (mm) FINAL	ALTURA LIBRE (mm) INICIAL	ALTURA LIBRE (mm) FINAL	CARRERA (mm)	EXCENTRICA (mm)	Frec. Natural (rpm)
	231.04	922.28	72	287.42	30	119.76	101	11.24	89.76	44.9	86.4
No Existe, ok						Aplicar					

6.6. INSTALACIÓN DE PROBETAS Y REGISTRO DE RESULTADOS (EN CUMPLIMIENTO AL 5.4.25 Y 5.4.26)

Las probetas se instalaron según lo especificado en el capitulo 5.3.3, ensayando primero las hojas que no fueron granalladas. Obteniéndose los siguientes resultados:

Código de probeta	Cantidad de ciclos	Promedio	Observación
1	33,225	31,873	Hojas sin granallado
2	30,521		
C1	60,020	67,385.5	Hojas con granallado y puestas en la parte central de la faja transportadora
C2	74,751		
D1	30,026	30,575.5	Hojas con granallado y puestas en el lado derecho de la faja transportadora
D2	31,125		
I1	28,820	30,370	Hojas con granallado y puestas en el lado izquierdo de la faja transportadora
I2	31,920		

6.7. INSPECCIÓN VISUAL (EN CUMPLIMIENTO AL 5.4.27)

Todas las hojas se inspeccionaron visualmente al término del ensayo, observándose que todas rompieron por fatiga según la rotura que presentaron.

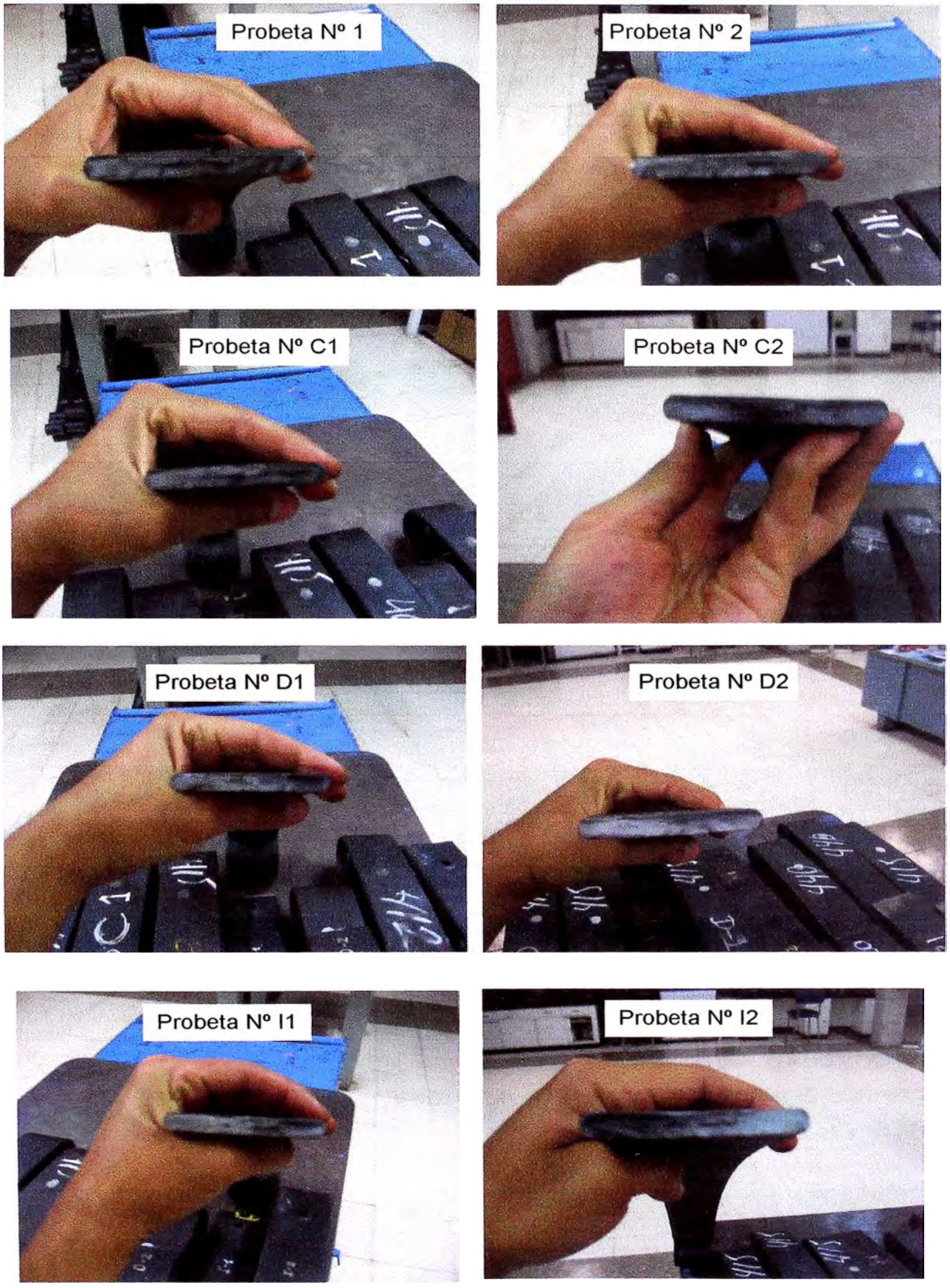


Figura 6.1: Fotografías de la zona de rotura de las probetas fatigadas

6.8. ANÁLISIS METALOGRAFICO DE HOJAS CICLADAS (EN CUMPLIMIENTO AL 5.4.28)

Los resultados del análisis metalograficos se muestran en las siguientes páginas.

INDUSTRIA PERUANA DEL ACERO S.A.
LABORATORIO DE CONTROL DE CALIDAD

ANALISIS METALOGRAFICO

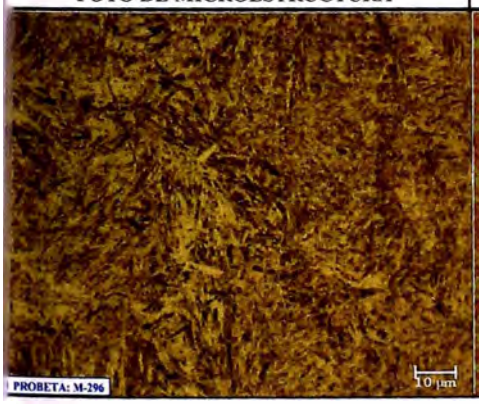
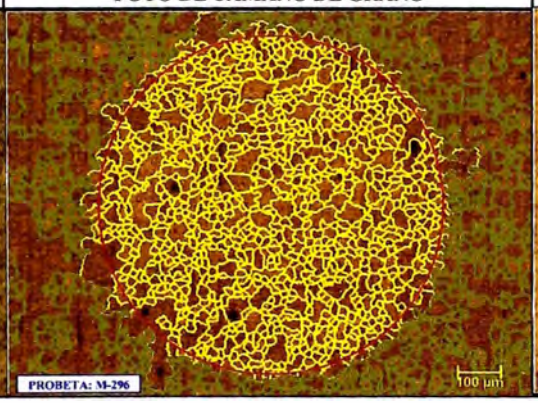
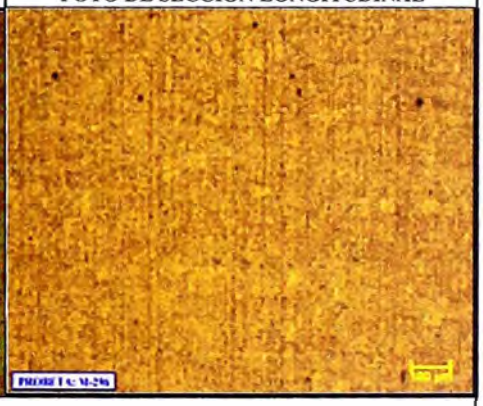
ALISIS N°: 22/11Lab.	**FECHA:** 28/04/2011	**MUESTRA CODIGO N° :** M - 296
ATERIAL: 70 x 9 mm		**PROVEEDOR:** Jiangyin Xingcheng Special Steel
OCEDENCIA: Shanghai - CHINA		**OF:** 174172
COLADA: - R31004822VX		**TIPO DE EVALUACION:** Evaluación de hoja rota por fatiga (**33 225 ciclos**)
C : 156/2010	**N° ATADO:** 822-13	Hoja Sin Shot Peening

TRATAMIENTO TERMICO

ODIGO DE HOJA DE MUELLE: 2000-01A		**CODIGO DE LA PROBETA:** 1	
NSAYO DE TEMPLE	**TEMP.°C :** -	**TIEMPO PERMAN. :** -	**DUREZA (HB):** -
NSAYO DE REVENIDO	**TEMP.°C :** -	**TIEMPO PERMAN. :** -	**DUREZA (HB):** 415 - 415

EXAMEN METALOGRAFICO

GREGACIONES: No Presenta					**AUMENTO:**	100X
ESCARBURIZACIÓN: No Presenta					**AUMENTO:**	100X
NCLUSIONES NO METALICAS **ORMA ASTM E-45**	**OXIDO GLOB.:**D-2.5 **SERIE :** Gruesa	**SILICATOS:**C-1 **SERIE :** Fina	**ALUMINA:** - **SERIE :** -	**SULFURO:** **SERIE :** -	**AUMENTO:**	100X
AMAÑO DE GRANO **ORMA ASTM E-112**	8				**AUMENTO:**	100X
IICROESTRUCTURA	**%PERLITA LAM.** -	**% FERRITA** -	**%MARTEN.** -	**%C. CALCUL.** -	**R. ATAQUE** Picral	**AUMENTO** 1000X

FOTO DE MICROESTRUCTURA	FOTO DE TAMAÑO DE GRANO	FOTO DE SECCION LONGITUDINAL
		

OBSERVACIONES:

- La muestra para la sección longitudinal se tomo de la parte central de la zona de rotura de la hoja de muelle.
- Tiene como microcontituyentes: Martensita Revenida
- Se observa un bajo nivel de inclusiones no metalicas.
- No presenta concentración de segregaciones bandeadas en su microestructura.
- Presenta tamaño de grano fino.

CONCLUSIONES:

- La hoja evidencia un tratamiento termico optimo sin descarburización y una microestructura de martensita revenida homogenea.
- La probeta cumple con las especificaciones metalograficas

INSPECCIONADO POR: Ing.W. Magallanes H.	**REVISADO POR:** Bach. José Carlos Valdiviezo G.

INDUSTRIA PERUANA DEL ACERO S.A.
LABORATORIO DE CONTROL DE CALIDAD

ANALISIS METALOGRAFICO

ALISIS N°: 23/11Lab.	**FECHA:** 28/04/2011	**MUESTRA CODIGO N° :** M - 297
ATERIAL: 70 x 9 mm		**PROVEEDOR:** Jiangyin Xingcheng Special Steel
OCEDENCIA: Shanghai - CHINA		**OF:** 174172
COLADA: - R31004822VX		**TIPO DE EVALUACION:** Evaluación de hoja rota por fatiga (**30 521 ciclos**)
C : 156/2010	**N° ATADO:** 822-13	Hoja Sin Shot Peening

TRATAMIENTO TERMICO

ODIGO DE HOJA DE MUELLE: 2000-01A		**CODIGO DE LA PROBETA:** 2	
NSAYO DE TEMPLE	**TEMP.°C :** -	**TIEMPO PERMAN. :** -	**DUREZA (HB):** 415 - 440
NSAYO DE REVENIDO	**TEMP.°C :** -	**TIEMPO PERMAN. :** -	**DUREZA (HB):** -

EXAMEN METALOGRAFICO

GREGACIONES: Presenta mínima concentración de segregaciones bandeadas					**AUMENTO:**	100X
ESCARBURIZACIÓN: No Presenta					**AUMENTO:**	100X
ICLUSIONES NO METALICAS **ORMA ASTM E-45**	**OXIDO GLOB.:** D-2 **SERIE :** Fina	**SILICATOS:** C-3.5 **SERIE :** Fina	**ALUMINA:** - **SERIE :** -	**SULFURO:** **SERIE :** -	**AUMENTO:**	100X
AMAÑO DE GRANO **ORMA ASTM E-112**	7.5				**AUMENTO:**	100X
ICROESTRUCTURA	**%PERLITA LAM.** -	**% FERRITA** -	**%MARTEN.** -	**%C. CALCUL.** -	**R. ATAQUE** Picral	**AUMENTO** 1000X

FOTO DE MICROESTRUCTURA

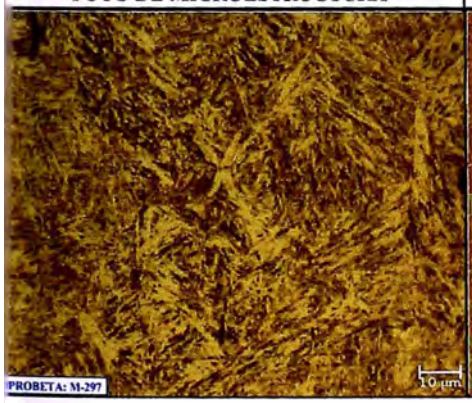


FOTO DE TAMAÑO DE GRANO

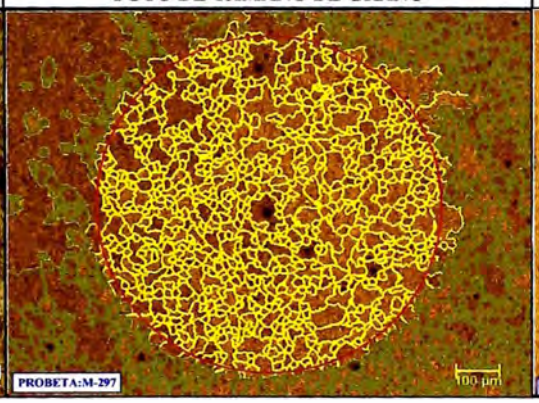
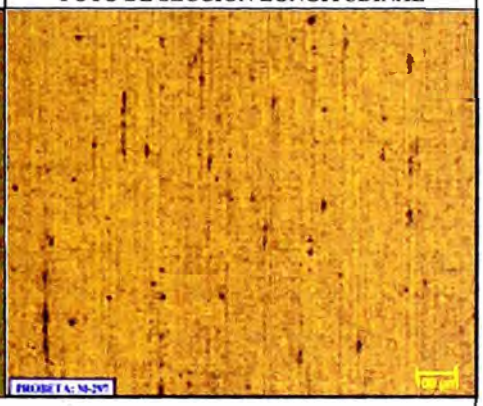


FOTO DE SECCION LONGITUDINAL



OBSERVACIONES:

. La muestra para la sección longitudinal se tomo de la parte central de la zona de rotura de la hoja de muelle.
. Tiene como microcontituyentes: Martensita Revenida
. No presenta concentración de segregaciones bandeadas en su microestructura.
. Presenta tamaño de grano fino.

CONCLUSIONES:

. La hoja evidencia un tratamiento termico optimo sin descarburización y una microestructura de martensita revinida homogenea.
. La probeta cumple con las especificaciones metalograficas

INSPECCIONADO POR: Ing. W. Magallanes H.	**REVISADO POR:** Bach. José Carlos Valdiviezo G.

INDUSTRIA PERUANA DEL ACERO S.A.
LABORATORIO DE CONTROL DE CALIDAD

ANALISIS METALOGRAFICO

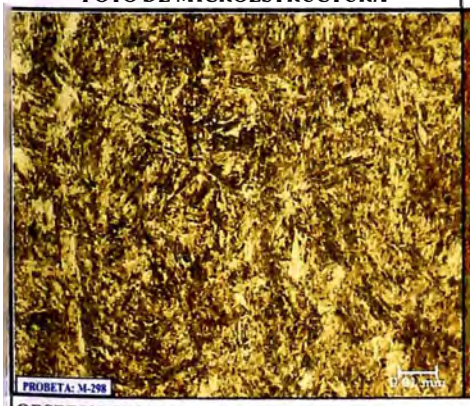
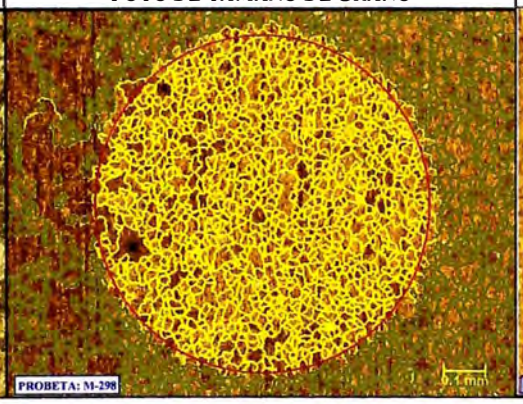
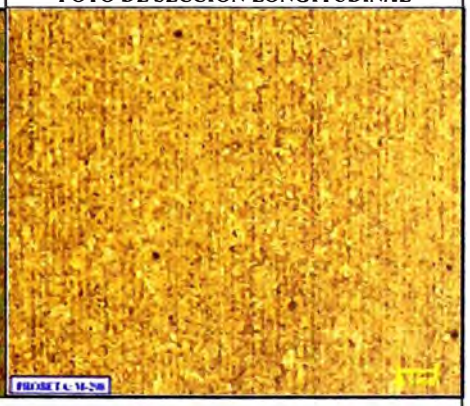
NALISIS Nº: 24/11Lab.	**FECHA:** 11/05/2011	**MUESTRA CODIGO Nº :** M-298
IATERIAL: 70 x 9 mm		**PROVEEDOR:** Jiangyin Xingcheng Special Steel
ROCEDENCIA: Shanghai - CHINA		**OF:** 174172
I° COLADA: - R31004822VX		**TIPO DE EVALUACION:** Evaluación de hoja rota por fatiga (**28 820 ciclos**)
)/C : 156/2010	**Nº ATADO:** 822-13	Hoja con Shot Peening

TRATAMIENTO TERMICO

CODIGO DE HOJA DE MUELLE: 2000-01A		**CODIGO DE LA PROBETA:** I 1	
ENSAYO DE TEMPLE	**TEMP.°C :** -	**TIEMPO PERMAN. :** -	**DUREZA (HB):** 412 - 415
ENSAYO DE REVENIDO	**TEMP.°C :** -	**TIEMPO PERMAN. :** -	**DUREZA (HB):** -

EXAMEN METALOGRAFICO

SEGREGACIONES: No Presenta					**AUMENTO:**	100X
DESCARBURIZACIÓN: Presenta 0.064 mm de profundidad					**AUMENTO:**	100X
INCLUSIONES NO METALICAS **NORMA ASTM E-45**	**OXIDO GLOB.:**D-2 **SERIE :** Fina	**SILICATOS:**C-2.5 **SERIE :** Fina	**ALUMINA:** - **SERIE :** -	**SULFURO:** **SERIE :** -	**AUMENTO:**	100X
TAMAÑO DE GRANO **NORMA ASTM E-112**	8				**AUMENTO:**	100X
MICROESTRUCTURA	**%PERLITA LAM.**	**% FERRITA**	**%MARTEN.**	**%C. CALCUL.**	**R. ATAQUE**	**AUMENTO**
	-	-	-	-	Picral	1000X

FOTO DE MICROESTRUCTURA	FOTO DE TAMAÑO DE GRANO	FOTO DE SECCION LONGITUDINAL
		

OBSERVACIONES:

- La muestra para la sección longitudinal se tomo de la parte central de la zona de rotura de la hoja de muelle.
- Tiene como microcontituyentes: Martensita Revenida
- No presenta concentración de segregaciones bandeadas en su microestructura.
- Presenta tamaño de grano fino.

CONCLUSIONES:

- La hoja evidencia un tratamiento termico optimo sin descarburización y una microestructura de martensita revenida homogenea.
- La probeta cumple con las especificaciones metalograficas

INSPECCIONADO POR: Ing.W. Magallanes H.	**REVISADO POR:** Bach.José Carlos Valdiviezo G.

INDUSTRIA PERUANA DEL ACERO S.A.
LABORATORIO DE CONTROL DE CALIDAD

ANALISIS METALOGRAFICO

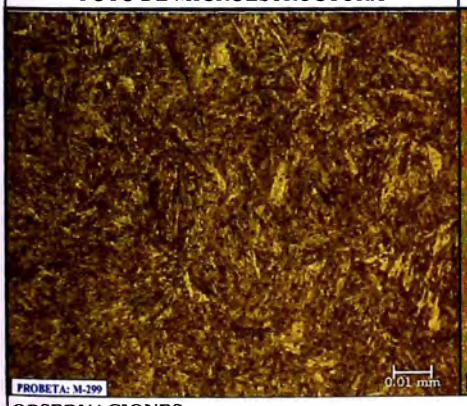
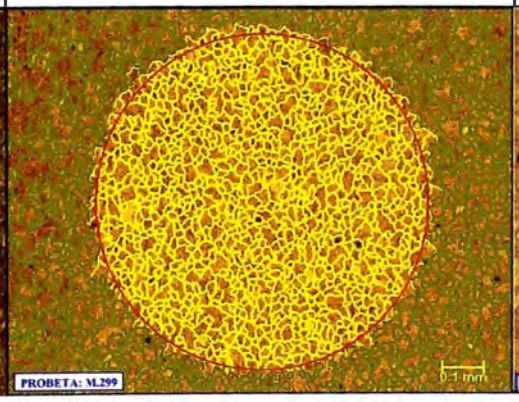
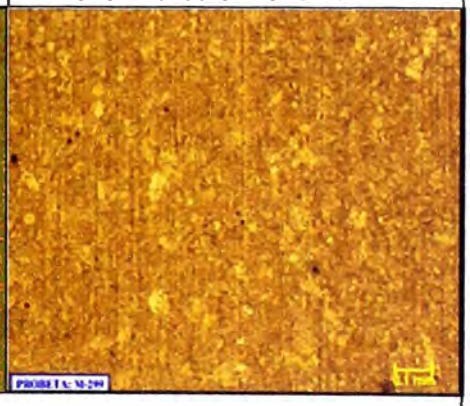
ANALISIS Nº: 25/11Lab.	**FECHA:** 11/05/2011	**MUESTRA CODIGO Nº :** 299
MATERIAL: 70 x 9 mm		**PROVEEDOR:** Jiangyin Xingcheng Special Steel
PROCEDENCIA: Shanghai - CHINA		**OF:** 174172
Nº COLADA: - R31004822VX		**TIPO DE EVALUACION:** Evaluación de hoja rota por fatiga **(31 920 ciclos)**
O/C : 156/2010	**Nº ATADO:** 822-13	Hoja con Shot Peening

TRATAMIENTO TERMICO

CODIGO DE HOJA DE MUELLE: 2000-01A		**CODIGO DE L A PROBETA:** I 2	
ENSAYO DE TEMPLE	**TEMP.°C :** -	**TIEMPO PERMAN. :** -	**DUREZA (HB):** -
ENSAYO DE REVENIDO	**TEMP.°C :** -	**TIEMPO PERMAN. :** -	**DUREZA (HB):** -

EXAMEN METALOGRAFICO

SEGREGACIONES: No Presenta					**AUMENTO:**	100X
DESCARBURIZACIÓN: No Presenta					**AUMENTO:**	100X
INCLUSIONES NO METALICAS **NORMA ASTM E-45**	**OXIDO GLOB.:**D-2	**SILICATOS:**C-1	**ALUMINA:** -	**SULFURO:**	**AUMENTO:**	100X
	SERIE : Fina	**SERIE :** Fina	**SERIE :** -	**SERIE :** -		
TAMAÑO DE GRANO **NORMA ASTM E-112**	8				**AUMENTO:**	100X
MICROESTRUCTURA	**%PERLITA LAM.**	**% FERRITA**	**%MARTEN.**	**%C. CALCUL.**	**R. ATAQUE**	**AUMENTO**
	-	-	-	-	Picral	1000X

FOTO DE MICROESTRUCTURA	FOTO DE TAMAÑO DE GRANO	FOTO DE SECCION LONGITUDINAL
		

OBSERVACIONES:

- La muestra para la sección longitudinal se tomo de la parte central de la zona de rotura de la hoja de muelle.
- Tiene como microcontituyentes: Martensita Revenida
- No presenta concentración de segregaciones bandeadas en su microestructura.
- Presenta tamaño de grano fino.

CONCLUSIONES:

- La hoja evidencia un tratamiento termico optimo sin descarburización y una microestructura de martensita revinida homogenea.
- La probeta cumple con las especificaciones metalograficas

INSPECCIONADO POR: Ing.W. Magallanes H.	**REVISADO POR:** Bach. José Carlos Valdiviezo G.

INDUSTRIA PERUANA DEL ACERO S.A.
LABORATORIO DE CONTROL DE CALIDAD

ANALISIS METALOGRAFICO

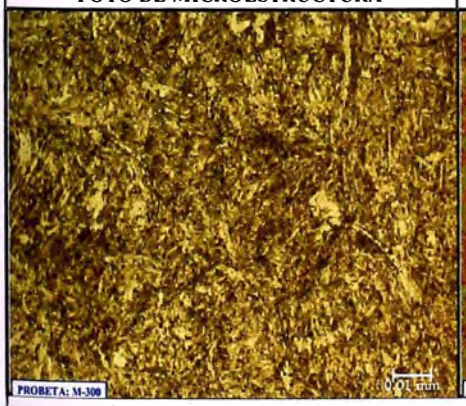
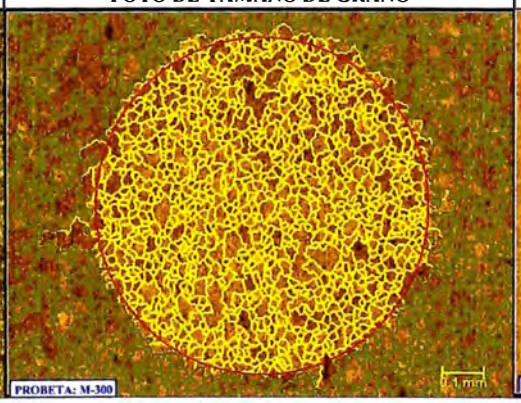
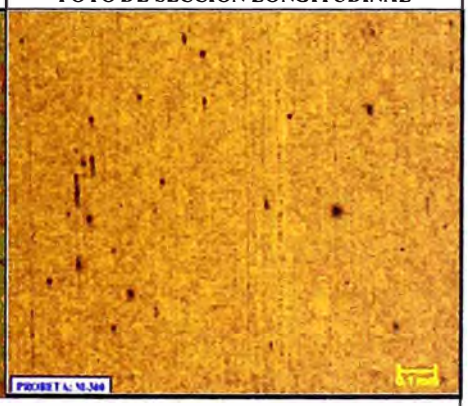
ANALISIS N°: 26/11Lab.	**FECHA:** 11/05/2011	**MUESTRA CODIGO N° :** 300
MATERIAL: 70 x 9 mm		**PROVEEDOR:** Jiangyin Xingcheng Special Steel
PROCEDENCIA: Shanghai - CHINA		**OF:** 174172
N° COLADA: - R31004822VX		**TIPO DE EVALUACION:** Evaluación de hoja rota por fatiga (**30 026 ciclos**)
O/C : 156/2010	**N° ATADO:** 822-13	Hoja con Shot Peening (En la parte derecha de la faja)

TRATAMIENTO TERMICO

CODIGO DE HOJA DE MUELLE: 2000-01A		**CODIGO DE LA PROBETA:** D 1	
ENSAYO DE TEMPLE	**TEMP.°C :** -	**TIEMPO PERMAN. :** -	**DUREZA (HB):** 401 - 415
ENSAYO DE REVENIDO	**TEMP.°C :** -	**TIEMPO PERMAN. :** -	**DUREZA (HB):** -

EXAMEN METALOGRAFICO

SEGREGACIONES: No Presenta					**AUMENTO:**	100X
DESCARBURIZACIÓN: No Presenta					**AUMENTO:**	100X
INCLUSIONES NO METALICAS **NORMA ASTM E-45**	**OXIDO GLOB.:**D-1.5	**SILICATOS:**C-1	**ALUMINA:** -	**SULFURO:**	**AUMENTO:**	100X
	SERIE : Fina	**SERIE :** Fina	**SERIE :** -	**SERIE :** -		
TAMAÑO DE GRANO **NORMA ASTM E-112**	8				**AUMENTO:**	100X
MICROESTRUCTURA	**%PERLITA LAM.**	**% FERRITA**	**%MARTEN.**	**%C. CALCUL.**	**R. ATAQUE**	**AUMENTO**
	-	-	-	-	Picral	1000X

FOTO DE MICROESTRUCTURA	FOTO DE TAMAÑO DE GRANO	FOTO DE SECCION LONGITUDINAL
		

OBSERVACIONES:

- La muestra para la sección longitudinal se tomo de la parte central de la zona de rotura de la hoja de muelle.
- Tiene como microcontituyentes: Martensita Revenida
- No presenta concentración de segregaciones bandeadas en su microestructura.
- Presenta tamaño de grano fino.

CONCLUSIONES:

- La hoja evidencia un tratamiento termico optimo sin descarburización y una microestructura de martensita revinida homogenea.
- La probeta cumple con las especificaciones metalograficas

INSPECCIONADO POR: Ing.W. Magallanes H.	**REVISADO POR:** Bach. José Carlos Valdiviezo G.

INDUSTRIA PERUANA DEL ACERO S.A.
LABORATORIO DE CONTROL DE CALIDAD

ANALISIS METALOGRAFICO

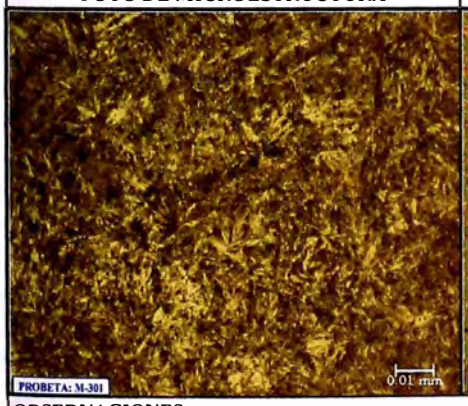
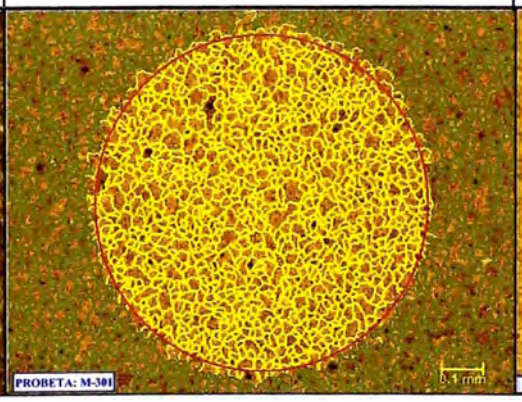
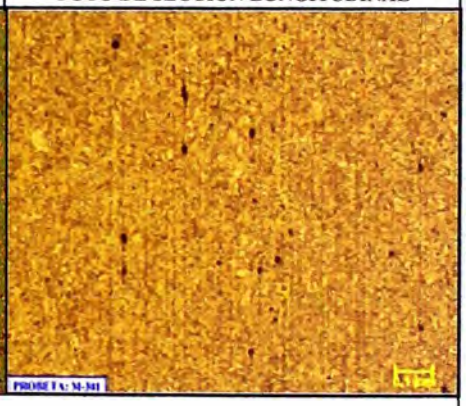
ANALISIS N°: 27/11Lab.	**FECHA:** 11/05/2011	**MUESTRA CODIGO N° :** 301
MATERIAL: 70 x 9 mm		**PROVEEDOR:** Jiangyin Xingcheng Special Steel
PROCEDENCIA: Shanghai - CHINA		**OF:** 174172
N° COLADA: - R31004822VX		**TIPO DE EVALUACION:** Evaluación de hoja rota por fatiga (**31 125 ciclos**)
O/C : 156/2010	**N° ATADO:** 822-13	Hoja conn Shot Peening (En la parte derecha de la faja)

TRATAMIENTO TERMICO

CODIGO DE HOJA DE MUELLE: 2000-01A		**CODIGO DE LA PROBETA:** D 2		
ENSAYO DE TEMPLE	**TEMP.°C :** -	**TIEMPO PERMAN. :** -	**DUREZA (HB):**	415 - 415
ENSAYO DE REVENIDO	**TEMP.°C :** -	**TIEMPO PERMAN. :** -	**DUREZA (HB):**	-

EXAMEN METALOGRAFICO

SEGREGACIONES: No Presenta					**AUMENTO:**	100X
DESCARBURIZACIÓN: No Presenta					**AUMENTO:**	100X
INCLUSIONES NO METALICAS **NORMA ASTM E-45**	**OXIDO GLOB.:**D-2 **SERIE :** Fina	**SILICATOS:**C-2 **SERIE :** Fina	**ALUMINA:** - **SERIE :** -	**SULFURO:** **SERIE :** -	**AUMENTO:**	100X
TAMAÑO DE GRANO **NORMA ASTM E-112**	8				**AUMENTO:**	100X
MICROESTRUCTURA	**%PERLITA LAM.**	**% FERRITA**	**%MARTEN.**	**%C. CALCUL.**	**R. ATAQUE**	**AUMENTO**
	-	-	-	-	Picral	1000X

FOTO DE MICROESTRUCTURA	FOTO DE TAMAÑO DE GRANO	FOTO DE SECCION LONGITUDINAL
		

OBSERVACIONES:

- La muestra para la sección longitudinal se tomo de la parte central de la zona de rotura de la hoja de muelle.
- Tiene como microcontituyentes: Martensita Revenida
- No presenta concentración de segregaciones bandeadas en su microestructura.
- Presenta tamaño de grano fino.

CONCLUSIONES:

- La hoja evidencia un tratamiento termico optimo sin descarburización y una microestructura de martensita revinida homogenea.
- La probeta cumple con las especificaciones metalograficas

INSPECCIONADO POR: Ing.W. Magallanes H.	**REVISADO POR:** Bach. José Carlos Valdiviezo G.

INDUSTRIA PERUANA DEL ACERO S.A.
LABORATORIO DE CONTROL DE CALIDAD

ANALISIS METALOGRAFICO

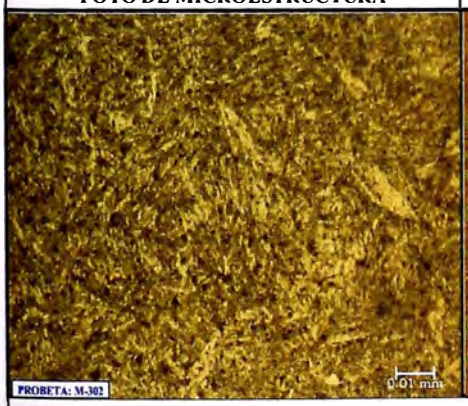
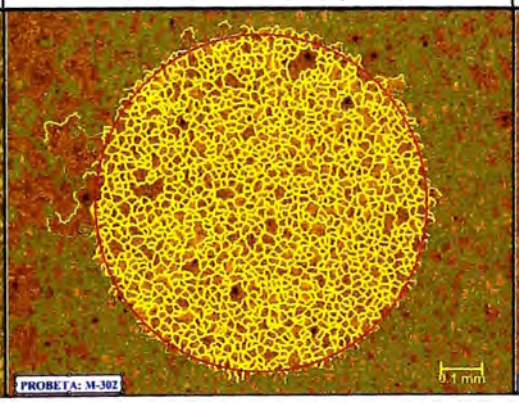
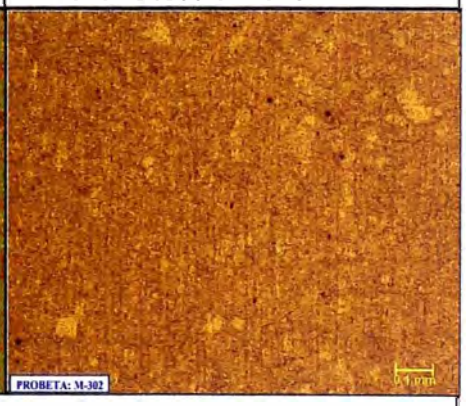
ANALISIS N°: 28/11Lab.	**FECHA:** 11/05/2011	**MUESTRA CODIGO N° :** 302
MATERIAL: 70 x 9 mm		**PROVEEDOR:** Jiangyin Xingcheng Special Steel
PROCEDENCIA: Shanghai - CHINA		**OF:** 174172
N° COLADA: - R31004822VX		**TIPO DE EVALUACION:** Evaluación de hoja rota por fatiga **(60 020 ciclos)**
O/C : 156/2010	**N° ATADO:** 822-13	Hoja con Shot Peening (En la parte central de la faja)

TRATAMIENTO TERMICO

CODIGO DE HOJA DE MUELLE: 2000-01A		**CODIGO DE LA PROBETA:** C 1		
ENSAYO DE TEMPLE	**TEMP.°C :** -	**TIEMPO PERMAN. :** -	**DUREZA (HB):**	438 - 440
ENSAYO DE REVENIDO	**TEMP.°C :** -	**TIEMPO PERMAN. :** -	**DUREZA (HB):**	-

EXAMEN METALOGRAFICO

SEGREGACIONES: No Presenta					**AUMENTO:**	100X
DESCARBURIZACIÓN: No Presenta					**AUMENTO:**	100X
INCLUSIONES NO METALICAS **NORMA ASTM E-45**	**OXIDO GLOB.:**D-2	**SILICATOS:**C-0.5	**ALUMINA:** -	**SULFURO:**	**AUMENTO:**	100X
	SERIE : Gruesa	**SERIE :** Fina	**SERIE :** -	**SERIE :** -		
TAMAÑO DE GRANO **NORMA ASTM E-112**	8				**AUMENTO:**	100X
MICROESTRUCTURA	**%PERLITA LAM.**	**% FERRITA**	**%MARTEN.**	**%C. CALCUL.**	**R. ATAQUE**	**AUMENTO**
	-	-	-	-	Picral	1000X

FOTO DE MICROESTRUCTURA	FOTO DE TAMAÑO DE GRANO	FOTO DE SECCION LONGITUDINAL
		

OBSERVACIONES:

. La muestra para la sección longitudinal se tomo de la parte central de la zona de rotura de la hoja de muelle.

. Tiene como microcontituyentes: Martensita Revenida

. Presenta tamaño de grano fino.

CONCLUSIONES:

. La hoja evidencia un tratamiento termico optimo sin descarburización y una microestructura de martensita revinida homogenea.OK.

. La probeta cumple con las especificaciones metalograficas

INSPECCIONADO POR: Ing.W. Magallanes H.	**REVISADO POR:** Bach.José Carlos Valdiviezo G.

INDUSTRIA PERUANA DEL ACERO S.A.
LABORATORIO DE CONTROL DE CALIDAD

ANALISIS METALOGRAFICO

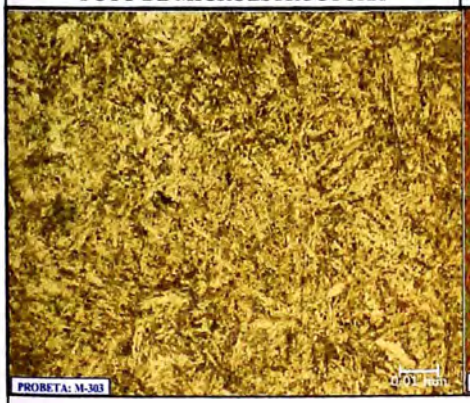
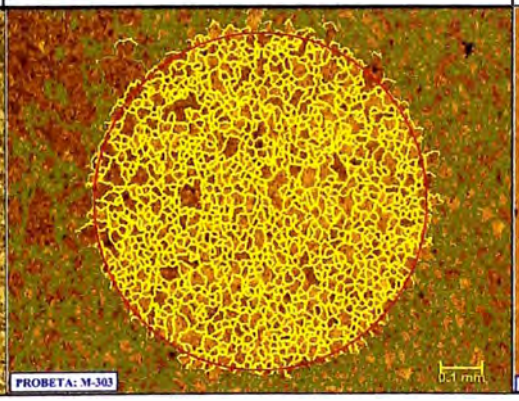
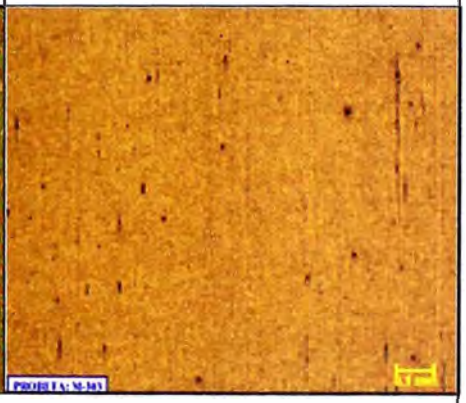
ANALISIS N°: 29/11Lab.	**FECHA:** 11/05/2011	**MUESTRA CODIGO N° :** 303
MATERIAL: 70 x 9 mm		**PROVEEDOR:** Jiangyin Xingcheng Special Steel
PROCEDENCIA: Shanghai - CHINA		**OF:** 174172
N° COLADA: - R31004822VX		**TIPO DE EVALUACION:** Evaluación de hoja rota por fatiga (**74 751 ciclos**)
O/C : 156/2010	**N° ATADO:** 822-13	Hoja con Shot Peening (En la parte central de la faja)

TRATAMIENTO TERMICO

CODIGO DE HOJA DE MUELLE: 2000-01A		**CODIGO DE LA PROBETA:** C 2		
ENSAYO DE TEMPLE	**TEMP.°C :** -	**TIEMPO PERMAN. :** -	**DUREZA (HB):**	415 - 415
ENSAYO DE REVENIDO	**TEMP.°C :** -	**TIEMPO PERMAN. :** -	**DUREZA (HB):**	-

EXAMEN METALOGRAFICO

SEGREGACIONES: No Presenta					**AUMENTO:**	100X
DESCARBURIZACIÓN: Presenta 0.071 mm de profundidad					**AUMENTO:**	100X
INCLUSIONES NO METALICAS **NORMA ASTM E-45**	**OXIDO GLOB.:**D-2	**SILICATOS:**C-1	**ALUMINA:** -	**SULFURO:**	**AUMENTO:**	100X
	SERIE : Fina	**SERIE :** Fina	**SERIE :** -	**SERIE :** -		
TAMAÑO DE GRANO **NORMA ASTM E-112**	8				**AUMENTO:**	100X
MICROESTRUCTURA	**%PERLITA LAM.**	**% FERRITA**	**%MARTEN.**	**%C. CALCUL.**	**R. ATAQUE**	**AUMENTO**
	-	-	-	-	Picral	1000X

FOTO DE MICROESTRUCTURA	FOTO DE TAMAÑO DE GRANO	FOTO DE SECCION LONGITUDINAL
		

OBSERVACIONES:

- La muestra para la sección longitudinal se tomo de la parte central de la zona de rotura de la hoja de muelle.
- Tiene como microcontituyentes: Martensita Revenida
- No presenta concentración de segregaciones bandeadas en su microestructura.
- Presenta tamaño de grano fino.

CONCLUSIONES:

- La hoja evidencia un tratamiento termico optimo una microestructura de martensita revinida homogenea.
- La probeta cumple con las especificaciones metalograficas

INSPECCIONADO POR: Ing.W. Magallanes H.	**REVISADO POR:** Bach.José Carlos Valdiviezo G.

CONCLUSIONES

1. El granallado es un tratamiento de deformación superficial en frio que sí aumenta la resistencia a la fatiga en las hojas de muelle tipo ballesta para uso automotriz.
2. La combinación de impactación y cobertura da diferentes niveles de aumento en la resistencia a la fatiga, tal es así, que si estos parámetros son muy bajos, el aumento a la resistencia es nulo.
3. La máquina granalladora impacta a las piezas puestas en el lado derecho, izquierdo y central con diferentes intensidades y coberturas de granallado, siendo la mejor de todas la encontrada en la parte central. Debido a ello, las piezas procesadas en diferentes posiciones de la granalladora tienen diferentes resistencias a la fatiga.

Código de probeta	Intensidad (Almen A)	Cobertura (%)	Cantidad de ciclos	Promedio	Aumento con respecto a las hojas sin granallar
1	-	-	33,225	31,873	-
2			30,521		
C1	0.44 mm	85	60,020	67,385.5	2.1
C2			74,751		
D1	0.22 mm	40	30,026	30,575.5	Ninguno
D2			31,125		
I1	0.27 mm	49	28,820	30,370	Ninguno
I2			31,920		

4. El aumento de la productividad no puede ser a costa de la calidad del producto, por tanto, las hojas de ballesta deben ser granalladas únicamente en la posición central de la faja transportadora, posición en donde siempre se debe medir la intensidad y cobertura del granallado.

5. En la actualidad los fabricantes de automóviles que usan mulles tipo ballesta, están reemplazando los muelles elípticos por parabólicos, porque dada su geometría:

   - El paquete de muelle parabólico armado, consta de menos hojas que un muelle elíptico para una misma constante de elasticidad y capacidad de carga.
   - Se disminuye la fricción entre hojas.
   - Da mayor confort y seguridad, ya que absorbe la energía cinética en forma más suave.

RECOMENDACIONES

1. Debido a que la tendencia mundial de los fabricantes de automóviles que utilizan muelles tipo ballesta, es utilizar muelles parabólicos, IPASA debe evaluar la factibilidad de fabricar estos tipos de muelles teniendo en cuenta que en la actualidad a nivel nacional y en los países a que exporta (Bolivia, Ecuador y Colombia) aún el mercado de muelles parabólicos es muy pequeño.

2. En IPASA, solamente la cara de la hoja de muelle que trabaja a tracción es sometida al granallado antes del proceso de pintado, por el contrario, la cara que trabaja a compresión es pintada sin ninguna preparación previa. Como mejora se recomienda que la cara que trabaja a compresión también se granalle antes del pintado, ya que el efecto secundario de este proceso es la limpieza de las superficies, es decir, la eliminación de óxidos y demás suciedades que no permiten una correcta adhesión de la pintura al acero. Vale la pena resaltar, que al granallar la cara que trabaja a compresión no se va a aumentar ni disminuir la resistencia a la fatiga, ya que las fisuras no se propagan en las superficies sometidas a compresión.

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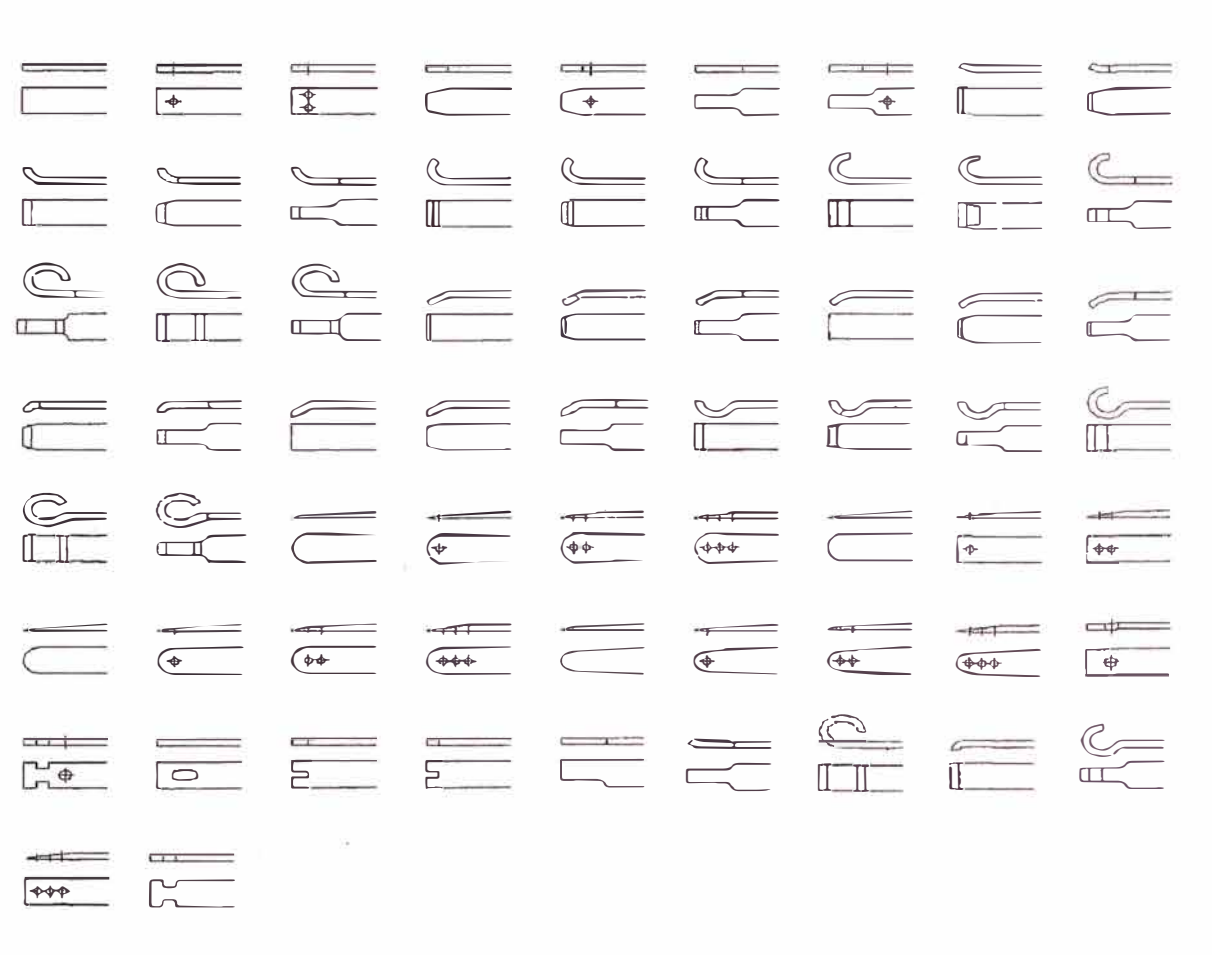
APÉNDICE A

TIPOS DE PUNTAS FABRICADAS POR IPASA

Tipos de Puntas Fabricadas Por IPASA



APÉNDICE B

SAE J419 DEC83

METHODS OF MEASURING DECARBURIZATION

3.12

Where greater accuracy than that obtainable by the comparison method is required, a quantitative grain count may be made either by the Jeffries' planimetric or Heyn's intercept method. Both methods are more accurate for a given microscopic field but are more laborious, particularly where a number of fields must be viewed because of variations in grain size within the specimen. Heyn's intercept method is particularly suitable where the grains are not equiaxed. (See ASTM E 112.)

5. Report—In reporting grain size, the test conditions should be stated, including the temperature and time used in establishing the austenite grain size, and the method of revealing the grain size.

6. Fracture Method—There are sets of fracture standards in which the grain size is judged from the appearance of the fracture. It has been found that the arbitrarily numbered fracture grain sizes agree very well with the arbitrarily numbered grain sizes presented in Plate Series I. This coincidence makes the fracture grain sizes interchangeable with the austenite grain sizes determined microscopically (except that "duplexing" or mixed grain size is not readily discernible in fractures). The sizes observed microscopically shall be considered the primary standard, since they can be determined with measuring instruments.

METHODS OF MEASURING DECARBURIZATION—SAE J419 DEC83

SAE Recommended Practice

Report of the Iron and Steel Technical Committee, approved May 1959, first revision, Division 3, December 1983.

1. Scope—This report covers the recommended practice for the evaluation and measurement of decarburization in ferrous material. Included are definitions of types with charts and micrographs and methods most commonly used for the measurement of decarburization.

2. Definition—Decarburization is the loss of carbon at the surface of commercial ferrous materials which have been heated for fabrication or when heated to modify mechanical properties.

2.1 Complete Decarburization—Complete loss of carbon as determined by examination.

2.2 Partial Decarburization—Any measurable loss of carbon content, less than complete, with respect to carbon level of base material.

2.3 Effective Decarburization—Any measurable loss of carbon content which results in mechanical properties below the minimum acceptable specifications for hardened material.

3. Types of Decarburization—Three general types of decarburization may be prevalent in ferrous materials dependent on manner and degree of carbon loss from the material. Classifying decarburization into three types may aid in selecting the process necessary to utilize the material to meet a product specification. Accompanying photomicrographs are illustrations of typical conditions which may be encountered.

3.1 Type 1 Decarburization—Indicated by the curve and photomicrographs in Fig. 1, covers that condition in which carbon free ferrite exists for a measurable distance below the surface. Underneath the ferrite will exist varying degrees of partial decarburization.

3.2 Type 2 Decarburization—Indicated by the curve and photomicrographs in Fig. 2, covers that condition in which there is a loss of more than 50% of the base carbon at the surface but where no measurable depth of complete decarburization is evident.

3.3 Type 3 Decarburization—Indicated by the curve and photomicrographs in Fig. 3, covers that condition where some loss of carbon at the surface is evident but to a degree less than 50% of the base carbon of the material.

3.3.1 Further subdividing of Type 3 Decarburization may be necessary for highly stressed members such as spring or high strength materials. In this category, the effective decarburization may be determined by microhardness testing for materials lower than 0.6% base carbon.

Chemical analysis procedures may be required when examining high carbon materials.

4. Methods of Measuring Decarburization—The common methods used for the measurement of decarburization are:

(a) microscopic;
(b) hardness, including cross section microhardness traverse, longitudinal traverse, and file hardness; and
(c) chemical analysis.

The accuracy of the method to be used is dependent on the degree decarburization, microstructure, and base carbon content of the steel. metallographic method is sufficiently accurate for most annealed hot rolled materials, but inaccurate for small amounts of decarburization in high carbon (above 0.60%), high hardness steels. The hardness thod is also insensitive in this latter case and recourse must be taken hemical analysis.

The file method is often suitable for detecting decarburization of hardened materials during shop processing but not for accurate measurement. is fundamental that true measure of decarburization lies in chemical lysis for carbon content. This method is normally used only in research stigations or to check accuracy of other methods. With the possible eption of specialized electron microprobe analytical techniques, which recommended when available, analysis is difficult and slow in applica- because of limitations of size and section of material. The method rocuring sample itself depends upon shape and hardness of test piece. ts and/or test specimens too hard to machine should be tempered 00 to 650°C (1100 to 1200°F) to permit machining of surface layers chips for subsequent carbon analysis. Obviously, a sample which is ealed to permit milling of chips may be modified in its condition of arburization. Standard methods for carbon determination are debed in textbooks of analytical chemistry.

4.1 Microscopic Method

.1.1 SPECIMEN—The area to be examined should be cut at right angles he surface. Samples are preferably taken when the material is in full ealed or in hot rolled condition. Other conditions, such as spheroidd annealed, hardened, or cold worked material, may be examined but e must be used in interpretation. For sections up to 13 mm (½ in), entire cross section is normally mounted for examination. For larger tions, a specimen should be cut to include about 19 mm (¾ in) of surface to be examined. Corners of straight sided sections should t be included, since they are not considered representative.

.1.2 PREPARATION—In mounting the specimen for grinding and polish-, protection from rounding the surface to be examined is essential. e specimen should be mounted in a clamp or in a plastic mount, the ter being the preferred method. An additional method of protection to deposit (by electroless or electroplating) a metallic coating of 0.03–)8 mm (0.001–0.003 in) on the specimen before mounting.

After mounting, the surface should be ground and polished in accorhce with good metallographic practice.

Etching in a 3% nital (concentrated nitric acid in alcohol) is usually itable for showing changes in microstructure caused by decarburization.

4.1.3 MEASUREMENT—Magnification for examination can be agreed on tween purchaser and producer. However, it is recommended that 0 × magnification be used. If the microscope is of a type with a ground ass screen, the extent of decarburization can be measured directly with scale. If an eyepiece is used for measurement, it should be an appropriate pe containing a cross hair or a scale.

4.2 Hardness Methods

4.2.1 CROSS SECTION MICROHARDNESS TRAVERSE

4.2.1.1 *Specimen*—Sample to be checked should be cut at right angles to the surface. If cross section is too large, a portion of suitable size including surface to be checked should be cut before examination.

4.2.1.2 *Preparation*—The specimen shall be hardened by quenching from equipment under conditions which minimize further change in carbon distribution. The time at temperature should be minimized to avoid excessive carbon diffusion. In the case of finished parts, which have been previously quenched and tempered, no further treatment is necessary. For sections up to 13 mm (½ in), the entire cross section is normally Φ mounted in plastic. After mounting, the surface should be ground and polished in accordance with good metallographic practice.

4.2.1.3 *Measurement*—A series of microhardness impressions made by pyramidal or Knoop indentors should be extended from the surface until the hardness of the base metal is obtained.

4.2.2 LONGITUDINAL TRAVERSE (TAPER OR STEP GRIND)

4.2.2.1 *Specimen*—A specimen containing the surface on which decarburization is to be measured is prepared so that it can be manipulated on a superficial hardness tester.

4.2.2.2 *Preparation*—If the specimen is not in the hardened condition, it is recommended that it be hardened by quenching from heating equipment under conditions which avoid further change in carbon distribution.

For the taper grind specimen, a shallow taper is ground through the decarburized layer, see SAE Recommended Practice, Methods of Measuring Case Depth—SAE J423. The angle is chosen so that hardness readings spaced equal distances apart will represent the hardness at the desired increments below the surface. Unless special anvils are used on the hardness tester, a parallel section should be prepared so that indentations will be at right angles to the tapered surface.

For the step grind procedure, flats are ground at predetermined intervals below the original surface. These flats should have sufficient area to allow several hardness readings to be taken on each flat.

4.2.2.3 *Measurement*—A superficial hardness tester such as a Rockwell Superficial or Vickers Tester using a light load should be employed in making the hardness measurements. The depth of decarburization is defined as the distance measured from the nearest original surface to the point at which no increase in hardness is found.

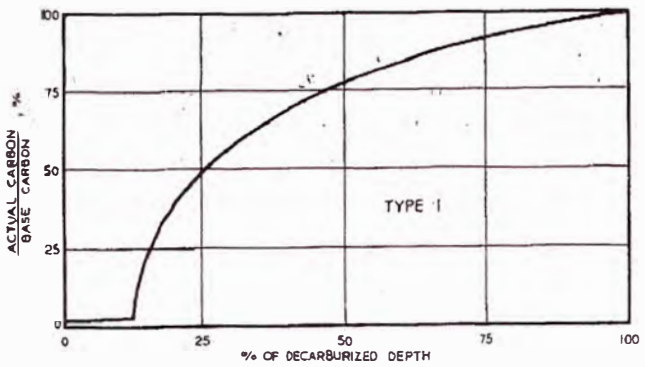
4.2.3 FILE METHOD

4.2.3.1 *Specimen*—A specimen of suitable size is obtained from the desired location.

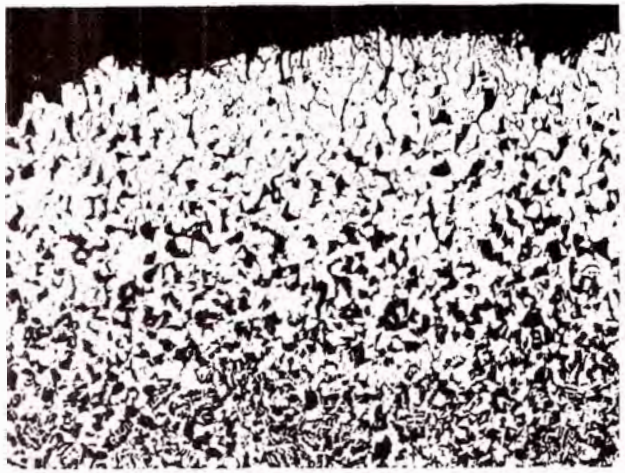
4.2.3.2 *Preparation*—The specimen shall be hardened by quenching from heating equipment under conditions which avoid further decarburization.

4.2.3.3 *Measurement*—After hardening, the sample is filed. Base metals expected to harden to above 60 HRC and found to be file soft are probably decarburized. Decarburization of base metals that will not harden to 60 HRC cannot be detected by this method unless specially prepared files are used. The extent and severity of any decarburization detected by this method should be verified by either of the other two methods.

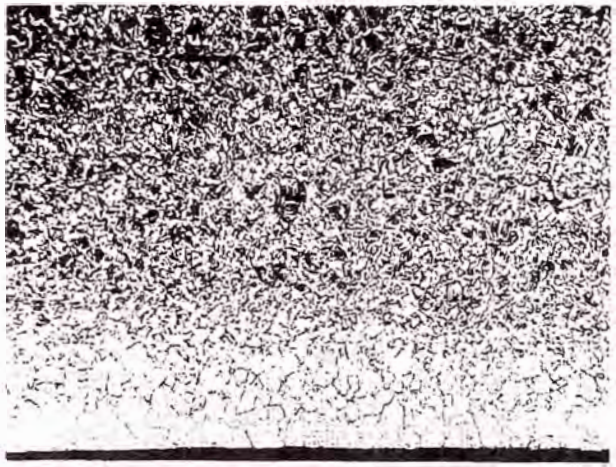
4.3 Chemical Analysis—Procedure is the same as SAE J423.



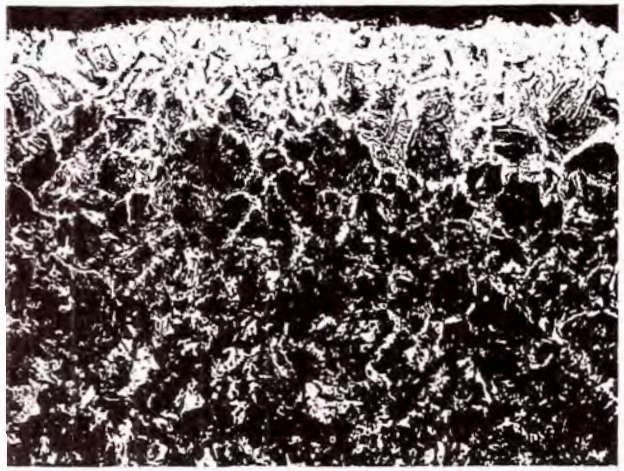
TYPE 1 DECARBURIZATION CURVE



MEDIUM CARBON STEEL



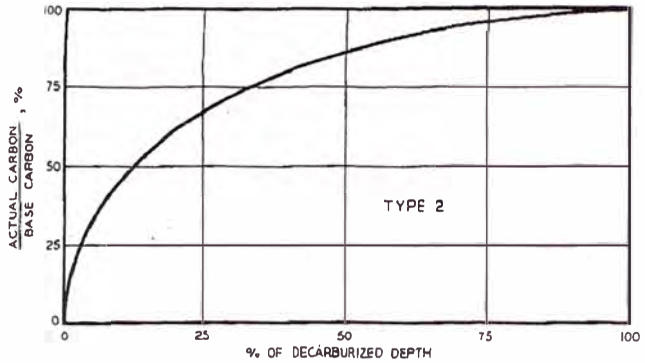
LOW CARBON STEEL



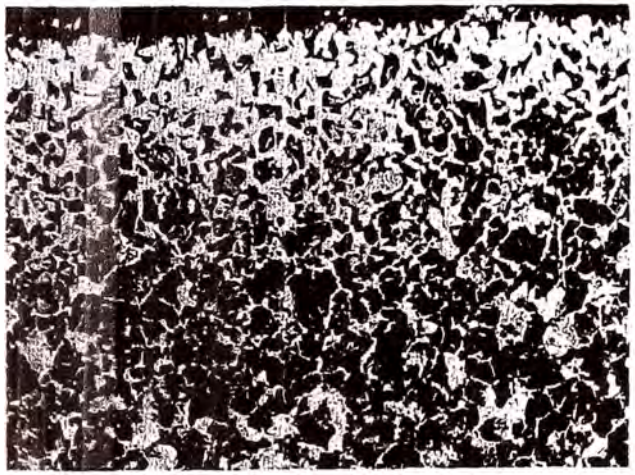
HIGH CARBON STEEL

Magnification 100 X—Nital Etch

ϕ FIG. 1—TYPE 1 DECARBURIZATION



TYPE 2 DECARBURIZATION CURVE



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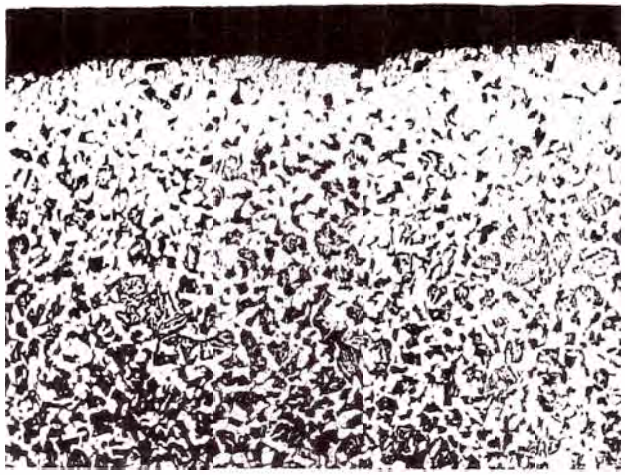
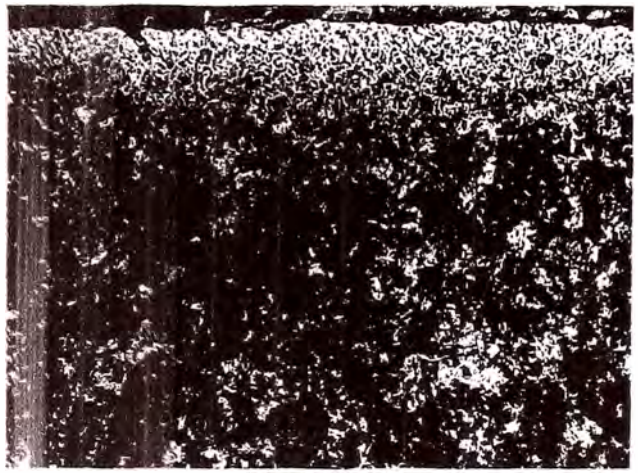


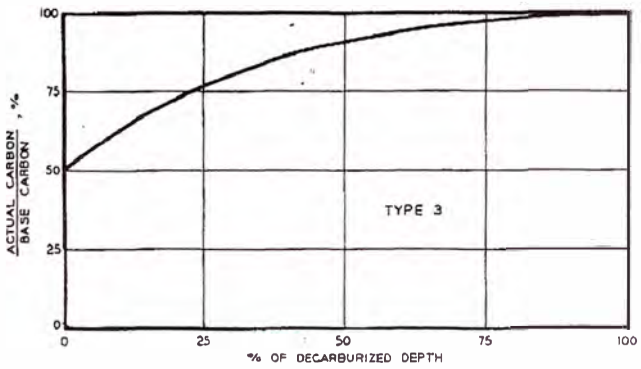
LOW CARBON STEEL



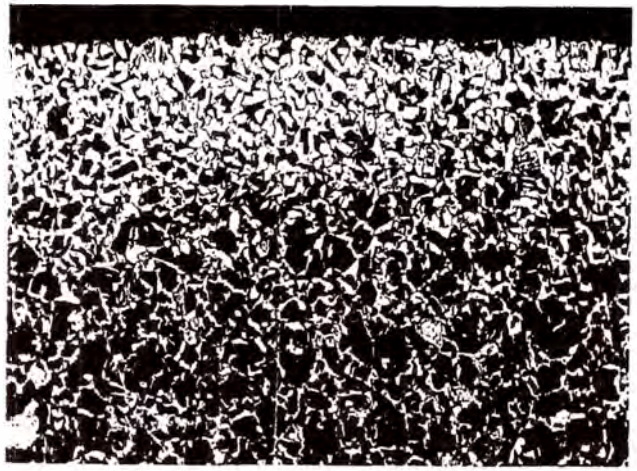
HIGH CARBON STEEL

Magnification 100 X—Nital Etch

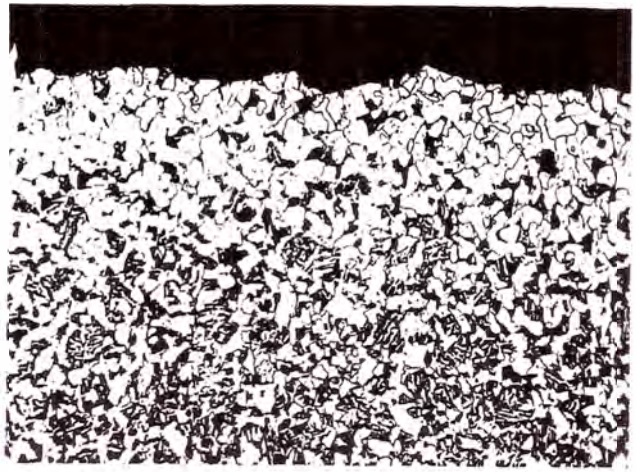
FIG. 2—TYPE 2 DECARBURIZATION



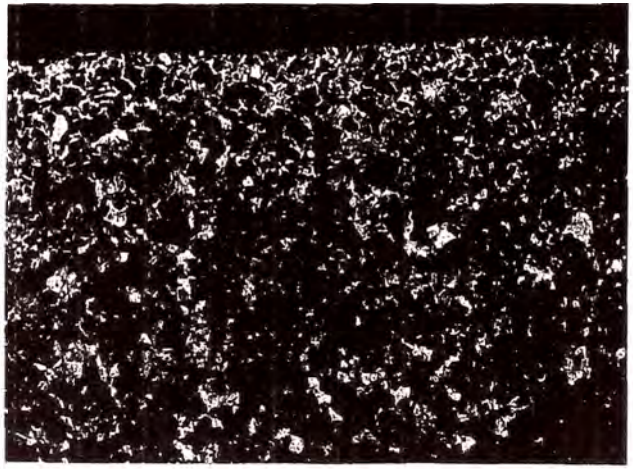
TYPE 3 DECARBURIZATION CURVE



MEDIUM CARBON STEEL



LOW CARBON STEEL



HIGH CARBON STEEL

Magnification 100 X—Nital Etch

FIG. 3—TYPE 3 DECARBURIZATION

APENDICE C

ASTM E45 - 87

STANDART PRACTICE FOR DETERMINATION THE INCLUSION CONTENT OF STEEL

Designation: E 45 – 87

Standard Practice for Determining the Inclusion Content of Steel[1]

This standard is issued under the fixed designation E 45; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This practice has been approved for use by agencies of the Department of Defense as part of Federal Test Method Standard No. 151b and for listing in the DoD Index of Specifications and Standards.

1. Scope

1.1 This practice[2] covers the recognized methods for determining the nonmetallic inclusion content of steel. Macroscopic methods include macroetch, fracture, step-down, and magnetic particle tests. Microscopical methods include four generally accepted systems of examination. In these microscopical methods, inclusions are assigned to a category based on similarities in morphology, and not necessarily on their chemical identity. Inclusions such as carbides, nitrides, carbonitrides, borides, and intermetallic phases may not be rated using these methods.

1.2 Depending on the type of steel and the properties required, either a macroscopic or a microscopical method for determining the inclusion content, or combinations of the two methods, may be found most satisfactory.

1.3 This practice deals only with recommended test methods and nothing in it should be construed as defining or establishing limits of acceptability for any grade of steel.

1.4 The contents appear in the following order:

1.5 Values stated in inch-pound units are to be regarded as the standard. SI units are provided for information only.

1.6 *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

A 295 Specification for High-Carbon Ball and Roller-Bearing Steel[3]

D 96 Test Method for Determination of Sediment and Water in Crude Oil by the Centrifuge Method[4]

E 3 Methods of Preparation of Metallographic Specimens[5]

E 381 Method of Macroetch Testing, Inspection, and Rating Steel Products, Comprising Bars, Billets, Blooms, and Forgings[6]

E 709 Practice for Magnetic Particle Examination[7]

2.2 *Society of Automotive Engineers:*

2.2.1 *SAE Handbook:*

J422, Recommended Practice for Determination of Inclusions in Steel[8]

2.2.2 *Aerospace Material Specification:*

2301, Aircraft Quality Steel Cleanliness: Magnetic Particle Inspection Procedure[8]

2.3 *Adjuncts:*

Inclusions in Steel Plates I, II, and III[9]

Four Photomicrographs of Low Carbon Steel[10]

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[1] This practice is under the jurisdiction of ASTM Committee E-4 on Metallography and is the direct responsibility of Subcommittee E04.09 on Inclusions.

Current edition approved Aug. 28, 1987. Published October 1987. Originally published as E 45 – 42 T. Last previous edition E 45 – 85.

[2] Supporting data are available from ASTM Headquarters. Request RR: E04-1000.

[3] *Annual Book of ASTM Standards*, Vol 01.05.

[4] *Annual Book of ASTM Standards*, Vol 05.01.

[5] *Annual Book of ASTM Standards*, Vol 03.01.

[6] *Annual Book of ASTM Standards*, Vols 01.05 and 03.01.

[7] *Annual Book of ASTM Standards*, Vol 03.03.

[8] Available from the Society of Automotive Engineers, 400 Commonwealth Drive, Warrendale, PA 15096.

[9] Available from ASTM Headquarters. Order PCN 12-500450-01.

[10] Available from ASTM Headquarters. Order PCN 12-500454-01.

3. Significance and Use

3.1 These methods cover four macroscopical and four microscopical test methods for describing the inclusion content of steel and procedures for expressing test results.

3.2 Inclusions are characterized by their size, shape, concentration, and distribution rather than their chemical composition. Only those inclusions present at the test surface can be detected.

3.3 The macroscopical test methods evaluate a larger surface area than microscopical test methods, and, because examination is visual or at low magnifications, these methods are best suited for detecting the larger inclusions that may be present in the steel. Macroscopical methods are not suitable for detecting inclusions smaller than about 1/64 in. (0.40 mm) in length and the methods do not discriminate inclusions by type.

3.4 The microscopical test methods are employed to characterize inclusions that form as a result of deoxidation or due to limited solubility in solid steel (indigenous inclusions). These inclusions are characterized by morphological type, that is, by size, shape, concentration, and distribution, but not specifically by composition. The microscopical methods are not intended for assessing the content of exogenous inclusions (those from entrapped slag or refractories), nor for rating the content of carbides, carbonitrides, nitrides, borides, or intermetallic phases.

3.5 Because the inclusion population within a given lot of steel varies with position, the lot must be statistically sampled in order to assess its inclusion content. The degree of sampling must be adequate for the lot size and its specific characteristics.

3.6 Results of macroscopical and microscopical test methods may be used to qualify material for shipment, but these test methods do not provide guidelines for acceptance or rejection purposes. Qualification criteria for assessing the data developed by these methods can be found in other ASTM standards or may be described by purchaser-producer agreements.

MACROSCOPIC METHODS

4. Test Methods

4.1 *Summary:*

4.1.1 *Macroetch Test*—The macroetch test is used to indicate inclusion content and distribution, usually in the cross section or transverse to the direction of rolling or forging. In some instances, longitudinal sections are also examined. Tests are prepared by cutting and machining a section through the desired area and etching with a suitable reagent. A solution of one part hydrochloric acid and one part water at a temperature of 160 to 180°F (71 to 82°C) is widely used. As the name implies, the etched surface is examined visually or at low magnification for inclusions. Details of this test are included in Method E 381. The nature of questionable indications should be verified by microscopical or other means of inspection.

4.1.2 *Fracture Test*—The fracture test is used to determine the presence and location of inclusions as shown in the fracture of hardened slices approximately 3/8 to 1/2 in. (9.5 to 12.7 mm) thick. This test is used mostly for steels where it is possible to obtain a hardness of approximately 60 HRC and a fracture grain size of 7 or finer. Tests should not have excessive external indentations or notches which might guide the fracture. It is desirable that fractures be in the longitudinal direction approximately across the center of the slice. The fractured surfaces are examined visually and at magnifications up to approximately 10 diameters and the length and distribution of inclusions noted. In some instances, indications as small as 1/64 in. (0.40 mm) in length are recorded.

4.1.3 *Step-Down Method*—The step-down test method is used to determine the presence of inclusions on a machined surface of rolled or forged steel. The test sample is machined to specified diameters below the surface and surveyed for inclusions under good illumination with the unaided eye or with low magnification. In some instances, test samples are machined to smaller diameters for further examination after the original diameters are inspected. This test is essentially used to determine the presence of inclusions 1/8 in. (3.18 mm) in length and longer.

4.1.4 *Magnetic Particle Method*—The magnetic particle method is a variation of the step-down method for ferromagnetic materials in which the test sample is machined, magnetized, and magnetic powder applied. Discontinuities as small as 1/64 in. (0.40 mm) in length create magnetic leakage fields which attract the magnetic powder, thereby outlining the inclusion. See Section 5.

4.2 The advantages of the macroscopic methods are:

4.2.1 They enable the examination of specimens with large surface areas. The larger inclusions in steel, which are the main concern in most cases, are not uniformly distributed and the spaces between them are relatively large, so that the chances of revealing them are better when large specimens are examined.

4.2.2 Specimens for macroscopic examination may be quickly prepared by machining and grinding. A highly polished surface is not necessary. The macroscopic methods are amply sensitive to reveal the larger inclusions.

4.3 The disadvantages of the macroscopic methods are:

4.3.1 They do not distinguish between the different types of inclusions such as sulfides, silicates, and oxides.

4.3.2 They are not suitable for the detection of small globular inclusions or of chains of very fine elongated inclusions.

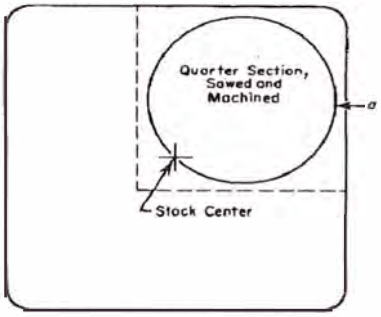
5. Magnetic Particle Method

5.1 *Test Specimens:*

5.1.1 The specimens shall be prepared in accordance with the details given in 5.2. The recommended procedure for developing the specimens from blooms, billets, and bars in round or square sections, is as follows:

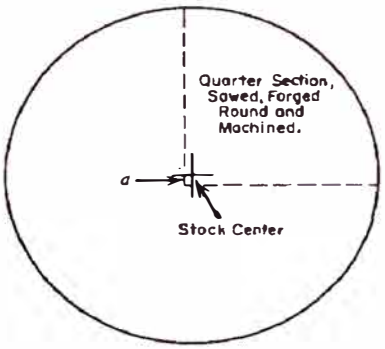
5.1.1.1 *Cross Section over 36 in.² (232 cm²)*—Cut a quarter section as shown in Fig. 1 or 2 and develop the specimen by machining, or forging and machining, to a straight cylinder of a diameter between 2½ and 6 in. (63.5 and 152 mm). An alternative method is to forge or roll the full section to 6-in. (152-mm) square or round and machine the quarter section in accordance with 5.1.1.2.

5.1.1.2 *Cross Section 16 to 36 in.² (103 to 232 cm²), inclusive*—Cut a quarter section as shown in Fig. 1 or 2 and develop the specimen by machining, or forging and machining, to a straight cylinder of the largest possible diameter.



a, denotes surface removal.
NOTE—This method is also applicable to round sections.

FIG. 1 Quarter Section Specimen from Square Section for Magnetic-Particle Test, Machine Only



a, denotes distance equal to surface removal.
NOTE—Method also applicable to square sections.

FIG. 2 Quarter Section Specimen from Round Section for Magnetic Particle Test, Forging and Machining

5.1.1.3 *Cross Section Less than 16 in.² (103 cm²)*—Machine the specimen to a straight cylinder. An alternative method is to use a three-step step-down specimen, each step being 3 in. (76 mm) in length. The diameter, *D*, of the first step is the stock size less standard removal allowance; the diameter of the second step is ¾ *D*; and the diameter of the third step is ½ *D*.

5.1.2 The specimens shall conform to the following requirements unless specified otherwise in 5.1.1.1 through 5.1.1.3:

5.1.2.1 The length of the rated surface is nominally 5 in. (127 mm). A 1-in. (25.4-mm) extension for holding is usually employed.

5.1.2.2 The minimum amount of stock removed from the surface shall be as follows:

Nominal Stock Size, Round or Square, in. (mm)	Minimum Stock Removal from the Surface, in. (mm)
To ½ (12.7)	0.030 (0.76)
Over ½ to ¾ (12.7 to 19)	0.045 (1.13)
Over ¾ to 1 (19 to 25.4)	0.060 (1.52)
Over 1 to 1½ (25.4 to 38)	0.075 (1.89)
Over 1½ to 2 (38 to 51)	0.090 (2.28)
Over 2 to 2½ (51 to 64)	0.125 (3.17)
Over 2½ to 3½ (64 to 89)	0.156 (3.96)
Over 3½ to 4½ (89 to 115)	0.187 (4.75)
Over 4½ to 6 (115 to 152)	0.250 (6.35)

5.1.2.3 All quarter sections shall be cut oversize as shown in Figs. 1 and 2 so that the center of the original stock will be approximately on the surface of the test specimen. The location of the center of the original stock shall be identified on the test specimen.

5.2 *Preparation of Specimen:*

5.2.1 After the specimen is rough turned, heat treat it to a hardness of about 300 HB by oil or water quenching from well above the critical temperature and temper within the range 400 to 1200°F (204 to 649°C), depending upon the composition of the steel. Take care to avoid quenching cracks. The heat treatment tends to develop a more uniform structure hard enough to retain some residual magnetism, thus helping to hold the magnetic powder in place after test.

5.2.2 After heat treatment, grind the specimen, including the ends, or otherwise clean to ensure good contact for magnetizing. Take care to avoid grinding checks during the grinding. The grinding shall be transverse to the length of the specimen. Longitudinal grinding scratches may be deep enough to retain the magnetic powder and confuse the inclusion determination.

5.2.3 Before magnetizing, thoroughly wash the specimen with some quick-drying solvent in order to remove all grease and finger marks.

5.3 *Procedure:*

5.3.1 Circularly magnetize the specimen by passing direct current through it in the longitudinal direction for ⅛ to ½ s. The magnitude of the current shall be 400 to 1200 A/in. (157 A/cm to 472 A/cm) of the diameter of the specimen.

5.3.2 In general, use the wet continuous method (Note 1) when the specimen is covered with magnetic particle suspension during magnetization. Hardened steel specimens (50 HRC or higher) may be tested using the wet residual method by applying the suspension after magnetization. Take care not to disturb indications before inspection is completed.

NOTE 1—For a detailed description of the various wet methods of magnetic particle inspection, see Practice E 709.

5.3.3 It is the usual practice to suspend the finely divided magnetic particles in kerosine or other light oil of about 40 SUS viscosity. Use about 1 oz of nonfluorescent magnetic particles to 1 gal (7.7 g/L) of oil. The suspension concentration of nonfluorescent particles shall be 1.0 to 2.0 % by volume when tested by demagnetizing and allowing to settle 30 to 45 min in an ASTM 100-mL cone-shaped graduated centrifuge tube.

NOTE 2—For a description of a cone-shaped centrifuge tube, see Test Methods D 96.

5.4 *Examination of Specimen:*

5.4.1 Examine the specimen under a well-diffused light. The standard white fluorescent light is satisfactory. In order

to obtain the best dispersion, place the longitudinal axis of the light at right angles to the longitudinal axis of the specimen. The larger inclusions will be plainly visible and the relatively small inclusions may also be detected. If inclusions of 1/32 in. (0.8 mm) or smaller are of interest, it will be helpful to use a low-power hand magnifying glass. The magnetic powder indications produced by inclusions can be distinguished by an experienced operator from indications due to other causes, such as cracks, flow lines, carbides, etc. Record the size of each inclusion appearing on the surface of the specimen.

5.4.2 The indications representing inclusions may be recorded by photographing, drawing a diagram, or transferring to a receptor medium. One such medium is specially prepared absorbent paper, known as imbibition paper. Another is a solution of plastic coating material, usually applied by aerosol means. The plastic film is removed and mounted after drying. Ordinary transparent adhesive tapes will also lift the magnetic powder from the specimen, for mounting on a card. The transfer methods are rapid, sufficiently accurate to be examined under low-power magnification, and are more accurate than photography on curved surfaces. Additionally, the imbibition paper and plastic aerosol methods maintain the locations of indications in the specimen with respect to the original surface and centerline of the material.

5.5 *Expression of Results:*

5.5.1 Magnetic particle test results are normally expressed in terms of frequency and severity.

5.5.2 Frequency is the total number of indications in a given area. A common area has been 40 in.^{2} (258 cm^2). Frequency may also be expressed in terms of number of indications per unit area of surface examined.

NOTE 3—The method of evaluating inclusions per square inch for frequency and severity has been adopted by the Society of Automotive Engineers. Refer to Aeronautical Materials Specification 2301.

5.5.3 Severity is the weighted value of the magnetic particle indications in accordance with the following table taken from AMS 2301:

Length of Inclusions, in. (mm)	Weight Factor
Over 1/16 to 1/8 (1.6 to 3.2)	0.5
Over 1/8 to 1/4 (3.2 to 6.4)	1
Over 1/4 to 1/2 (6.4 to 12.7)	2
Over 1/2 to 3/4 (12.7 to 19.1)	4
Over 3/4 to 1 (19.1 to 25.4)	8
Over 1 (25.4)	16

5.5.3.1 The severity value is obtained by multiplying the number of indications of a given length by the weight factor and adding these results. Severity should be expressed as the weighted value for a given area. A common area has been 40 in.^{2} (258 cm^2). Severity may also be expressed as the weighted value per unit area of surface examined (see AMS 2301).

5.5.4 The averages of the frequency and severity values for all of the specimens in a heat may be used to express the magnetic particle results for the heat.

5.5.5 The frequency and severity values for one heat may be readily compared with the values of another heat. In making such comparisons between heats, however, care should be taken to compare only results obtained on billets or bars of approximately the same size.

5.5.6 If a step-down test is used, results should be related to the individual diameters.

5.5.7 Magnetic particle results may also be expressed as the total length of indications for a stated area or per square inch.

MICROSCOPICAL METHODS

6. Background

6.1 Microscopical methods are used to determine the size, distribution, number, and type of inclusions. This can be done by the usual procedure of examining specimens with the microscope and describing the results of the metallographic study in a report which may be illustrated by representative photomicrographs. To save time, and to express such results more uniformly, it has been found useful to refer to charts of representative photomicrographs.

6.2 Various reference charts of this nature have been devised, such as the JK chart[11] (Method A), the modified JK chart (Method D), and the SAE chart found in SAE Recommended Practice J422 of the *SAE Handbook* (Method C). The modified JK chart for Method D has been designed primarily for low inclusion content steels. In both JK charts, the thin and heavy series of inclusions are shown to scale, and the nominal thicknesses of the inclusions are also recorded above each column. These values for the thicknesses of inclusions are not intended to be exact but only to permit approximate classifications. In the SAE charts, the inclusions are compared to a series of oxide and silicate-type inclusions and the classification based essentially on length.

6.3 No chart can represent all of the various types and forms of inclusions. The use of any chart is thus limited to determining the content of the most common types of inclusions and it must be kept in mind that such a determination is not a complete metallographic study of inclusions.

6.4 Another microscopical method for determining the inclusion content is the unit method (Method B), which is based on counting inclusions over 0.005 in. (0.127 mm) long and obtaining the length of the longest inclusion, average length, and a background condition. This does not distinguish between the different types of inclusions. It has been widely used as a count or quantitative method, as opposed to the usual qualitative methods.

6.5 The advantages of the microscopical methods are:

6.5.1 The character or type of inclusions can be determined.

6.5.2 Extremely small inclusions can be revealed.

6.6 A disadvantage of the microscopical method is that specimens are necessarily limited in size. The areas between the larger inclusions in the steel may be considerably larger than the area of the polished section of the specimen. Thus, the result obtained by a microscopical examination for the inclusions may be governed very largely by chance if an insufficient number of specimens is taken. The end use of the steel determines the significance of the microscopical results. Experience in interpreting these results is necessary in

[11] The JK chart derives its name from its sponsors Jernkontoret, the Swedish Ironmasters Association.

order not to exaggerate the importance of small inclusions in some applications.

6.7 In determining the inclusion content, it is important to realize that, whatever method is used, the result actually applies only to the areas of the specimens that are examined. For practical reasons such specimens are relatively small compared to the total amount of steel represented by them. For the inclusion determination to have any value, adequate sampling is just as necessary as a proper method of testing.

6.8 Steel often differs in inclusion content not only from heat to heat, but also from ingot to ingot in the same heat, and even in different portions of the same ingot. It is advisable that the unit lot of steel, the inclusion content of which is to be determined, shall not be larger than one heat. Sufficient samples should be selected to represent the lot adequately. The exact sampling procedure should be incorporated in the individual product requirements or specification. For semifinished products, the specimens should be selected after the material has been sufficiently cropped and suitable discards made. If the locations of the different ingots and portions of ingots in the heat cannot be identified in the lot being tested, random sampling should involve a greater number of test specimens for an equivalent weight of steel. A value for the inclusion content of an isolated piece of steel, even if accurately determined, should not necessarily be expected to represent the inclusion content of the whole heat.

6.9 The size and shape of the steel product tested has a marked influence on the size and shape of the inclusions. During reduction from the ingot by rolling or forging, the inclusions are elongated and broken up according to the degree of reduction of the steel cross section. In reporting results of inclusion determinations, therefore, the size, shape, and method of manufacture of the steel from which the specimens were cut should be stated. In comparing the inclusion content of different steels, they should all be rolled or forged as nearly as possible to the same size and shape, and from ingots of about the same size. Specimens cut lengthwise or parallel to the direction of rolling or forging should be used.

6.10 It may be convenient, in order to obtain more readily comparable results, to forge specimen lengths from the larger billets. These forged sections may then be sampled in the same way as rolled sections. Care must be taken, however, to crop specimens of sufficient length from the billets for forging; otherwise, there is danger of the shear-dragged ends being incorporated in the specimens. Such distorted material will give a false result in the inclusion determination. To avoid this, it is helpful to saw the ends of the billet length for forging and to take the specimen from the middle of the forged length.

6.11 In all of the various methods described in this practice, the whole area of the prepared surface of the specimen is surveyed, and all of the significant inclusions observed are recorded and expressed in the results. The result for each specimen examined is, therefore, a more accurate representation of the inclusion content than a photomicrograph or diagram.

6.12 To make comparisons possible between different heats and different parts of heats, the results should be expressed in such a manner that an average for the inclusion content of the different specimens in the heat can be obtained. When the lengths of the inclusions are measured, the simplest number is that for the aggregate length of all the inclusions per area examined. However, it may be desirable not merely to add the lengths, but also to weight the inclusions according to their length. The length of the largest inclusion found and the total number of inclusions may also be expressed.

7. Sampling

7.1 To obtain a reasonable estimate of inclusion variations within a lot, at least six locations, chosen to be as representative of the lot as possible, should be examined. In this context, a lot shall be defined as a unit of material processed at one time and subjected to similar processing variables.

NOTE 4—For example if a lot consists of one heat, sampling locations might be in the product obtained from the top and bottom of the first, middle, and last usable ingots in the pouring sequence. For strandcast or bottom pour processing a similar sampling plan per heat should be invoked.

7.2 In cases where a definite location within a heat, ingot, or other unit lot is unknown, statistical random sampling with a greater number of samples should be employed.

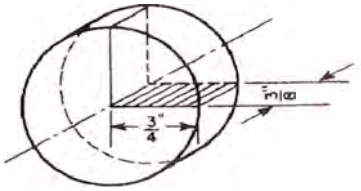
8. Test Specimen Geometry

8.1 The polished surface of a specimen for the microscopical determination of the inclusion content should be approximately 0.25 in.^{2} (160 mm^2) (0.375 by 0.75 in. (9.5 by 19 mm)). The polished surface should be parallel to the longitudinal axis of the product. In addition, for flat-rolled products, the section should also be perpendicular to the rolling plane; for rounds and tubular shapes, the section should also be in the radial direction.

8.2 *Thick Sections (Product Section Sizes Greater than 0.375 in. (9.5 mm) Thick, Such as Forgings, Billet, Bar, Slab, Plate, and Pipe):*

8.2.1 For wide products, each specimen should be taken from the one-quarter point along the product width.

8.2.2 For round sections, the manner of cutting a specimen from a 1.5-in. (38-mm) diameter section is shown in Fig. 3. A disk 0.375 in. (9.5 mm) thick is cut from the product. The quarter-section indicated in Fig. 3 is cut from the disk and the shaded area is polished. Thus the specimen extends 0.375 in. along the length of the product, and from the outside to the center.



Metric Equivalents: ⅜ in. = 9.5 mm; ¾ in. = 19 mm.

FIG. 3 Specimen from 1½-in. (38.1 mm) Round Section for Microscopical Test

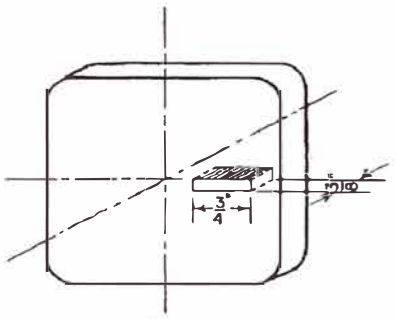


FIG. 4 Specimen from Large Bar or Billet for Microscopical Test

8.2.3 For large sections, each specimen should be taken from the mid-radius location, as shown by the shaded area in Fig. 4. The specimen face to be polished extends 0.375 in. (9.5 mm) parallel to the longitudinal axis of the billet and 0.75 in. (19 mm) in the longitudinal radial plane, with the polished face midway between the center and the outside of the billet. Such midway sampling is used to decrease the number of specimens polished and examined. Other areas, such as the center and the surface, may be examined as well, provided the sampling used is stated in the results. A billet or bar about 2 to 4-in. (50 to 100-mm) round or square is the preferred size from which specimens should be taken. However, larger or smaller sizes may be used, provided the product sizes are reported with the results.

8.3 *Thin Sections (Product Section Sizes 0.375 in. (9.5 mm) Thick or Less, Such as Strip, Sheet, Rod, Wire, and Tubing)*—Full cross section longitudinal specimens shall be cut in accordance with the following plan:

8.3.1 For 0.0375 to 0.375-in. (0.95 to 9.5-mm) cross section thicknesses inclusively, a sufficient number of pieces from the same sampling point are mounted to provide approximately 0.25 in.^{2} (160 mm^2) of polished specimen surface. (Example: For a sheet 0.050 in. (1.27 mm) thick, select 7 or 8 longitudinal pieces uniformly across the sheet width to provide one specimen.)

8.3.2 For cross section thicknesses less than 0.0375 in. (0.95 mm), ten longitudinal pieces from each sampling location shall be mounted to provide a suitable specimen surface for polishing. (Dependent on material thickness and piece length, the polished specimen area may be less than 0.25 in.^{2} (160 mm^2). Because of practical difficulties in mounting a group of more than ten pieces, the reduced specimen area will be considered sufficient.)

9. Preparation of Specimens

9.1 Methods of specimen preparation must be such that the section plane is flat, on both macroscopic and microscopic scales, and the size and shape of inclusions or other structural details are accurately shown. To obtain satisfactory and consistent inclusion ratings, the specimen must have a polished surface free of artifacts such as pitting, foreign material (for example, polishing media), and scratches. In polishing the specimen it is very important that the inclusions not be pitted, dragged, or obscured. Specimens must be examined in the as-polished condition, free of the effects of any prior etching (if used). It is recommended that the procedure described in Methods E 3 be followed.

9.2 If the conditions for inclusion evaluation stated in 8.1 cannot be met in the as-polished condition with the as-received sample, the sample shall be heat-treated to the maximum attainable hardness before polishing. Necessary precautions shall be taken to eliminate the effects of heat treatment such as scale, decarburization, etc. (This practice is recommended for heat-treatable grades of carbon, low-alloy, and stainless steels.)

10. Precision and Bias

10.1 Studies of JK ratings made by different laboratories have shown that there is an inherent problem in inclusion identification, chiefly in discrimination between A (sulfides) and C (silicate) deformable inclusions. Hence, the accuracy of JK ratings can be severely influenced by such problems. The accuracy of both Method A and Method D, as well as Method C ratings, is influenced also by the total inclusion content. As the inclusion content increases, the accuracy of such ratings decreases. For steels that are rateable using Plate III, worst field ratings are generally accurate within ±1 severity number and may be within ±0.5 severity at low-inclusion content. In general, the accuracy of ratings of Type B and D inclusions are better than for Type A and C inclusions. Also, the accuracy of the thin series are generally better than for the thick series regardless of the inclusion type. For steels that must be rated using Plate I, the accuracies are generally poorer, approaching ±2 at the higbest severity levels. The same trends apply here regarding A and C versus B and D Types and thin versus thick. Greater inaccuracies will occur if inclusions are misidentified. The accuracy of inclusion × field counts using Method D is not as good as for the worst field ratings. A good, accurate Method D rating does require considerable effort. The accuracy of Method C ratings is significantly influenced by misidentification of S type (deformable oxides) inclusions. When such problems are not encountered, steels with low-inclusion contents will agree within ±1 unit, while steels with high-inclusion content generally agree within ±2 units of severity. Method C, Plate II, is only used to rate oxides, never sulfides. The precision of ratings made by the use of Plates I to III generally agrees with the chart severity increments, but may in certain cases be slightly higher.

11. Method A[12]

11.1 *Procedure:*

11.1.1 Survey the entire surface (approximately 0.25 in.^{2} (160 mm^2) of the polished specimen at a magnification of 100× with a field area on the specimen of 0.000779 in.^{2} (0.50 mm^2) (a circle of 0.0315-in. (0.80-mm) diameter or a square with sides 0.02791 in. (0.71 mm) long). Compare each field of the specimen with the fields of Plate I, which also have areas of 0.000779 in.^{2} each. Record the inclusion rating shown at the left of Plate I for each inclusion type (A, B, C, and D) that appears most like the field under observation, for both the thin and heavy series. Do this only for each field

[12] This method is similar to the Jernkontoret Method, Uppsala, Sweden (1936).

containing inclusions equivalent to or greater than the base or No. 1 series. Classify a field with sizes or numbers of inclusions intermediate between configurations shown on Plate I as the lower inclusion rating (that is, Plate I represents the minimum inclusion content for respective inclusion ratings). As the nominal size of the D heavy inclusions shown in Plate I is 0.0005 in. (0.0127 mm) those inclusions larger than 0.0005 in. may be recorded separately.

11.1.2 The minimum inclusion lengths (or numbers for Type D only) that determine the inclusion rating numbers are printed on Plate I and listed in Table 1. Although Method A and Plate I are designed for integral inclusion rating numbers, various standards such as Specification A 295 permit rating to ½ inclusion rating numbers. This practice is permissible provided Table 1, Plate I, or Plate III (see Section 14) is used.

11.1.3 The use of wide-field optics or a projection system, or both, may lead to an area of view larger than 0.000779 in.^{2} (0.50 mm^2) on the specimen. Therefore, employ appropriate area correction (for example, reticle, opaque mask, etc.) to assure that equivalent areas (0.000779 in.^{2}) are compared. (A suitable projection screen mask should contain a circular aperture 3.15 in. (80 mm) in diameter, or a square aperture with sides 2.79 in. (71 mm) long.)

11.1.4 The typical chemical types of inclusions listed at the top of Plate I for Categories A, B, C, and D are for convenience only, and do not mandate knowledge of the inclusion chemistry. In this method, inclusions are assigned to a category based on similarities in morphology, and not necessarily on their chemical identity. Inclusions such as borides, carbides, nitrides, carbonitrides, and intermetallic phases may not be rated using this method.

11.1.5 Arbitrarily classify broken stringered inclusions of Types B or C as two distinct inclusions when they are separated by at least 0.5 in. (12.7 mm) of clear area at 100× (that is, 0.005 in. (0.127 mm) actual separation). If two or more inclusions of the *same* type, that is, either Type A, B, or C, appear in one microscope field, their summed length determines the inclusion rating number. Usually, direct comparison with Plate I will establish the inclusion rating number without the necessity for measurements.

11.2 *Expression of Results:*

11.2.1 The averages of the worst fields for each inclusion type in all of the specimens of the lot shall be calculated in accordance with the inclusion ratings given at the sides of Plate I. An example showing the averages obtained for six specimens examined is given in Table 2.

11.2.2 If desired, the total number of fields in the entire polished surface of the specimen corresponding to each inclusion rating for Inclusion Types A, B, C, and D in both the thin and heavy series shown in Plate I may be recorded to indicate the frequency.

11.2.3 The fields shown in Plate I represent the entire lengths of the inclusions and their limiting widths or diameters. If any inclusions are present that are longer than the fields shown in Plate I, their lengths should be recorded separately. If their widths or diameters are greater than the limiting values shown in Plate I, they also should be recorded separately.

11.2.4 If desired, the predominant chemical type of inclusions may be determined and recorded, as sulfide, alumina, silicate, or globular oxide.

TABLE 1 Minimum Values for Inclusion Rating Numbers (Methods A and D)

Inclusion Rating Number	Minimum Total Length in One Field at 100×, in. (mm)			Minimum Inclusions in One Field
	Type A	Type B	Type C	Type D
½	0.15 (3.8)	0.15 (3.8)	0.15 (3.8)	1
1	0.50 (12.7)	0.30 (7.6)	0.30 (7.6)	3
1½	1.00 (25.4)	0.70 (17.8)	0.70 (17.8)	9
2	1.70 (43.2)	1.20 (30.5)	1.20 (30.5)	14
2½	2.50 (63.5)	2.00 (50.8)	2.00 (50.8)	20
3	3.50 (88.9)	3.20 (81.3)	3.00 (76.2)	26
3½	4.50 (114.3)	4.60 (116.8)	4.00 (101.6)	35
4	6.00 (152.4)	6.00 (152.4)	5.00 (127.0)	44
4½	7.50 (190.5)	8.00 (203.2)	7.00 (177.8)	52
5	9.00 (228.6)	10.00 (254.0)	8.50 (215.9)	64

12. Method B

12.1 *Procedure:*

12.1.1 Survey the entire surface (approximately 0.25 in.^{2} (160 mm^2)) of the polished specimen at a magnification of 100×. Project the fields brought into view successively on a ground glass that is ruled with a series of parallel lines 0.5 in. (12.7 mm) apart. The distance between any two parallel lines (0.5 in., equivalent to 0.005 in. (0.127 mm) on the specimen) shall be called one unit, in terms of which the lengths of the inclusions shall be measured.

12.1.2 Instead of projecting the image onto a ruled ground glass, it may be more convenient to use an eyepiece or other internal reticle containing a micrometer disk or other figure with parallel lines separated by a distance equivalent to 0.005 in. (0.127 mm) on the specimen.

12.1.3 All inclusions one unit in length or longer shall be individually tallied in terms of whole units of length. Inclusions separated by a distance greater than one unit (0.005 in. (0.127 mm)) shall be arbitrarily classified as two inclusions.

12.2 *Expression of Results:*

12.2.1 The determination for each specimen shall be divided into two parts, as follows:

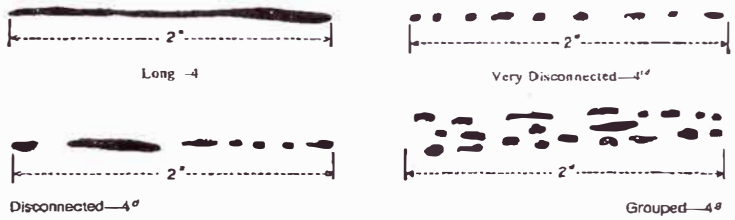
12.2.1.1 The length of the longest inclusion shall be recorded first. It may be supplemented to describe the inclusion width by a superscript *T* for thin (0.04 in. (1.0 mm) or less in width) or *H* for heavy (0.12 in. (3.0 mm) or greater in width). Inclusions between 0.04 in. and 0.12 in. wide shall not be represented by a superscript. Superscripts *d* (disconnected), *vd* (very disconnected) and *g* (grouped) may also be used to describe the degree of connectivity or clustering as illustrated in Fig. 5.

12.2.1.2 The average length of all inclusions one unit and longer in length, but excluding the longest inclusion, shall be reported as a single number, followed by a superscript denoting the number of inclusions averaged.

12.2.2 A series of comparison photomicrographs at 100×, which illustrates all other nonmetallic particles present, may be used to characterize the background appearance of the specimen. If used, these shall be labeled *A*, *B*, . . . etc., in order of increasing inclusion population. The specific photomicrographs used shall be mutually agreed upon between the

TABLE 2 Worst-Field Inclusion Ratings (Method A) (see 9.2.1)

Specimen	Type A		Type B		Type C		Type D	
	Thin	Heavy	Thin	Heavy	Thin	Heavy	Thin	Heavy
1	2	1	2	1	1	0	2	1
2	3	1	2	1	0	1	2	2
3	2	1	2	1	0	0	2	2
4	2	1	2	1	1	0	2	1
5	2	1	2	1	0	1	2	1
6	3	1	2	1	0	0	2	1
Average	2.3	1.0	2.0	1.0	0.3	0.3	2.0	1.3



NOTE 1—d = disconnected, vd = very disconnected, and g = grouped.
NOTE 2—2 in. = 50.8 mm.

FIG. 5 Designation of Length and Weight of Inclusions (4 Units)

interested parties.[13]

NOTE 5—The following is an example of the expression of results for a single specimen by this method: 6^{d}-2^{3}-A. This indicates that the longest inclusion observed was six units long and disconnected, that three other inclusions were observed whose average length was two units, and that the background inclusions were similar in appearance to the A figure from a background photomicrographic series.

12.2.3 The results for all specimens from a lot should be tabulated. If desired, the predominant type of inclusions (sulfides, silicates, or oxides) may be recorded.

13. Method C[14]

13.1 *Procedure*—Survey the entire surface (approximately 0.25 $in.^2$ (160 mm^2)) of the polished specimen at a magnification of 100×. The image size in the microscope should be masked to a rectangle covering 0.03125 by 0.04125 in. (0.79 by 1.05 mm) on the specimen. The longer side of the rectangle shall be parallel to the longitudinal sample direction. As each field comes into view, compare it visually with the photomicrographs shown in Plate II. Oxides and silicates are classified from one to eight, inclusive. Record the worst field of each inclusion type (oxide and silicate) found for each of the specimens examined.

13.2 *Expression of Results:*

13.2.1 The maximum length of each type of inclusion, oxide or silicate, is generally used to evaluate a specimen. The silicate photomicrographs are used for all slag or deformable-type inclusions, and the oxide photomicrographs for all oxide or hard-type inclusions. For example, a specimen may be classified O-5 (oxide) S-4 (silicate), to indicate that the longest oxide or hard-type inclusion seen was comparable to oxide photomicrograph 5, and the longest silicate or deformable-type inclusion seen was comparable to silicate photomicrograph 4.

13.2.2 Broken stringered inclusions shall be arbitrarily classified as two distinct inclusions when they are separated by at least 0.5 in. (12.7 mm) of clear area at 100× (that is, 0.005 in. (0.127 mm) actual separation).

13.2.3 Modifications may be used, such as suffix numerals to indicate the number of long inclusions noted, or the exact length of a particular inclusion when it is over the maximum length indicated by the photomicrographs.

14. Method D

14.1 *Introduction:*

14.1.1 This test method is designed for application to steels with low inclusion contents, and classifies these inclusions in ½-step increments. In addition, this method permits the classification of inclusions smaller than those covered by Methods A, B, and C. Such inclusions are those normally associated with certain melting procedures and with product that receives heavy reduction in processing, such as sheet, foil, tube, and wire.

14.1.2 Table 3 shows the inclusion width ranges utilized in Plate III. The minimum resolvable width for the thin inclusions rated at 100× is 2 μm.

14.1.3 Higher magnifications may be used to rate linear inclusions (Types A, B, and C only) finer than 2 μm in width. To accomplish this, the total length of inclusion is measured at the higher magnification. For example, since four fields at 200× will give the same area as one field at 100×, four fields must be measured. The total inclusion length is then measured and divided by two to give the equivalent inclusion rating number by length relative to the 100× chart (Plate III). Similarly, if the measurements are

[13] A series of four photomicrographs of low carbon steel, previously printed as part of Practice E 45, may be obtained from ASTM Headquarters. Order PCN 12-500454-01.

[14] This method is similar to SAE Recommended Practice J422.

TABLE 3 Inclusion Width Parameters (Method D)

clusion Type	Thin Series		Heavy Series	
	Minimum Width, µm	Maximum Width (Nominal on Plate III), µm	Minimum Width, µm	Nominal Width on Plate III, µm
A	2	4	>4	6
B	2	9	>9	15
C	2	5	>5	9
D	2	8	>8	12

le at 500×, the total inclusion length in 25 fields must be asured and then divided by five to give the correct usion rating number relative to the 100× chart (Plate III). the measurements are originally made in terms of olute units of length on the specimen, no division is essary.) Type D globular inclusions shall be measured y at 100× because higher magnification measurements l give meaningless inclusion rating numbers.

4.1.4 The use of a higher rating magnification than ually required should be avoided. Unnecessary high gnifications could lead to substantially thicker particle lths in the specimen image than those on the 100× mparison chart (Plate III), thus making accurate compar- n ratings difficult. Also, the greatly increased labor neces- y for rating at higher magnifications is justified only when nsideration of very thin inclusions is important.

14.1.5 Inclusions less than 0.5 µm wide should not be ed with this method because of practical limitations in the olving power of light microscopes.

14.2 *Procedure:*

14.2.1 The use of wide field optics or a projection system, both, may lead to an area of view larger than 0.000779 .2 (0.50 mm^2) on the specimen. Therefore, employ appro- iate area correction (for example, reticle, opaque mask, c.) to assure that equivalent areas (0.000779 $in.^2$) are mpared. (A suitable projection screen mask should contain circular aperture 3.15 in. (80 mm) in diameter, or a square perture with sides 2.79 in. (71 mm) long.)

14.2.2 The typical chemical types of inclusions listed at e top of Plate III for Categories A, B, C, and D are for nvenience only, and do not mandate knowledge of the clusion chemistry. In this method, inclusions are assigned a category based on similarities in morphology, and not ecessarily on their chemical identity. Inclusions such as orides, carbides, nitrides, carbonitrides, and intermetallic hases may not be rated using this method.

14.2.3 Survey the entire surface (approximately 0.25 $in.^2$ 160 mm^2)) of the polished specimen at a magnification of 00× with a field area on the specimen of 0.000779 $in.^2$ (0.50 mm^2) (a circle of 0.0315-in. (0.80-mm) diameter or a square vith sides 0.02791 in. (0.71 mm) long). Compare each field f the specimen with fields of Plate III, which also have areas f 0.000779 $in.^2$ Record the inclusion rating number shown n the side of Plate III selected for each inclusion type (A, B, C, or D) that appears most like the field under observation or both the thin and heavy series. Do this for each field containing inclusions equivalent to or greater than the base or ½ series. Classify a field with sizes or numbers of nclusions intermediate between configurations shown on Plate III as the next lower inclusion rating number (that is, Plate III figures represent the minimum inclusion content for the respective inclusion rating numbers). It should be noted that the nominal size of the D inclusions shown in Plate III is maintained at 0.0005 in. (0.0127 mm). Record separately with their actual measured sizes these globular oxides larger than the size illustrated in Plate III. Illustrations of larger globular oxides appear at the bottom of the D column in Plate III.

14.2.4 The minimum inclusion lengths (or numbers for Type D only) that determine the inclusion rating numbers are printed on Plate III and listed in Table 1.

14.2.5 Arbitrarily classify broken stringered inclusions of Types B or C as two distinct inclusions when they are separated by at least 0.5 in. (12.7 mm) of clear area at 100× (that is, 0.005 in. (0.127 mm) actual separation).

14.2.6 If two or more stringered inclusions of the *same* type (either Type A, B, or C) appear in one microscope field, their summed length determines the inclusion rating number. Usually, direct comparison with Plate III will establish the inclusion rating number without the necessity for measurements.

14.2.7 While surveying the entire surface at 100×, if very fine linear inclusions (widths less than 2 µm) are encountered, then the procedure described in 13.1.3 may be followed. The use of more than one rating magnification on the same specimen is not permitted. Report the magnification used.

14.3 *Expression of Results:*

14.3.1 The number of fields of each inclusion type (A, B, C, and D of Plate III) found for both the thin and heavy series shall be recorded for each specimen in terms of the inclusion rating numbers on the side of the plate. If a magnification other than 100× is used to rate Type A, B, or C inclusions, the magnification shall also be recorded.

14.3.2 If any inclusions are found that are longer than those displayed on Plate III, they should be recorded separately. If the widths or diameters are greater than the limiting values shown on Plate III, these should also be recorded separately.

14.3.3 To average the results of more than one specimen, the average of the number of fields found for each inclusion rating number and type in the various specimens examined within a lot may be calculated as illustrated in Table 4.

14.3.4 If desired, the predominant chemical type of inclusions may be determined and recorded as sulfide, alumina, silicate, or globular oxide.

15. Method E: SAM Rating

15.1 *Introduction*—This method is used to express the inclusion content of steels in a manner that reflects the severity and frequency of occurrence of the larger B- and D-type oxide inclusions.

15.2 *Procedure:*

15.2.1 Survey the entire surface (approximately 0.25 $in.^2$ (160 mm^2)) of the polished specimen at a magnification of 100× with a field area on the specimen of 0.00079 $in.^2$ (0.50 mm^2) (a circle of 0.0315 in. (0.80 mm) diameter or a square with sides 0.02791 in. (0.71 mm) long).

15.2.2 A rating of B-type inclusions is obtained by comparing each field of the specimen with the fields in Plate III (Table 1 may also be used). Record all B-thin fields observed at each severity level, for levels of 1.5 or higher; all B-heavy

TABLE 4 Example of Inclusion Rating (Method D)

Inclusion Rating Number		Number of Fields in Each Specimen[A] — Specimen Number						Average of Six Specimens	
		1	2	3	4	5	6	Thin	Heavy
				Type A					
0.5	Thin	65	60	50	65	37	58	55.5	
	Heavy	9	8	12	6	16	8		9.6
1.0	Thin	19	15	31	8	12	10	15.6	
	Heavy	4	3	4	1	2	1		2.5
1.5	Thin	1	3	2	0	1	0	1.2	
	Heavy	0	0	0	0	0	0		0
2.0	Thin	1	0	0	0	0	0	0.2	
	Heavy	0	0	0	0	0	0		0
2.5	Thin	0	0	0	0	0	0	0	
	Heavy	0	0	0	0	0	0		0
				Type B					
0.5	Thin	13	8	7	6	11	10	9.2	
	Heavy	0	0	0	1	1	0		0.3
1.0	Thin	13	14	10	6	12	12	11.2	
	Heavy	0	0	0	0	2	1		0.5
1.5	Thin	1	6	6	3	3	2	3.5	
	Heavy	0	0	0	0	0	0		0
2.0	Thin	0	2	1	0	1	1	0.8	
	Heavy	0	0	0	0	0	0		0
2.5	Thin	0	1	0	0	1	0	0.3	
	Heavy	0	1	0	0	0	0		0.2
				Type C					
0.5	Thin	0	0	0	0	1	0	0.2	
	Heavy	0	0	0	0	0	0		0
1.0	Thin	0	0	0	0	0	0	0	
	Heavy	0	0	0	0	0	0		0
1.5	Thin	0	0	0	0	0	0	0	
	Heavy	0	0	0	0	0	0		0
2.0	Thin	0	0	0	0	0	0	0	
	Heavy	0	0	0	0	0	0		0
2.5	Thin	0	0	0	0	0	0	0	
	Heavy	0	0	0	0	0	1[B]		0.2
				Type D					
0.5	Thin	35	33	26	32	47	29	34.0	
	Heavy	9	4	5	6	9	9		7.0
1.0	Thin	13	10	20	9	12	41	17.5	
	Heavy	0	2	2	1	2	4		1.6
1.5	Thin	0	0	4	0	0	6	1.7	
	Heavy	0	0	0	0	0	0		0
2.0	Thin	0	0	0	0	0	0	0	
	Heavy	0	0	0	0	0	0		0
2.5	Thin	0	0	0	0	0	0	0	
	Heavy	0	0	0	0	0	0		0
Max D Size		0.0012 in. (0.0305 mm)		0.001 in. (0.0254 mm)			0.001 in. (0.0254 mm)		

[A] For a 0.25-in.^{2} (160-mm^2) specimen examined over the entire surface at 100× with a field area of 0.000779 in.^{2} (0.50 mm^2) (see 12.2.1), 321 fields would be observed.
[B] One field 0.033 in. (0.0838 mm) long by 0.0018 in. (0.0457 mm) wide.

fields observed at each severity level of 1.0 or higher. (For this method, B-heavy inclusions are defined as inclusions measuring 0.0005 in. (13 μm) or larger in width.) Classify a field with sizes of inclusions intermediate between configurations in Plate III or Table 1 as the lower inclusion rating.

15.2.3 Classify broken B-types as two distinct inclusions when they are separated by at least 0.5 in. (12.7 mm) of clear area at 100×. If two or more B-type appear in one microscope field, their summed length determines the inclusion rating number.

15.2.4 A rating of D-type inclusions is obtained by recording all D-heavy fields with a rating of 0.5 or higher. (For this method, D-type heavy oxides are defined as those particles measuring 0.0005 in. (13 μm) or larger at their widest point). Fields of 0.5 severity are counted as one unit; fields of 1.0 severity as two units; fields of 1.5 severity as three units and so on. The minimum inclusion numbers for D-type are printed on Plate III and listed in Table 1.

15.3 *Expression of Results:*

15.3.1 Results are expressed in terms of two rating numbers reflecting B-type and D-heavy type inclusion contents.

15.3.2 The number of B-type fields recorded at each severity level times the severity level is summed (see Table 5) and normalized by dividing by the total rated area of all samples in square inches. The nearest whole number is recorded as the rating.

15.3.3 The number of D units is summed (see Table 5) and normalized by dividing by the total rated area of all samples in square inches. The nearest whole number is recorded as the rating.

TABLE 5 SAM Rating (Method E)

B-Type Rating[A,B]				D-Type Rating[A,C]		
No. of Observed Fields	"B" Thin	No. of Observed Fields	"B" Heavy	No. of Observed Fields	"D" Heavy	Units
not recorded	0.5	not recorded	0.5	5	0.5	(1)
not recorded	1.0	2	1.0	2	1.0	(2)
3	1.5	1	1.5	1	1.5	(3)
1	2.0	0	2.0	0	2.0	(4)
0	2.5	0	2.5	0	2.5	(5)

[A] Total area observed = 1.5 in.^{2}
[B] SAM rating = (3 × 1.5) + (1 × 2) + (2 × 1) + (1 × 1.5) = 10 ÷ 1.5 = 7.
[C] SAM rating = (5 × 1) + (2 × 2) + (1 × 3) = 12 ÷ 1.5 = 8.

APENDICE D

ASTM E 112 – 88

STANDART TEST METHODS FOR DETREMINING AVERAGE GRAIN SIZE

Designation: E 112 – 88

Standard Test Methods for Determining Average Grain Size[1]

This standard is issued under the fixed designation E 112; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense to replace Methods 31 1.1 and 312 of Federal Test Method Standard No. 151b. Consult the DoD Index of Specifications and Standards for the specific year of issue which has been adopted by the Department of Defense.

INTRODUCTION

These test methods of determination of average grain size in metallic materials are primarily measuring procedures and, because of their purely geometric basis, are quite independent of the metal or alloy concerned. In fact, the basic procedures may also be used for the estimation of average grain, crystal, or cell size in nonmetallic materials. The comparison method may be used if the structure of the material approaches the appearance of one of the standard comparison charts. The intercept and planimetric methods are always applicable for determining average grain size. However, the comparison charts cannot be used for measurement of individual grains.

1. Scope

1.1 These test methods cover the measurement of average grain size and include the Comparison Procedure, the Planimetric (or Jeffries') Procedure, and the Intercept Procedures. These methods may also be applied to nonmetallic materials with structures having appearances similar to those of the metallic structures shown in the comparison charts.

1.2 The paragraphs appear in the following order:

1.3 *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

E 3 Methods of Preparation of Metallographic Specimens

E 29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specification[3]

E 45 Practice for Determining the Inclusion Content of Steel[2]

E 562 Practice for Determining Volume Fraction by Systematic Manual Point Count[2]

E 883 Guide for Metallographic Photomicrography[2]

E 1181 Test Methods for Characterizing Duplex Grain Sizes[2]

2.2 *Adjuncts*

2.2.1 For a complete adjunct list, see Appendix X1.

3. Significance and Use

3.1 These methods cover procedures for estimating and rules for expressing the average grain size of all metals consisting entirely, or principally, of a single phase. The methods may also be used for any structures having appearances similar to those of the metallic structures shown in the comparison charts. The three basic procedures for grain size estimation are:

3.1.1 *Comparison Procedure*—The comparison procedure is a visual estimation for which the results are generally

[1] These test methods are under the jurisdiction of ASTM Committee E-4 on Metallography and are the direct responsibility of Subcommittee E04.08 on Grain Size.

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[2] *Annual Book of ASTM Standards*, Vol 03.01.

[3] *Annual Book of ASTM Standards*, Vol 14.02.

TABLE 1 Suggested Comparison Charts for Metallic Materials

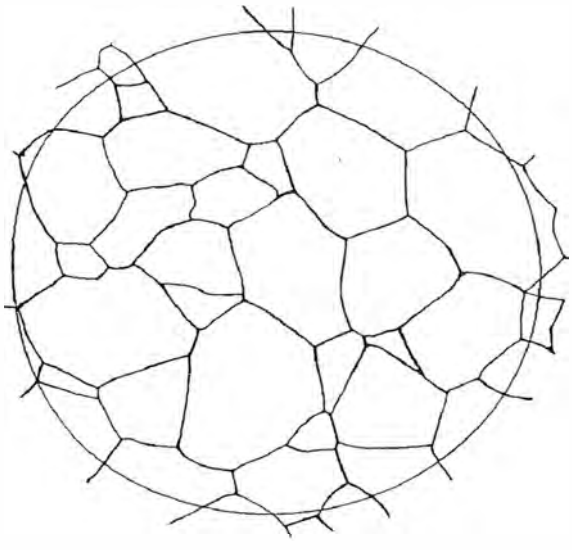
NOTE—These suggestions are based upon the customary practices in industry. For specimens prepared according to special techniques, the appropriate comparison standards should be selected on a structural-appearance basis in accordance with 8.2.

Material	Plate Number	Basic Magnification
Aluminum	I	100×
Copper and copper-base alloys (see Annex A4)	III	75×
Iron and steel:		
Austenitic	II or IV	100×
Ferritic	I	100×
Carburized	IV	100×
Stainless	II	100×
Magnesium and magnesium-base alloys	I or II	100×
Nickel and nickel-base alloys	II	100×
Super-strength alloys	I or II	100×
Zinc and zinc-base alloys	I or II	100×

within plus or minus a whole grain size number of the value determined with the intercept method.

3.1.2 *Planimetric Procedure*—The planimetric procedure is to be treated as an estimation method generally valid only to plus or minus a half grain size number when no statistical control has been applied. When sufficient measurements have been made and statistically analyzed to comply with the requirements of Section 13, the result may be stated to have been determined to plus or minus a quarter grain size number.

3.1.3 *Intercept Procedure*—The intercept procedure is to be treated as an estimation method generally valid only to plus or minus a half grain size number when no statistical control has been applied. When sufficient measurements have been made and statistically analyzed to comply with the requirements of Section 13, the result may be stated to have been determined to the precision indicated, but not normally closer than plus or minus a tenth of a grain size number.



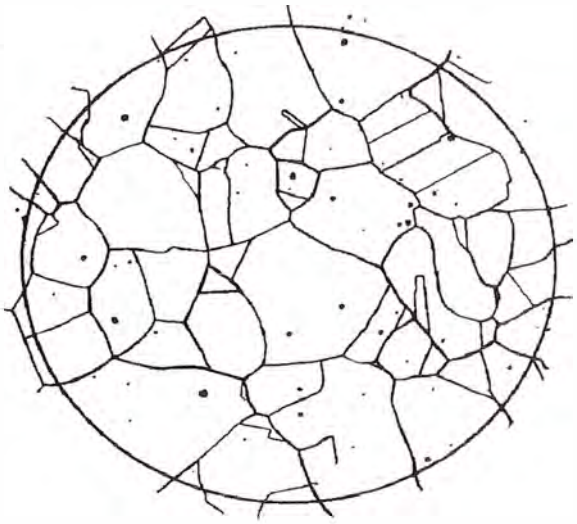


FIG. 2 Example of Twin Grains (Flat Etch) from Plate II. Grain Size No. 3 at 100×

3.2 For specimens consisting of equiaxed grains, the method of comparing the specimen with a standard chart is most convenient and is sufficiently accurate for most commercial purposes. For higher degrees of accuracy in determining average grain size, the intercept or planimetric procedures may be used. The intercept procedure is particularly useful for structures consisting of elongated grains.

3.3 In case of dispute, the intercept procedure shall be the referee procedure in all cases.

3.4 No attempt should be made to estimate the average grain size of heavily cold-worked material or partially recrystallized wrought alloys. Lightly to moderately cold-worked material may be considered as consisting of non-equiaxed grains, if a grain size measurement is necessary.

3.5 *Individual grain measurements should not be made based on the standard comparison charts.* These charts were constructed to reflect the typical log-normal distribution of grain sizes that result when a plane is passed through a three-dimensional array of grains. Because they show a distribution of grain dimensions, ranging from very small to very large, depending on the relationship of the planar section and the three-dimensional array of grains, the charts are not applicable to measurement of individual grains.

4. Description of Grain Area

4.1 *Grain*—For the purposes of applying these methods, a grain shall be considered as all that area within the confines of the original (primary) boundary. In materials having twinned grain structures, a crystal and its twin bands shall be ed as one grain.

FIG. 3 Example of Twin Grains (Contrast Etch) from Plate III. Grain Size 0.090 mm at 75×

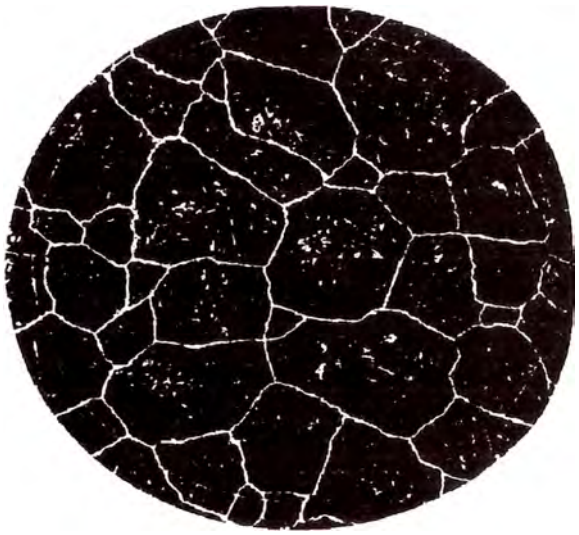


FIG. 4 Example of Austenite Grains in Steel from Plate IV. Grain Size No. 3 at 100×

4.2 *Grain Size*—In materials consisting of two or more constituents, the grain size shall refer to that of the matrix, except that, in those materials wherein the second phase is of sufficient amount, size, or continuity to be significant, the grain size may be estimated and reported separately. Minor constituent phases, inclusions, and additives are not normally considered in the estimation of grain size.

4.3 *Subgrains*—The sizes of subgrains may be estimated by the same methods applicable to the grains themselves.

5. Generalities of Application

5.1 It is important, in using these methods, to recognize that the estimation of average grain size is not a precise measurement. A metal structure is an aggregate of three-dimensional crystals of varying sizes and shapes. Even if all these crystals were identical in size and shape, the grain cross sections, produced by a random plane (surface of observation) through such a structure, would have a distribution of areas varying from a maximum value to zero, depending upon where the plane cuts each individual crystal. Clearly, no two fields of observation can be exactly the same.

5.2 The size and location of grains in a microstructure are normally completely random. No nominally random process of positioning a test pattern can improve this randomness, but random processes can yield poor representation by concentrating measurements in part of a specimen. "Representative" implies that all parts of the specimen contribute to the result, not, as sometimes has been presumed, that fields of average grain size are selected. Visual selection of fields, or casting out of extreme measurements, may not falsify the average when done by unbiased experts, but will in all cases give a false impression of high precision. For representative sampling, the area of the specimen is mentally divided into several equal coherent sub-areas and stage positions prespecified, which are approximately at the center of each sub-area. The stage is successively set to each of these positions and the test pattern applied blindly, that is, with the light out, the shutter closed, or the eye turned away. No touch-up of the position so selected is allowable. Only measurements made on fields chosen in this way can be validated with respect to precision and bias.

6. Preparation of Specimen

6.1 The specimen shall be prepared and etched according to the metallographic procedures recommended in Methods E 3.

7. Preparation of Photomicrographs

7.1 When photomicrographs are used for estimating the average grain size, they shall be prepared in accordance with Guide E 883.

8. Comparison Procedure

8.1 The comparison procedure shall apply to completely recrystallized or cast materials with equiaxed grains.

8.2 When grain size estimations are made by the more convenient comparison method, repeated checks by individuals as well as by interlaboratory tests have shown that unless the appearance of the standard reasonably well approaches that of the sample, errors may occur. To minimize such errors, the comparison charts are presented in four categories as follows:[4]

[4] Plates I, II, III, and IV are available from ASTM Headquarters. Order PCN 12-501120-10 (Plate I), 12-501120-20 (Plate II), 12-501120-30 (Plate III), and 12-501120-40 (Plate IV). A combination of all four plates is also available. Order PCN 12-501121-28.

TABLE 2 Micro-Grain Size Relationships Computed for Uniform Randomly Oriented Equiaxed Grains

NOTE—For diameters in inches, see Table 4 (divide by 100).

ASTM Micro-Grain Size Number G	"Diameter" of Average Grain Section[A]		Average Intercept Distance[B] $\bar{l}$, mm	Intercept Count, n/l per mm	Area of Average Grain Section, $\bar{a}$, mm²	Calculated Number of Grains per mm³, n/v[C]	Average	
	Nominal d_n, mm	Feret's d_f, mm					Grains per mm² at 1×,[D] n/a	Grains per in.² at 100×, n/a
00[E]	0.51	0.570	0.453	2.210	0.258	6.11	3.88	0.250
0	0.36	0.403	0.320	3.125	0.129	17.3	7.75	0.500
0.5	0.30	0.339	0.269	3.716	0.0912	29.0	11.0	0.707
1.0	0.25	0.285	0.226	4.42	0.0645	48.8	15.50	1.000
1.5	0.21	0.240	0.190	5.26	0.0456	82	21.9	1.414
(1.7)[F]	0.200	0.226	0.177	5.64	0.0400	100	25.0	1.613
2.0	0.18	0.202	0.160	6.25	0.0323	136	31.0	2.000
2.5	0.15	0.170	0.135	7.43	0.0228	232	43.8	2.828
	µm	µm	µm		mm² × 10⁻³			
3.0	125	143	113	8.84	16.1	391	62.0	4.000
(3.2)[F]	120	135	106	9.41	14.4	463	69.4	4.480
3.5	105	120	95	10.51	11.4	657	87.7	5.657
(3.7)[F]	100	113	89	11.29	10.0	800	100	6.452
4.0	90	101	80.0	12.5	8.07	1105	124	8.000
4.5	75	85	67.3	14.9	5.70	1659	175	11.31
(4.7)[F]	70	79	62.0	16.1	4.90	2331	204	13.17
5.0	65	71	56.6	17.7	4.03	3126	248	16.00
(5.2)[F]	60	68	53.2	18.8	3.60	3708	278	17.92
5.5	55	60	47.6	21.0	2.85	5258	351	22.63
(5.7)[F]	50	56	44.3	22.6	2.50	6400	400	25.81
6.0	45	50	40.0	25.0	2.02	8842	496	32.00
(6.4)[F]	40	45	35.4	28.2	1.60	12 500	625	40.32
6.5	38	42	33.6	29.7	1.43	14 671	701	45.25
(6.7)[F]	35	39	31.0	32.2	1.23	18 659	816	52.67
7.0	32	36	28.3	35.4	1.008	25 010	992	64.00
(7.2)[F]	30	34	26.6	37.6	0.900	29 630	1111	71.68
7.5	27	30	23.8	42.0	0.713	41 061	1403	90.51
(7.7)[F]	25	28	22.2	45.1	0.625	51 200	1600	103.23
	µm	µm	µm		mm² × 10⁻⁶	×10⁶	×10³	
8.0	22	25	20.0	50.0	504	0.0707	1.98	128.0
(8.4)[F]	20	23	17.7	56.4	400	0.1000	2.50	161.3
8.5	19	21	16.8	59.5	356	0.1190	2.81	181.0
9.0	16	18	14.1	70.7	252	0.200	3.97	256.0
(9.2)[F]	15	17	13.3	75.2	225	0.237	4.44	286.7
9.5	13	15	11.9	84.1	178	0.336	5.61	362.0
10.0	11	13	10.0	100	126	0.586	7.94	512.0
(10.3)[F]	10	11.3	8.86	113	100	0.800	10.00	645.2
10.5	9.4	10.6	8.41	119	89.1	0.952	11.22	724.1
(10.7)[F]	9.0	10.2	7.98	125	81.0	1.097	12.35	796.5
11.0	8	8.9	7.07	141	63.0	1.600	15.87	1024
(11.4)[F]	7.0	7.9	6.20	161	49.0	2.332	20.41	1317
11.5	6.7	7.5	5.95	168	44.6	2.692	22.45	1448
(11.8)[F]	6.0	6.8	5.32	188	36.0	3.704	27.78	1792
12.0	5.6	6.3	5.00	200	31.5	4.527	31.7	2048
(12.3)[F]	5.0	5.6	4.43	226	25.0	6.40	40.0	2581
12.5	4.7	5.3	4.20	238	22.3	7.61	44.9	2896
13.0	4.0	4.5	3.54	283	15.8	12.60	63.5	4096
13.5	3.3	3.7	2.97	336	11.1	21.54	89.8	5793
(13.8)[F]	3.0	3.4	2.66	376	9.0	29.6	111.1	7168
14.0	2.8	3.2	2.50	400	7.88	36.2	127	8192
(14.3)[F]	2.5	2.8	2.22	451	6.25	51.2	160	10323

[A] Feret's diameter = height between tangents; $d_f = \bar{a}/\bar{l}$. Values of d_n and d_f rounded to digits shown.
[B] Value of Heyn intercept or mean free path.
[C] Computation of n/v based on grains averaging to spherical shape for which $n/v = 0.5659\,(n/l)^3$.
[D] To obtain grains per mm² at 100×, multiply by 10^{-4}.
[E] The use of "00" is recommended instead of "minus 1" to avoid confusion.
[F] The G values shown in parentheses are calculated to one decimal place and correspond to some of the nominal "diameter" sizes, (d_n) customarily used in reporting average grain size by the copper and brass industry.

8.2.1 *Plate I*—Untwinned grains (flat etch). Includes grain size numbers 00, 0, ½, 1, 1½, 2, 2½, 3, 3½, 4, 4½, 5, 5½, 6, 6½, 7, 7½, 8, 8½, 9, 9½, 10, at 100×.

8.2.2 *Plate II*—Twinned grains (flat etch). Includes grain size numbers, 1, 2, 3, 4, 5, 6, 7, 8, at 100×.

8.2.3 *Plate III*—Twinned grains (contrast etch). Includes nominal grain diameters of 0.200, 0.150, 0.120, 0.090, 0.070, 0.060, 0.050, 0.045, 0.035, 0.025, 0.020, 0.015, 0.010, 0.005 mm at 75×.

8.2.4 *Plate IV*—Austenite grains in steel (McQuaid-Ehn). Includes grain size numbers 1, 2, 3, 4, 5, 6, 7, 8, at 100×.

TABLE 3 Relationships Between the Actual Grain Size of Specimens Viewed at Various Magnifications and the Standard Series of Photomicrographs

Specimen Magnification		Actual Grain Size of Specimen, Expressed as "Diameter" of Average Cross Section When Specimen Image at Magnification Indicated,[A] Matches Standard Series of Photographs										
		Standard Series of Photomicrographs at 100×										
ASTM Micro-Grain Size Number		0	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5
100×	mm	0.360	0.300	0.250	0.210	0.180	0.150	0.130	0.110	0.090	0.075	0.065
	in.	0.014	0.012	0.010	0.008	0.007	0.006	0.005	0.004	0.0035	0.003	0.0025
75×	mm	0.480	0.400	0.330	0.280	0.240	0.210	0.170	0.140	0.120	0.100	0.085
	in.	0.019	0.016	0.013	0.011	0.009	0.008	0.0065	0.0055	0.0045	0.004	0.0033
50×	mm	0.720	0.600	0.500	0.420	0.360	0.300	0.250	0.210	0.180	0.150	0.130
	in.	0.028	0.024	0.020	0.016	0.014	0.012	0.010	0.008	0.007	0.006	0.005
25×	mm	1.440	1.200	1.000	0.840	0.720	0.600	0.500	0.420	0.360	0.300	0.250
	in.	0.056	0.047	0.040	0.033	0.028	0.024	0.020	0.016	0.014	0.012	0.010

ASTM Micro-Grain Size Number		5.5	6	6.5	7	7.5	8	8.5	9	9.5	10
100×	mm	0.055	0.045	0.035	0.030	0.026	0.022	0.019	0.016	0.013	0.011
	in.	0.002	0.0018	0.0014	0.0012	0.001	0.0009	0.0007	0.0006	0.0005	0.0004
75×	mm	0.075	0.060	0.045	0.040	0.035	0.030	0.025	0.020	0.018	0.015
	in.	0.003	0.0023	0.0018	0.0016	0.0014	0.0012	0.001	0.0008	0.0007	0.0006
50×	mm	0.110	0.090	0.075	0.065	0.055	0.045	0.035	0.030	0.026	0.022
	in.	0.004	0.0035	0.003	0.0025	0.002	0.0018	0.0014	0.0012	0.001	0.0009
25×	mm	0.210	0.180	0.150	0.130	0.110	0.090	0.075	0.065	0.055	0.045
	in.	0.008	0.007	0.006	0.005	0.004	0.0035	0.003	0.0025	0.002	0.0018

Standard Series of Photomicrographs at 75× (Plate III)[B]													
25×	mm	0.030	0.045	0.060	0.080	0.110	0.140	0.150	0.180	0.210	0.270	0.360	0.450	0.600
50×	mm	0.015	0.020	0.030	0.040	0.050	0.070	0.080	0.090	0.100	0.140	0.180	0.220	0.300
75×	mm	0.010	0.015	0.020	0.025	0.035	0.045	0.050	0.060	0.070	0.090	0.120	0.150	0.200
100×	mm	...	0.010	0.015	0.020	0.025	0.035	0.040	0.045	0.050	0.070	0.090	0.110	0.150

[A] It is recommended that the macro-grain size numbers (see 8.12) be used for grain sizes larger than 0.5 mm (0.02 in.), 25× be used only for grain sizes larger than 0.210 mm (0.008 in.), that 50× be used only for grain sizes larger than 0.075 mm (0.003 in.). For the smaller grain sizes, greater accuracy generally can be secured by increasing the magnification. This table can be used for comparisons at 250×, 300×, 500×, 750×, or 1000× by dividing by 10 the grain size indicated at 25×, 30×, 50×, 75×, or 100×, respectively. Thus, at 250×, a grain size which will match the same standard photograph of 0.050 mm (0.0015 in.) at 75×, will be an 0.015 mm grain size (0.150 at 25× divided by 10).

[B] The values shown in this table have been rounded to approximate commercial usage. See Table 2 for exact values.

8.3 Table 1 lists a number of materials and the comparison charts that are suggested for use in estimating their average grain sizes. For example, for twinned copper and brass with a contrast etch, use Plate III.

NOTE 1—Examples of grain-size standards from Plates I, II, III, and IV are shown in Figs. 1, 2, 3, and 4.

8.4 The estimation of micro-grain size should usually be made by direct comparison at the same magnification as the appropriate chart. Accomplish this by comparing a projected image or a photomicrograph of a representative field of the test specimen with the photomicrographs of the appropriate standard grain-size series, or with suitable reproductions or transparencies of them, and select the photomicrograph which most nearly matches the image of the test specimen or interpolate between two standards. Report this estimated grain size to the nearest appropriate unit listed in Table 2.

8.5 Good judgment on the part of the observer is necessary to select the magnification to be used, the proper size of area (number of grains), and the number and location in the specimen of representative sections and fields for estimating the characteristic or average grain size. It is not sufficient to visually select what appear to be areas of average grain size. Recommendations for choosing appropriate areas for all procedures have been noted in 5.2.

8.6 Grain size estimations shall be made on three or more representative areas of each sample section.

8.7 When the grains are of a size outside the range covered by the standard photographs, or when magnifications of 75× or 100× are not satisfactory, other magnifications may be employed for comparison by using the relationships given in Note 2 and Table 3. It may be noted that alternative magnifications are usually simple multiples of the basic magnifications.

NOTE 2—If the grain size is reported in ASTM numbers, it is convenient to use the relationship:

$$Q = 2 \log_2 (M/M_b)$$
$$= 6.64 \log_{10} (M/M_b)$$

where Q is a correction factor that is added to the apparent micro-grain size of the specimen, as viewed at the magnification, M, instead of at the basic magnification, M_b (75× or 100×), to yield the true ASTM grain-size number. Thus, for a magnification of 25×, the true ASTM grain-size number is 4 numbers lower than that of the corresponding photomicrograph at 100× ($Q = -4$). Likewise, for 400×, the true ASTM grain-size number is 4 numbers higher ($Q = +4$) than that of the corresponding photomicrograph at 100×. Similarly, for 300×, the true ASTM grain-size number is 4 numbers higher than that of the corresponding photomicrograph at 75×.

8.8 The small number of grains per field at the coarse end of the chart series, that is, size 00, and the very small size of the grains at the fine end make accurate comparison difficult. When the sample grain size falls at either end of the chart range, a more meaningful comparison can be made by changing the magnification so that the grain size lies closer to the center of the range.

TABLE 4 Macro-Grain Size Relations Computed for Uniform Randomly Oriented, Equiaxed Grains

NOTE—Use of micro-grain size numbers (Table 2) is recommended for all grain sizes higher than M-14. Micro-size numbers may be converted to macro-size numbers by adding 13.288 size numbers.

ASTM Macro-Grain Size Number (M)G	ASTM Micro-Grain Size Number G	"Diameter" of Average Grain Section			Average Intercept Distance[A]		Intercept Count N in 100 mm	Area of Average Grain Section		Grains per Area at 1 ×	
		Nominal d_n		Feret's d_f, mm	$\bar{l}$, mm	$\bar{l}$, in.		$\bar{a}$, mm²	$\bar{a}$, in.²	n_a, mm² × 10^{-3}	n_a, in.²
		mm	in.								
M-0	...	36	1.4	40.3	32.00	1.26	3.125	1290	2.00	0.775	0.50
M-0.5	...	30	1.2	33.9	26.91	1.06	3.716	912	1.41	1.10	0.71
M-1	...	25	1.0	28.5	22.63	0.891	4.419	645	1.00	1.55	1.00
M-1.5	...	21	0.84	24.0	19.03	0.749	5.256	456	0.707	2.19	1.41
M-2	...	18	0.71	20.1	16.00	0.630	6.25	323	0.500	3.10	2.00
M-2.5	...	15	0.59	17.0	13.45	0.530	7.43	228	0.354	4.39	2.83
M-3	...	13	0.50	14.3	11.31	0.445	8.84	161	0.250	6.20	4.00
M-3.5	...	11	0.42	12.0	9.51	0.375	10.51	114	0.177	8.77	5.66
M-4	...	9	0.35	10.1	8.000	0.315	12.5	80.6	0.125	12.40	8.00
M-4.5	...	7.5	0.30	8.5	6.727	0.265	14.9	57.0	0.088	17.53	11.31
M-5	...	6.5	0.25	7.1	5.657	0.223	17.7	40.3	0.063	24.80	16.00
M-5.5	...	5.5	0.21	6.0	4.757	0.187	21.0	28.5	0.044	35.08	22.63
M-6	...	4.5	0.18	5.0	4.000	0.157	25.0	20.2	0.031	49.60	32.00
M-6.5	...	4	0.15	4.2	3.364	0.132	29.7	14.3	0.022	70.14	45.25
M-7	...	3.2	0.125	3.6	2.828	0.111	35.4	10.1	0.0156	99.20	64.00
M-7.5	...	2.7	0.105	3.0	2.378	0.094	42.0	7.2	0.0110	140.3	90.51
			in. × 10^{-3}			in. × 10^{-3}			in.² × 10^{-3}		
M-8	...	2.2	88	2.5	2.000	78.7	50.0	5.04	7.81	198.4	128.0
M-8.5	...	1.9	74	2.1	1.682	66.2	59.5	3.56	5.52	280.6	181.0
M-9	...	1.6	63	1.8	1.414	55.7	70.7	2.52	3.91	396.8	256.0
M-9.5	...	1.3	53	1.5	1.189	46.8	84.1	1.78	2.76	561.1	362.0
M-10	...	1.1	44	1.26	1.000	39.4	100.0	1.26	1.95	793.6	512
M-10.5	...	0.95	37	1.06	0.841	33.1	112.2	0.891	1.38	1122	724
M-11	...	0.80	31	0.89	0.707	27.8	141.4	0.630	0.976	1587	1024
M-11.5	...	0.67	26	0.75	0.595	23.4	168.2	0.446	0.690	2244	1448
M-12	...	0.56	22	0.63	0.500	19.7	200.0	0.315	0.488	3174	2048
(M-12.3)	00	0.51	20	0.57	0.453	17.8	221.0	0.258	0.400	3875	2500
M-12.5	...	0.47	18.6	0.53	0.420	16.6	237.8	0.223	0.345	4489	2896
M-13	...	0.40	15.6	0.45	0.354	13.9	282.8	0.158	0.244	6349	4096
(M-13.3)	0	0.36	14.1	0.40	0.320	12.6	312.5	0.129	0.200	7750	5000
M-13.5	...	0.33	13.1	0.37	0.297	11.7	336.4	0.111	0.172	8979	5793
(M-13.8)	0.5	0.30	11.9	0.34	0.269	10.6	317.8	0.0912	0.141	10 960	7071
M-14	...	0.28	11.0	0.32	0.250	9.84	400.0	0.0788	0.122	12 698	8192
(M-14.3)	1.0	0.25	10.0	0.28	0.226	8.91	442	0.0645	0.100	15 500	10 000

[A] Value of Heyn intercept or mean free path.

8.9 The use of transparencies[5] or prints of the standards, with the standard and the unknown placed adjacent to each other, is to be preferred to the use of wall chart comparison with the projected image on the microscope screen.

8.10 No particular significance should be attached to the fact that different observers often obtain slightly different results, provided the different results fall within the confidence limits reasonably expected with the procedure used.

8.11 There is a possibility when an operator makes repeated checks on the same sample using the comparison method that he will be prejudiced by his first estimate. This disadvantage can be overcome, when necessary, by changes in magnification, through bellows extension, or objective or eyepiece replacement between estimates (**1**)[6].

8.12 Make the estimation of macro-grain sizes (extremely coarse) by direct comparison, at a magnification of 1×, of the properly prepared specimen, or of a photograph of a representative field of the specimen, with photographs of the standard grain series shown in Plate I (for untwinned material) and Plates II and III (for twinned material). Since the photographs of the standard grain size series were made

[5] Transparencies of the various grain sizes in Plate I are available from ASTM Headquarters. Order PCN 12-501122-28 for set. Transparencies of individual grain size groupings are available on request. Order PCN 12-501121-11 (Grain Size 00), 12-501121-12 (Grain Size 0), 12-501121-13 (Grain Size 0.5), 12-501121-14 (Grain Size 1.0), 12-501121-15 (Grain Size 1.5), 12-501121-16 (Grain Size 2.0), 12-501121-17 (Grain Size 2.5), 12-501121-18 (Grain Sizes 3.0, 3.5, and 4.0), 12-501121-19 (Grain Sizes 4.5, 5.0, and 5.5), 12-501121-21 (Grain Sizes 6.0, 6.5, and 7.0), 12-501121-22 (Grain Sizes 7.5, 8.0, and 8.5), and 12-501121-23 (Grain Sizes 9.0, 9.5, and 10.0). Charts illustrating grain size numbers 00 to 10 are on 8½ by 11 in. (215.9 by 279.4 mm) film. Transparencies for Plates II, III, and IV are not available.

[6] The boldface numbers in parentheses refer to the list of references appended to these methods.

TABLE 5 Relationship Between Magnification Used and Jeffries' Multiplier, *f*, for an Area of 5000 mm² (a Circle of 79.8-mm Diameter) ($f = 0.0002\ M^2$)

Magnification Used, *M*	Jeffries' Multiplier, *f*, to Obtain Grains/mm²
1	0.0002
10	0.02
25	0.125
50	0.5
75[A]	1.125
100	2.0
150	4.5
200	8.0
250	12.5
300	18.0
500	50.0
750	112.5
1000	200.0

[A] At 75 diameters magnification, Jeffries' multiplier, *f*, becomes unity if the area used is 5625 mm² (a circle of 84.5-mm diameter).

at 75 and 100 diameters magnification, grain sizes estimated in this way do not fall in the standard ASTM grain-size series and hence, preferably, should be expressed either as "diameter" of the average grain or as one of the macro-grain size numbers listed in Table 4. For the smaller macro-grain sizes, it may be preferable to use a higher magnification and the correction factor given in Note 3, particularly if it is desirable to retain this method of reporting.

NOTE 3—If the grain size is reported in ASTM macro-grain size numbers, it is convenient to use the relationship:

$$Q_M = 2 \log_2 M = 6.64 \log_{10} M$$

where Q_M is a correction factor that is added to the apparent grain size of the specimen, when viewed at the magnification M, instead of at 1×, to yield the true ASTM macro-grain size number. Thus, for a magnification of 2×, the true ASTM macro-grain size number is 2 numbers higher ($Q = +2$), and for 4×, the true ASTM macro-grain size number is 4 numbers higher ($Q = +4$) than that of the corresponding photograph.

8.13 The comparison procedure shall be applicable for estimating the austenite grain size in ferritic steel after a McQuaid-Ehn test (see Annex A3, A3.2), or after the austenite grains have been revealed by any other means (see Annex A3, A3.3). Make the grain-size measurement by comparing the microscopic image, at magnification of 100×, with the standard grain size chart in Plate IV, for grains developed in a McQuaid-Ehn test (see Annex A3); for the measurement of austenite grains developed by other means (see Annex A3), measure by comparing the microscopic image with the plate having the most nearly comparable structure observed in Plates I, II, or IV.

8.14 The so-called "Fracture Method" of judging grain size from the appearance of the fracture of hardened steel (2), involves comparison of the specimen under investigation with a set of fracture standards. It has been found that the arbitrarily numbered fracture grain sizes agree well with the correspondingly numbered ASTM grain sizes presented in Table 2. This coincidence makes the fracture grain sizes interchangeable with the austenite grain sizes determined microscopically (except that "duplexed" or mixed grain size is not readily discernible in fractures). The sizes observed microscopically shall be considered the primary standard,

TABLE 6 Anticipated Standard Deviation in Lineal Analysis of an Ideal Specimen

N Intersections Counted	C.V. of *N*	Standard Deviation of[A]			Bias in Circle, % of *l*
		N	*l*, %	ASTM No.	
4	0.50	2	+100	−2.0	+10
			−33	+1.16	
			±67	±1.58	
6	0.41	2.45	+69	−1.51	+4.7
			−29	+0.98	
			±49	±1.25	
10	0.32	3.16	+46	−1.10	+1.7
			−24	+0.79	
			±35	±0.95	
15	0.26	3.87	+35	−0.86	+0.7
			−21	+0.66	
			±28	±0.76	
20	0.22	4.47	+29	−0.73	+0.4
			−18	+0.68	
			±24	±0.66	
30	0.18	5.48	+22	−0.58	+0.2
			−15	+0.48	
			±19	±0.53	
35	0.17	5.92	+20	−0.53	+0.13
			−14	+0.45	
			±17	±0.49	
40	0.16	6.32	+19	−0.50	+0.1
			−14	+0.42	
			±16	±0.46	
50	0.14	7.1	+17	−0.44	+0.07
			−12	+0.38	
			±14	±0.41	
75	0.12	8.7	±12	±0.33	+0.03
100	0.10	10.0	±10	±0.29	+0.02
150	0.08	12.2	±8	±0.24	...
200	0.07	14.1	±7	±0.20	...
300	0.06	17.3	±6	±0.17	...
500	0.045	22.4	±4.5	±0.13	...
1000	0.03	31.6	±3.2	±0.09	...

[A] Computed from σ of N = Poisson standard error of counting = $\sqrt{N}$

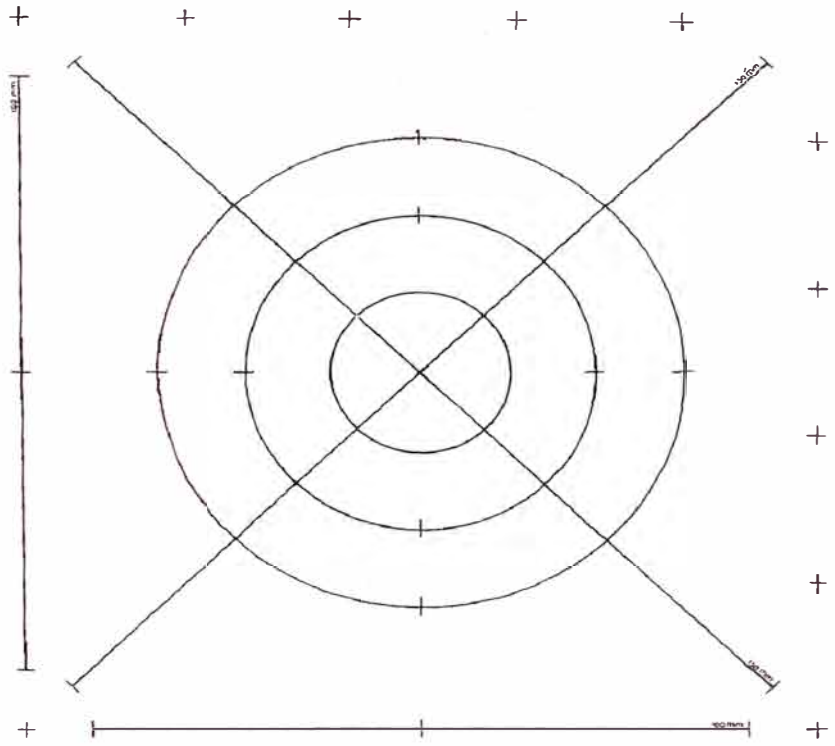
since they can be determined with measuring instruments

9. Planimetric (or Jeffries') (3) Procedure

9.1 In the planimetric procedure inscribe a circle (see Fig. 11)[7] or rectangle of known area (usually 5000 mm² to simplify the calculations) on a micrograph or on the ground-glass screen of the metallograph. Select magnification which will give at least 50 grains in the field to be counted. When the image is focused properly, count the number of grains within this area. The sum of all the grains included completely within the known area plus one half the number of grains intersected by the circumference of the area gives the number of equivalent whole grains, measured at the magnification used, within the area. If this number is multiplied by Jeffries' multiplier, *f*, in the second column of Table 5 opposite the appropriate magnification, the product will be the number of grains per square millimetre. Count a minimum of three fields to assure a reasonable average.

9.2 Statistical considerations of the grain-counting methods would require the counting of far more grains per given area than would seem to be practically feasible. Thus, while 100 or more grains per given area may be statistically acceptable for ordinary use, the more practical aspects of grain counting reduce such considerations to a minimum of

[7] A transparency of Fig. 11 is available from ASTM Headquarters. Order PCN 12-501123-91.



If reproduced to make straight lines marked length:
Straight lines total: 500 mm

Circles are:	Circumference, mm,	Diameter, mm
	250.0	79.58
	166.7	53.05
	83.3	26.53
	Total 500.0	

FIG. 5 Test Pattern for Intercept Counting

50 grains per given area; areas containing less than 50 grains being not acceptable. However, for higher orders of accuracy such as in experimental work, areas containing 500 to 1000 or more grains may be used.

9.3 Take care in choosing the location of the fields used for making the count. They must be "representative" in the sense described in 5.2.

9.4 By original definition, Micro Grain Size No. 1 has 1.000 grains/in.^{2} at 100×, hence 15.500 grains/mm^2 at 1× or /10 000 mm^2 at 100×. For areas other than the standard circle, determine the actual number of grains per square millimetre and find the nearest size from Table 2. For magnifications other than 100×, add the Q values from Note 2 (Section 8).

9.5 When the grains are not equiaxed, make a grain count on three mutually perpendicular planes that are determined by the longitudinal, transverse, and normal directions. Designate the number of grains per square millimetre for these planes as n_{ll}, n_{ln}, and n_{tn}, respectively. The number of grains per cubic millimetre, n_{lln}, is then given by $0.8\sqrt{n_{ll} \times n_{ln} \times n_{tn}}$. Subscripts, which are appended to the ASTM grain size number to show grain shape, are n_{tn}/n_{ll} and n_{ln}/n_{ll}.

10. General Intercept Procedures

10.1 Intercept procedures are more convenient to use than the planimetric procedure. These procedures are amenable to use with various types of machine aids. It is strongly recommended that at least a manual tally counter be used with all intercept procedures in order to prevent normal errors in counting and to eliminate bias which may occur when counts appear to be running higher or lower than anticipated.

10.2 Intercept procedures are recommended particularly for all structures that depart from the uniform equiaxed form. For anisotropic structures, procedures are available

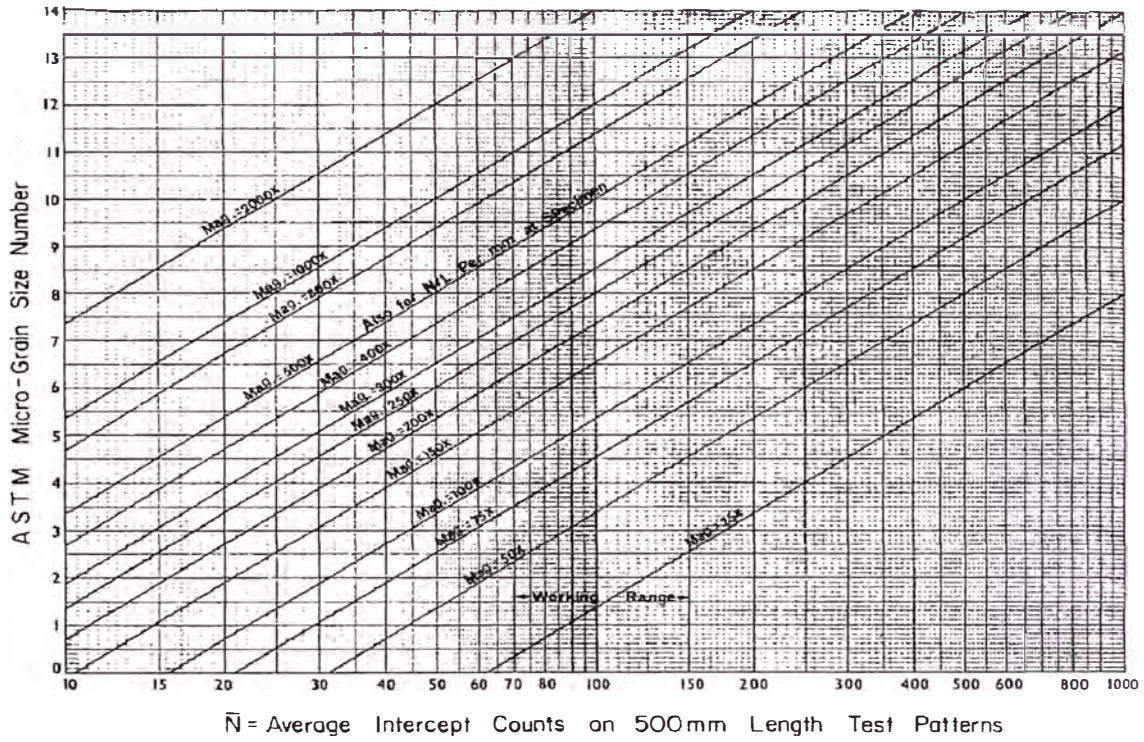


FIG. 6 Chart for Direct Determination of ASTM Micro-Grain Size Number from Intercept Count on 500-mm Test Pattern

either to make separate size estimates in each of the three principal directions, or to rationally estimate the average size, as may be appropriate.

10.3 Since the assumed formal relation between intercept size and planimetric average grain area, $\bar{l} = (\pi \bar{a}/4)^{1/2}$, is precise only for spheres and practically exact only for uniform equiaxed grains, the problem of variable conversion factors is eliminated by redefining the ASTM grain size number for intercept methods so that ASTM No. 0 has a mean intercept size of precisely 32.00 mm for the macro-size scale and of 32.00 mm measured on a field at 100× magnification for the micro-size scale. Thus:

$$G = \text{ASTM No.} = 2 \log_2 \frac{L_0}{\bar{L}}$$

$$= 10.00 - 2 \log_2 \bar{L}$$
$$= 10.00 + 2 \log_2 (N/L)$$

where $\bar{L}$ and $\bar{L}$ are in millimetres directly for macro-size numbers and in millimetres on a field at 100× for micro-size numbers. The scale so defined is in agreement within approximately 0.01 size number with the values converted from planimetric values for equiaxed grains, hence indistinguishable within presently feasible limits of precision. Additional working equations will be found in Annexes A1.2 and A2.

10.4 The mean intercept distance, $\bar{l}$ (also called mean free path or Heyn intercept), measured on a plane section is an unbiased estimate of the mean intercept distance within the solid material in the direction, or over the range of directions, measured. The surface-to-volume ratio is given exactly by $S_v = 2\ n/l$ when n/l is averaged over 3 dimensions. These relations are independent of grain shape. However, if the size of elongated grains, or of structures containing a mixture of actual grain sizes in space, is also estimated by planimetric methods, the resulting size will usually be measurably different from the intercept size. In the absence of a specific engineering judgment to the contrary, the intercept size is to be considered the appropriate value.

10.5 In all intercept procedures, the actual magnification used is to be validated by direct comparison of an engraved stage micrometer, or of some other suitable microscopic size standard, with the test line or test pattern used. A precision of at least 5 % is required when sizes are determined to the nearest ½ ASTM size number and of 1 % for determinations to 0.1 ASTM number.

11. Lineal Intercept (or Heyn (4)) Procedure

11.1 Estimate the average grain size by counting (on the ground-glass screen, on a photomicrograph of a representative field of the specimen, or on the specimen itself) the number of grains intercepted by one or more straight lines

TABLE 7 Exact ASTM Micro-Grain-Size Numbers for Intercept Counts on 500-mm Pattern: $G = G_b + \Delta G$

NOTE—Instructions: Table may be used in place of reference to Fig. 6. First, record base size number (G_b) for 100 counts on pattern at magnification used. Then record correction, ΔG, for actual average count, $\bar{N}$. Add base and correction to get actual ASTM size number. Round sum. Note that counts less than 100 add a negative correction, giving size number lower than base value.

Base Size, 100 Counts		Add ΔG Correction for Specific Count Obtained					
Mag	G_b	Count	ΔG	Count	ΔG	Count	ΔG
10	−1.288	50	−2.000	100	zero	131	+0.779
		55	−1.725	101	+0.029	132	+0.801
25	+1.356	60	−1.474	102	+0.057	133	+0.823
		65	−1.243	103	+0.085	134	+0.844
50	3.358	70	−1.029	104	+0.113	135	+0.868
				105	+0.141		
75	4.526	71	−0.988			136	+0.887
		72	−0.948	106	+0.168	137	+0.908
100	5.356	73	−0.908	107	+0.195	138	+0.929
		74	−0.869	108	+0.222	139	+0.950
125	6.000	75	−0.830	109	+0.249	140	+0.971
				110	+0.275		
150	6.526	76	−0.792			141	+0.991
		77	−0.754	111	+0.301	142	+1.012
200	7.356	78	−0.717	112	+0.327	143	+1.032
		79	−0.680	113	+0.353	144	+1.052
250	8.000	80	−0.644	114	+0.378	145	+1.072
				115	+0.403		
300	8.526	81	−0.608			146	+1.092
		82	−0.573	116	+0.428	147	+1.112
400	9.356	83	−0.538	117	+0.453	148	+1.131
		84	−0.503	118	+0.478	149	+1.151
500	10.000	85	−0.469	119	+0.502	150	+1.170
				120	+0.526		
600	10.526	86	−0.435			155	+1.265
		87	−0.402	121	+0.550	160	+1.356
700	10.971	88	−0.369	122	+0.574	165	+1.445
		89	−0.336	123	+0.597	170	+1.531
800	11.356	90	−0.304	124	+0.621	175	+1.615
				125	+0.644		
900	11.696	91	−0.272			180	+1.696
		92	−0.241	126	+0.667	185	+1.775
1000	12.000	93	−0.209	127	+0.690	190	+1.852
		94	−0.179	128	+0.712	195	+1.927
1250	12.644	95	−0.148	129	+0.735	200	+2.000
				130	+0.757		
1500	13.170	96	−0.118				
		97	−0.088				
1600	13.356	98	−0.058				
		99	−0.029				
1750	13.615	100	zero				
2000	14.000						

sufficiently long to yield at least 50 intercepts. It is desirable to select a combination of test line length and magnification such that a single field will yield the required number of intercepts. One such test will nominally allow estimation of grain size to the nearest whole ASTM size number, at the location tested. Additional lines, in a predetermined array, should be counted to obtain the precision required (see Table 6) Use of multiple fields to achieve 50 intercepts is discouraged, although permitted, due to an inherent bias which will decrease the accuracy as the number of fields increases. This is particularly true in those cases where a single test is used to estimate the average grain size, or where a high degree of precision is required. In such cases the selection of a lower magnification or use of a circular test line(s) is recommended.

11.2 Make counts first on 3 to 5 blindly selected and widely separated fields to obtain a reasonable average for the specimen. If the apparent precision of this average (calculated as indicated in Section 13) is not adequate, make counts on sufficient additional fields to obtain the precision required for the specimen average.

11.3 An *intercept* is a segment of test line overlaying on grain. An *intersection* is a point where a test line is cut by grain boundary. Either may be counted, with identical result in a single phase material. When counting intercepts, segments at the end of a test line which penetrates into a grai are scored as half intercepts. When counting intersection the end points of a test line are not intersections and are n counted except when the end appears to exactly touch grain boundary, when ½ intersection should be scored. tangential intersection with a grain boundary should b scored as 1 intersection. An intersection apparently coi ciding with the junction of 3 grains should be scored as 1½ With irregular grain shapes, the test line may generate tw intersections with different parts of the same grain, togeth with a third intersection with the intruding grain. The tw additional intersections are to be counted.

11.4 The Heyn procedure may be implemented by use an automated stage micrometer with visual observation, by use of fully automated scanning devices. High statisti precision can thereby be obtained with reasonable effort. T need to average counts on many fields is not, howev

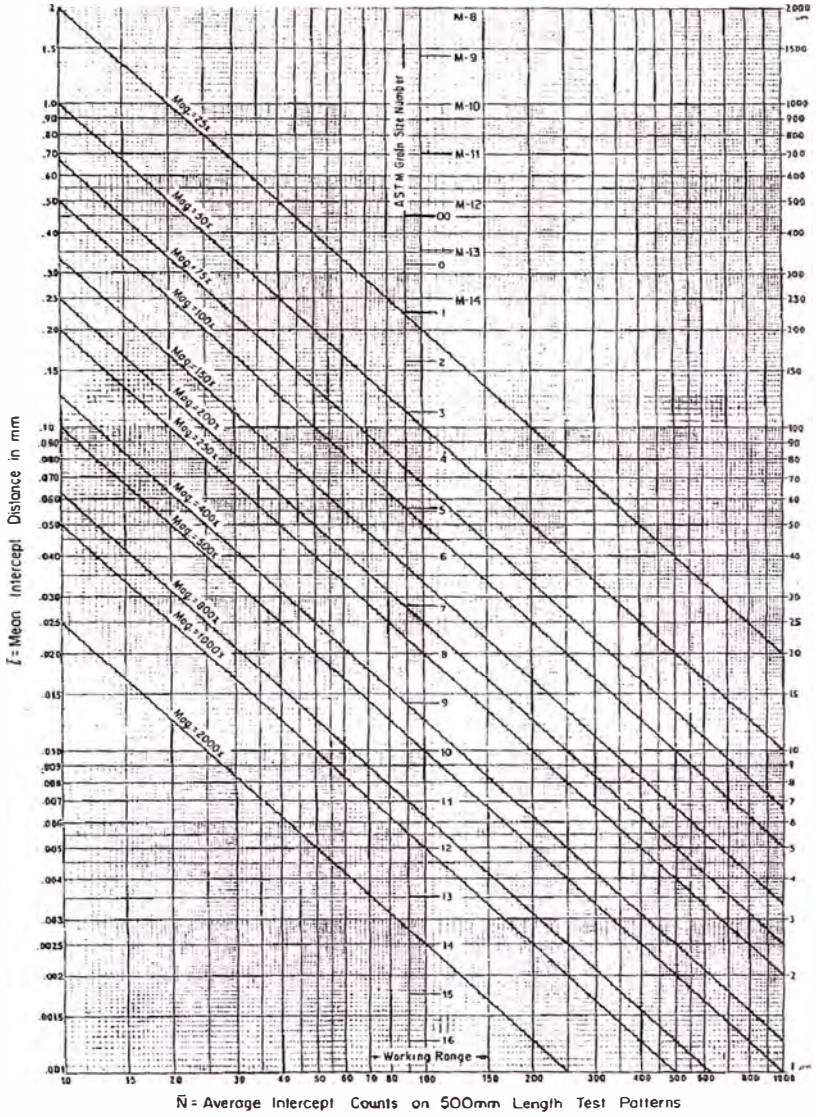


FIG. 7 Chart for Direct Determination of Mean Intercept Distance from Intercept Count on 500-mm Test Pattern

eliminated by the high precision which may be obtained for each field. Fractional scoring for line-end coincidences, tangential intersections, and triple points can normally be eliminated statistically. Fully automated machines, however, are subject to two biasing errors which can not be reduced by large numbers of counts: (*1*) The machine may count intersections with inclusions and second phase particles. The fraction of such false counts must be periodically determined and held within acceptable limits. When this cannot be accomplished by machine adjustment or control of specimen preparation, the material should be treated as second phase (see Section 14). (*2*) The machine may fail to count some grain boundary intersections when these are of low contrast or unusually thin. The fraction of such errors must be periodically determined. When beyond the acceptable limit, either the specimen preparation, magnification, or machine adjustments must be changed to reduce this error to an acceptable value. These two errors must not be assumed to

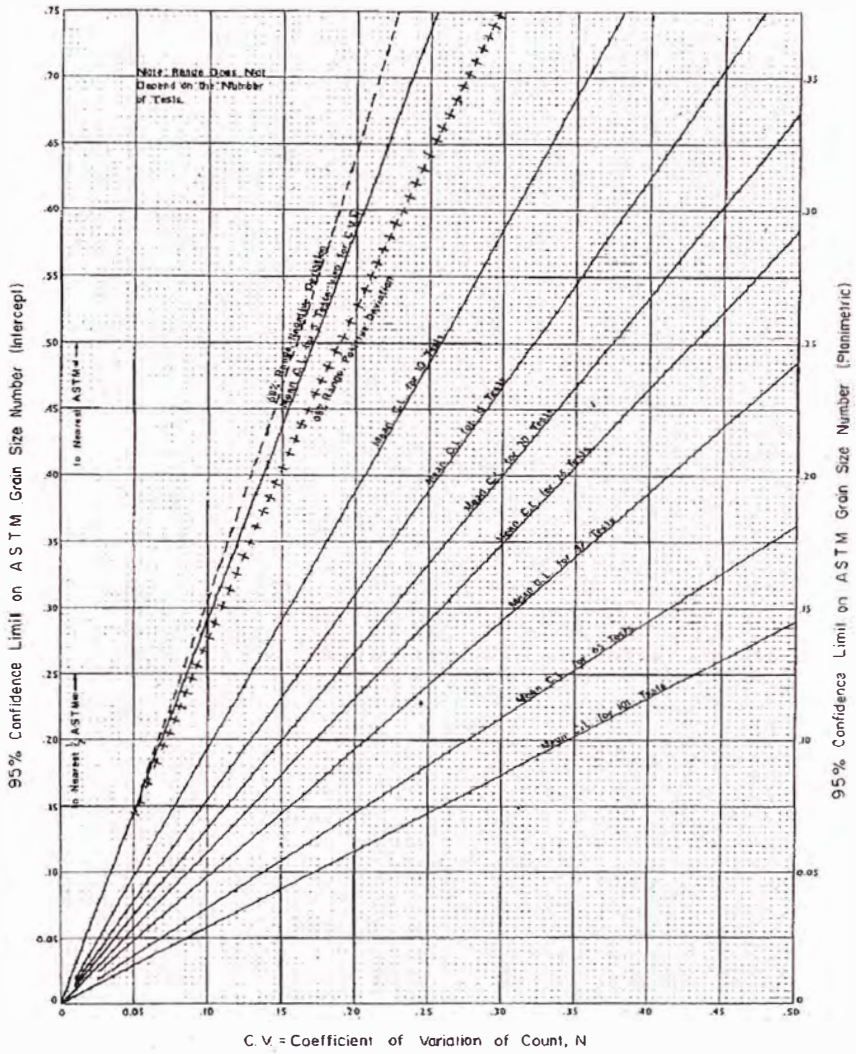


FIG. 8 Chart for Determination of Confidence Limit on Estimate of ASTM Grain Size Number

cancel, and should individually be held within 5 % of the count for confidence that the specimen average is accurate to the nearest ½ ASTM size number, and within 1 % for confidence to 0.1 ASTM number.

11.5 The effects of moderate departure from an equiaxed structure may be eliminated by making intercept counts on a fine array containing lines having four or more orientations. The four straight lines of Fig. 5[8] may be used. The form of such arrays is not critical, provided that all portions of the field are measured with approximately equal weight. An array of lines radiating from a common point is therefore not suitable. The number of intercepts is to be counted for the entire array and single values of N/L and $\bar{l}$ determined for each array as a whole.

11.6 For distinctly non-equiaxed structures such as moderately worked metals, more information can be obtained by making separate size determinations along parallel line arrays that coincide with all three principal directions of the specimen. Longitudinal and transverse specimen sections are normally used, the normal section being added when necessary. Either of the 100-mm lines of Fig. 5 may be applied 5

[8] A true-size transparency of Fig. 5 is available from ASTM Headquarters. Order PCN 12-501123-85.

times, using parallel displacements, placing the 5 "+" marks at the same point on the image.

11.6.1 If the average number of grains per millimetre intercepted by lines in the longitudinal direction is designated as n_l, in the transverse direction as n_t, and in the normal direction as n_n, then the number of grains per cubic millimetre, n_{llm} may be calculated as follows:

$$n/v = n_{llm} = 0.566 \times n_l \times n_t \times n_n \text{ (Note 4)}$$

11.6.2 In converting counts on non-equiaxed grains to ASTM grain size numbers, first select the ASTM grain size number nearest to the observed value of grains per cubic millimetre; then append subscripts, namely n_n/n_l and n_n/n_t, to indicate grain shape. For example, if the grains intercepted on a given specimen are $n_l = 11$, $n_t = 22$, and $n_n = 44$, there are $0.566 \times 11 \times 22 \times 44 = 6026$ grains/mm^3 and the grain size would be reported in ASTM as $5.5_{4,2}$ signifying that the average count (6026) is approximated by ASTM Size 5.5 (5258 grains, Column 7 of Table 2) and that the other observations show the grain shape n_n/n_l and n_n/n_t (of 4/1 and 2/1).

11.6.3 The actual intercept size of the deformed structure should be computed by the relation:

$$\bar{n} = 1/3\,(n_l + n_t + n_n)$$

This eliminates any uncertainty resulting from the use of an assumed (ellipsoidal) shape in the computation of n_{llm} above. For the example of the preceding paragraph, $\bar{n} = 1/3\,(11 + 22 + 44) = 25.67$ from which the intercept size, $\bar{l} = 0.039$ mm. From Table 2 the nearest listed ASTM number is 6, again to be reported as $6.0_{4,2}$. Thus, this computation correctly indicates that the average linear size of the grains has been slightly reduced, and the surface area increased, by deformation, although the number of grains per cubic millimetre presumably has not been changed.

NOTE 4—Editions of this standard issued through 1976 showed values of n/v in Column 7 of Table 2 as the 3/2 power of n/a (Column 8). This relation was valid only for parallelepipeds and unrealistic for real grains. Column 7 of Table 2 has now been recomputed on the assumption that a collection of randomly oriented polyhedra may, on the average, be represented by ellipsoids. The equation for n/v now shown in 11.6.1 applies and is correct for spheres and for ellipsoids of any degree of eccentricity. The factor of 0.8 shown in 9.3 is corrected for the same assumption. Assumption of a specific polyhedral shape would result in increasing the value of n/l (for any specified n/v) in exact proportion to the ratio of S/V for the polyhedron to the S/V for a sphere of the same volume (and thus to a small decrease in the n/v values as compared to Column 7). The value of n_{llm} computed by the method of 11.6.1 thus indicates the grain size characteristics of an equiaxed structure presumed to have existed prior to deformation. These calculations are valid to the nearest 1/2 ASTM number.

Alternatively, the relation

$$\bar{n}_l = (n_l \times n_t \times n_n)^{1/3}$$

is true for *any* grain configuration and for any deformation under which the identity of the grains is preserved. Consequently:

$$\bar{n}_o = (n_{ll} \times n_{lt} \times n_{tn})^{1/3}$$

is also true since the multiplying constant characteristic of assumed grain shape will disappear. These relations yield the size of the presumed original equiaxed structure prior to deformation to any precision justified by the data. For the example of 11.6.2,

$$\bar{n}_l = (11 \times 22 \times 44)^{1/3} = 22$$

for which the nearest listed ASTM size is 5.5 and the exact computed size is 5.63.

12. Circular Intercept Procedures

12.1 Use of circular test lines rather than straight test lines has been advocated by Underwood (5), Hilliard (6), and Abrams (7). Circular test arrays automatically compensate for departures from equiaxed grain shapes, without overweighting any local portion of the field. Ambiguous intersections at ends of test lines are eliminated. Circular intercept procedures are most suitable for use as fixed routine manual procedures for grain size estimation in quality control.

12.2 Circular procedures introduce a slight potential bias in the direction of overvaluing the mean intercept distance ($\bar{l}$). This may be seen by examining a specific application of a circle to a microstructure, yielding N intersections. The circle may now be replaced by an irregular polygon having N straight sides, each of which is a linear intercept with one grain. Thus the true length of linear test line is the sum of the sides of the polygon, which is slightly less than the circular length used, as shown in the last column of Table 6. The bias of a circle of 6 intersections is objectionable at a precision of 1/2 ASTM number. Bias falls rapidly as N increases, being reduced to an ignorable 0.5 % when $N = 18$. Desirable compensation can be introduced by counting an intersection at the junction of 3 grains as 2 intersections rather than 1½, as in the linear procedure. It is, however, recommended that no test circle be used under conditions where the number of intersections is less than 15. Thus test arrays of concentric circles should not include inner circles for which $N < 15$ under the recommended measuring conditions. For the specific recommendations to follow, the possible discrepancy between circular and linear arrays may be ignored.

12.3 *Single-Circle (Hilliard (6)) Procedure:*

12.3.1 The use of a single circle has been recommended particularly for materials in which the actual grain size varies significantly from one position to another on the specimen. In this situation, measurement on a relatively large number of fields is necessary, but high precision is not required for individual circle counts.

12.3.2 Any circle size of exactly known circumference may be used. Circumferences of 100, 200, or 250 mm are usually convenient. The largest (250 mm) circle of Fig. 5 may be used. This circle is, for practical purposes, indistinguishable from the standard Jeffries' planimetric circle (circumference = 250.7 mm). The two smaller circles of Fig. 5 will yield 500 mm total test length for three and six applications respectively. Blindly apply the selected circle to the microscope image at a convenient known magnification and count the number of grain boundaries intersecting the circle for each application. Apply the circle only once to each field of view, adding fields in a representative manner, until sufficient counts are obtained to yield the required precision. Considerable variation of counts between applications is expected and no count values may be discarded.

12.3.3 The number of times the test circle has to be applied must finally be determined by the standard deviation of observations in accordance with Section 13. If the grains are reasonably equiaxed and there is in fact no significant variation of size between fields, the number of counts

required per test circle and the total number of counts to obtain a specific required overall precision may be reasonably predicted from the Poisson "standard error of counting." Table 6 indicates these anticipated standard deviations for an ideal specimen. Usually real specimens may be expected to require more counts than here indicated. For conditions under which this procedure is appropriate, Hilliard has recommended use of a magnification yielding about 35 counts per circle, distributing the required number of circles blindly over as large a specimen area as feasible.

12.4 *Three-Circle (or Abrams (7)) Procedure:*

12.4.1 Based on an experimental finding that a total of 500 counts per specimen normally yields acceptable precision, Abrams has developed a specific procedure for routine average grain size rating of commercial steels. Use of the chi-square test on real data has demonstrated that the variation of intercept counts is close to normal, allowing the observations to be treated by the statistics of normal distributions. Thus both a measure of variability and the confidence limit of the result are computed for each average grain size determination.

12.4.2 The test pattern consists of three concentric and equally spaced circles having a total circumference of 500 mm, as shown in Fig. 5. Successively apply this pattern to five blindly selected and widely spaced fields, separately recording the count of intersections per pattern for each of the five tests. Then determine the average grain size and confidence limit. In the event that the confidence limit is inadequate, make additional tests until the confidence limit computed for the combined data is satisfactory. The specific procedure is as follows:

12.4.2.1 First perform a cursory examination of the microstructure and roughly estimate its ASTM grain size number by using the comparison method or by counting intersections on a single circle of the test pattern.

12.4.2.2 Using this estimated size, from Fig. 6 select a rational magnification that will yield approximately 100 intercepts for the 500-mm circular test pattern. Reset the microscope for this magnification.

12.4.2.3 Blindly select one field for measurement and apply the test pattern to the image. A transparency of the pattern may be applied directly to the ground glass, or to a photomicrograph when permanent records are desired. Direct counting using a properly sized reticule in the eyepiece is allowable, but it may here be expected that some operators will find difficulty in counting correctly at the count density recommended. Completely count each circle in turn, using a manually operated counter to accumulate the total number of grain boundary intersections with the test pattern. The manual counter is necessary to avoid bias toward unreal agreement between applications or toward a desired result, and to minimize memory errors. The operator should avoid keeping a mental score. Score intersections at the junction of 3 grains as 2 counts rather than the theoretical 1½; the error so introduced is small and in a direction to cancel the inherent bias of the curved test lines.

12.4.2.4 If the count for the first application is less than 70 or more than 150, discard the first result and adjust the microscope to a more suitable magnification. The count being acceptable, record it on a suitable record sheet (as in Fig. 10) and repeat the procedure four more times, using a new blindly selected field for each test.

12.4.3 *Calculation*—Calculate the average value ($\bar{N}$) of the intercept count per 500-mm test pattern. For common magnifications, the ASTM grain size number may now be directly determined from Fig. 6,[9] or by adding the two components of G which may be found from Table 7. Also, determine the mean intercept width, $\bar{l}$, in the same way, using Fig. 7.[9] If the magnification was different from any shown, determine the true value of n_l (per 1-mm length on the specimen) as follows:

$$\bar{n}_l = \frac{\bar{N}}{L/\text{Mag}} = \frac{\text{Mag} \times \bar{N}}{500}$$

Using this value of $\bar{n}_l$ in place of $\bar{N}$, the ASTM size number can be read from Fig. 6 at the 500× line. The value of $\bar{l}$ can be read from Fig. 7 at the 500× line, or computed as $\bar{l} = 1/n_l$. Finally, determine the precision of the size estimate in accordance with Section 13, and if this precision is inadequate, immediately make sufficient additional tests to yield the required precision.

12.4.3.1 *Example 1*—Original estimates indicated a magnification of 200× to be suitable. Five fields were tested with the 500-mm pattern, yielding counts of 92, 78, 109, 74, and 117. The average count ($\bar{N}$) is thus 94.0. Referring to Fig. 6, the average count of 94 is found on the horizontal scale and the "94" line followed up until it intersects the 200× graph, where the grain size number 7.2 is found. This is entered on the worksheet. Following the same procedure using Fig. 7, a value of 0.0265 mm (26.5 μm) is read for the mean intercept size ($\bar{l}$).

12.4.3.2 *Example 2*—The 5 counts of Example 1 were obtained, but a check of the microscope magnification showed that the actual magnification used was 275×. There is no chart line for 275×, hence the actual value of n_l must be computed. L on the specimen = 500 mm/Mag, hence:

$$\bar{n}_l = \frac{\bar{N}}{L/\text{Mag}} = \frac{275\bar{N}}{500} = \frac{275 \times 94}{500} = 51.7$$

Note now that the specimen length (L) is 1 mm when the pattern length and magnification are equal, hence the chart line for 500× may also be used for $\bar{n}_l$. In Fig. 6, taking 51.7 on the horizontal scale and following up to the 500× line gives 8.1 as the corrected ASTM grain size number. Similarly, Fig. 7 gives 0.0195 mm (19.5 μm) as the corrected mean intercept size ($\bar{l}$).

13. Determination of Confidence Limit for Grain Size Result

13.1 No determination of average grain size can be an exact measurement. Thus, no determination is complete without also calculating the precision within which the determined size may, with normal confidence, be considered to represent the actual average grain size of the specimen examined. In accordance with common engineering practice, this section assumes "normal confidence" to represent the expectation that the actual error will be within the stated uncertainty 95 % of the time. This stated (or expected)

[9] Double-size drawings of Figs. 6 to 9 are available from ASTM Headquarters. Order PCN 12-501123-86 (Fig. 6), 12-501123-87 (Fig. 7), 12-501123-88 (Fig. 8), and 12-501123-89 (Fig. 9). For a combination of Figs. 5 through 11, order PCN 12-501123-28.

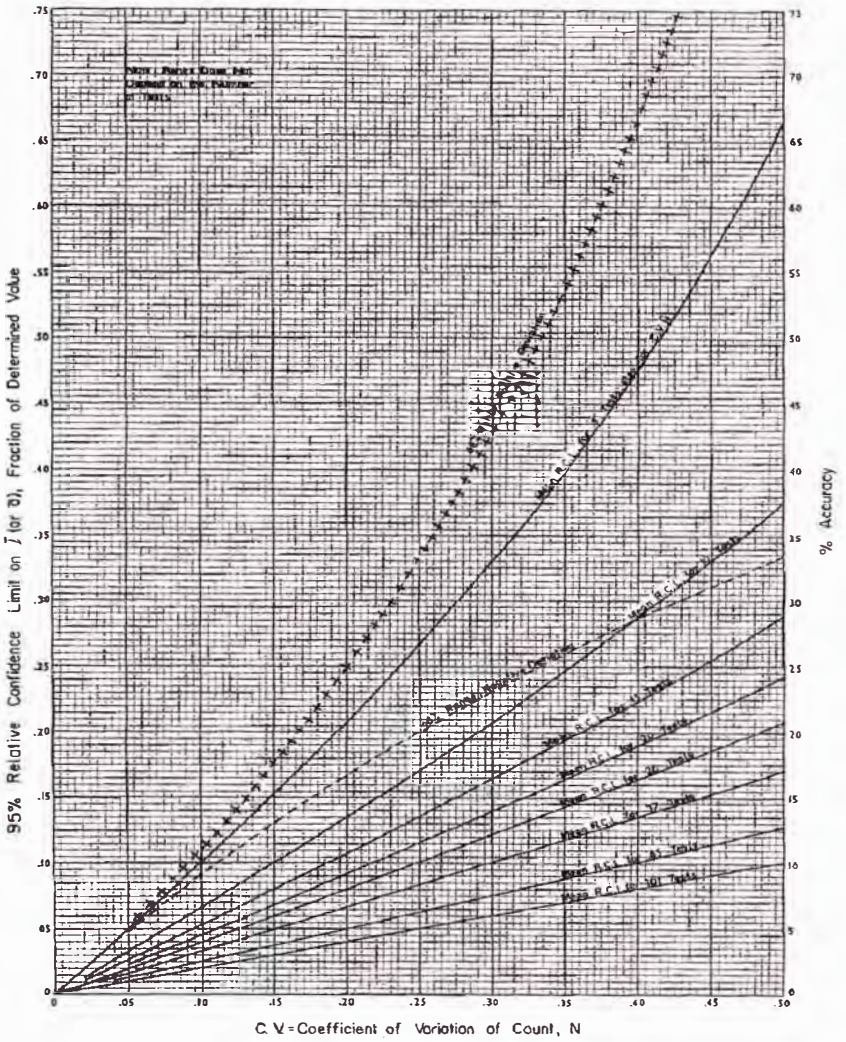


FIG. 9 Chart for Determination of Relative Confidence Limit on Estimation of Mean Intercept Distance

uncertainty is designated as "confidence limit" (C.L.) when expressed in the same units of measurement as the average itself. The term "relative confidence limit" (R.C.L.) is used when the C.L. is divided by the average measurement to yield a fractional or percentage uncertainty. On the logarithmic grain size number scale, the stated C.L. corresponds to, and normally is derived from, the R.C.L. of the average measurement.

13.1.1 Many specimens vary measurably in grain size from one field of view to another, this variation being responsible for a major portion of the uncertainty. Minimum effort in manual methods, to obtain a required precision, justifies individual counts whose precision is comparable to this natural variability (6). The high local precision that may be obtained by machine methods often will yield only a small increase in overall precision unless many fields also are measured, but does help distinguish natural variability from inaccuracies of counting. When the natural variability is higher than normal, it is desirable to indicate the range of sizes present as well as the precision of the average size determination.

13.2 The procedure of this section, originally developed as part of the Abrams procedure (7), should be applied to any circular or lineal intercept procedure in which five or more intercept counts are made for the same test pattern, each test being made on a different field (see 5.4). This procedure may

E 112

Sample number _____ Job number _____ Date _____

Material _____ Estimated grain size number _____

Processing _____ Magnification used for count _____ ×

Sectioning direction: L T N Method: Intercept ☐ Planimetric ○

Line Array: ◎ |× ||||| ☰ Length if NOT 500mm: _____

Observations				Confidence Limits
i Field no.	N_i no. of Intercepts	$\Delta N = N_i - \bar{N}$	$(\Delta N)^2$	C.V. = $\frac{S_o}{\bar{N}}$ = ___ = ☐
1				Using the C.V. calculated and Figure 8, determine the 95% confidence limit on the ASTM size number. Record below.
2				
3				Using the C.V. calculated and Figure 9, estimate the % Accuracy of the Mean Intercept Distance, $\bar{\ell}$.
4				
5				% Accuracy = ☐
Sum =		Sum$(\Delta N)^2$ =		Multiply the value of $\bar{\ell}$ by the accuracy of $\bar{\ell}$ and record the 95% confidence limit on $\bar{\ell}$.
$\bar{N}$ (average) = $\frac{Sum}{5}$ = ☐		V = $\frac{Sum}{4}$ =		← Record values for ASTM # and size on the report sheet.
$n\ell$ =	/mm	$S_o = \sqrt{V}$ =		
ASTM size number = ___ ± ___			(Fig. 6 + 8)	
$\bar{\ell}$ = Mean Intercept Distance = ___ ± ___			(Fig. 7 + 9)	

Additional Observations; (when necessary for required precision)

i	N_i	ΔN	$(\Delta N)^2$	i	N_i	ΔN	$(\Delta N)^2$
6				18			
7				19			
8				20			
9				21			
10				22			
11				23			
12				24			
13				25			
14				26			
15				Sum =		SUM$(\Delta N)^2$ =	
16				$\bar{N}$ =		V = $\frac{SUM}{i-1}$ =	
17				ASTM #		$S_o = \sqrt{V}$ =	

FIG. 10 Grain Size Worksheet

also be applied to five or more planimetric counts using the planimetric confidence limit scale at the right side of Fig. 8.[8] The procedure may be applied only to the directly observed quantities and number of counts, and may not be applied to any derived size measurements. A worksheet similar to that shown in Fig. 10[10] is helpful in following this procedure to obtain the confidence limit.

13.3 *Calculation*—Having recorded (i=) 5 or more count values obtained with the same test pattern applied to i fields, proceed as follows:

13.3.1 Calculate the average value of N, that is, $\bar{N} = (N_1 + N_2 + N_3 \ldots + N_i)/i$.

13.3.2 Calculate and record the i deviations (ΔN) from this average, where $\Delta N_i = N_i - \bar{N}$.

13.3.3 Square and record each ΔN value.

13.3.4 Calculate the variance of the observed coun about the unknown true $\bar{N}$ for the specimen as follows:

$$V_0 = [(\Delta N_1)^2 + (\Delta N_2)^2 + \ldots (\Delta N_i)^2]/(i - 1)$$

13.3.5 Calculate the apparent standard deviation of th counts as follows:

$$s_0 = \sqrt{V_0}$$

13.3.6 Calculate the coefficient of variation of N follows:

$$\text{C.V.} = s_0/\bar{N}$$

This coefficient of variation (C.V.) is expected to rema approximately constant when the number of tests is i creased. The C.V. is characteristic of the actual variability the material at the field size used, and of $\bar{N}$. It may be not that a C.V. that is markedly higher than shown in Table 6, an s_0 value markedly higher than $\sqrt{\bar{N}}$ indicates probat

[10] A pad of worksheets similar to Fig. 10 is available from ASTM Headquarters. Order PCN 12-501123-90. A combination of 23 components is also available. Order PCN 12-501120-28.

nonuniformity in the specimen.

13.4 The (95 %) confidence limits to be applied to the ASTM grain size number and to the mean intercept width, $\bar{l}$ (previously determined as in Section 11) may be read from Figs. 8 and 9,[9] respectively. Computed confidence limit (C.L.) values are shown for several selected numbers of tests.

13.4.1 Locate on Fig. 8 the C.V. value from 13.3.6 and determine the C.L. for ASTM size number at the line for the number of tests made. Attach this C.L. directly to the previously determined size number.

13.4.2 In the same way, determine the R.C.L. for intercept size from Fig. 9. This R.C.L. is shown as a fraction of the value of $\bar{l}$. Therefore multiply the value of $\bar{l}$ obtained from 12.4.3 by the R.C.L. from Fig. 9 and attach the resulting C.L. in length units to the previously determined value of $\bar{l}$.

13.4.3 If the C.V. value is abnormally large, determine the (standardized) positive and negative range limits for this C.V. from Fig. 8. Subtract the negative range limit from the previously determined mean size number and add the positive limit to this mean. Record the low and high values as the range of sizes encountered. Note that, unlike the confidence limit of the mean value, the range is expected to show little change when a larger number of tests are made. This range value nominally includes the size of 68 % of all of the possible fields, but since the variability of counting each field is included in the data used, a larger proportion of the actual fields will be included. Some observations outside the standardized range may always be expected. The fractional range limits for intercept size may be read from Fig. 9. After multiplying by $\bar{l}$, these ranges may be used to compute the low and high limiting values of $\bar{l}$.

13.4.4 If the confidence limit found for the average size is larger than has been specified, use Fig. 8 to select a number of tests that should be sufficient to attain the required C.L. at the same coefficient of variation. Make the necessary additional number of tests and recompute all parameters with the augmented data, including the tests originally made. However, if the required number of tests is not practical, make a reasonable number of additional tests and report the specimen to have variable size, showing the range of size numbers and of intercept widths determined as in 13.4.3, but using the newly determined C.V. value.

13.5 If the number of tests made (i) is different from any number shown in Figs. 8 and 9, or if more precision of computation is required, or if automated equipment is being used, the confidence limits and range limits may be computed directly. First, compute the "standard error of the mean count" as follows:

$$S_{\bar{N}} = S_0/\sqrt{i-1}$$

For the nominal 95 % confidence limit,

$$\text{C.L. of } \bar{N} = 2\, s_{\bar{N}}$$

Note that for 5 tests, these two steps cancel, yielding C.L. of $\bar{N} = s_0$. Now determine the limiting values of $\bar{N}$, that is, $\bar{N}$ − C.L. and $\bar{N}$ + C.L. Then, using equations shown in Annex A1.2, compute the mean and two limiting grain size values. Compute the two range values as the differences between the limiting sizes and the mean size. Both the magnification factor and the constant of the equation will drop out in this step; hence, actual values other than $\bar{N}$ + C.L. of $\bar{N}$ are not required. To obtain the confidence limit, average the absolute values of the two range values. A linear approximation for the values thus computed can ordinarily be substituted when the R.C.L. of $\bar{N}$ is not over 0.1. By approximation, the C.L. of ASTM size number is 2.9 × R.C.L. of $\bar{N}$ and the C.L. of intercept size ($\bar{l}$ is 1.01 × R.C.L. of $\bar{N}$ × $\bar{l}$.

NOTE 5—The small sample correction, $\sqrt{i-1}$, must be used twice, both in computing s_0 and in computing the C.L. of $\bar{N}$, to make allowance for the presence of two independent sources of variation, the fact that the test pattern rarely falls on a field in a position to give an extreme count value, and the fact that extreme fields are rarely included in a small number of tests.

13.6 *Example:*

13.6.1 Continuing with the five count values used in Example 1 of 12.4.3.1, the results of the steps in 13.3 and 13.4 are as follows:

13.6.1.1 $\bar{N} = 94$, the mean count.

13.6.1.2 The five differences, ΔN_i, are −2, −16, +15, −20 and +23.

13.6.1.3 Squaring each and summing the squares yields 1414.

13.6.1.4 The sum divided by $(i-1) = 4$ yields $V_0 = 353.5$ as the apparent variance of the material.

13.6.1.5 Taking the square root of 353.5 yields $s_0 = 18.80$ the standard deviation of observations.

13.6.1.6 Dividing s_0 by $\bar{N} = 94$ gives C.V. = 0.200 for the coefficient of variation of counts.

13.6.1.7 Turning to Fig. 8, C.V. = 0.20 is found on the horizontal scale and followed upward until the C.V. = 0.20 line intersects the 5-test line at 0.585, the 95 % confidence limit in ASTM size number. The ASTM grain size number is now written as 7.2 ± 0.6 (95 % C.L.).

13.6.1.8 Applying C.V. = 0.20 to Fig. 9, the R.C.L. for $\bar{l}$ is found to be 0.21, or 21 % of the determined value. The mean intercept width is now written $\bar{l} = 0.0265 \pm 0.0056$ mm, to be rounded to $\bar{l} = 0.027 \pm 0.006$ mm.

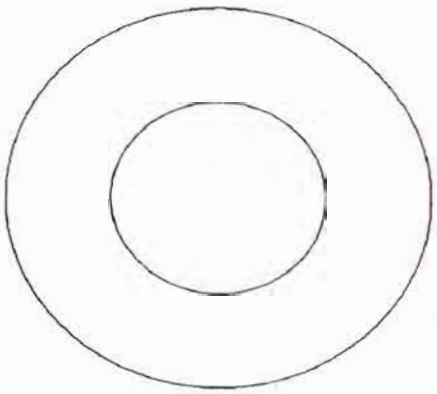
13.6.1.9 Recognizing that the C.V. of 0.20 is significantly higher than the value of 0.103 reasonably expected (see Table 6) for 5 tests at $\bar{N} = 94$, we consider the specimen to be actually variable and wish to show the grain size range. From Fig. 8 and at C.V. = 0.20, we find the deviations to be −0.64 and +0.53 and reexpress the ASTM grain size as range 6.6 to 7.7.

13.6.1.10 Having, however, been instructed to determine the mean grain size to the nearest ½ ASTM size number, we must make additional tests to obtain a 95 % C.L. of 0.25 number or less. Figure 8 indicates that this should be attained with a total of 26 counts if C.V. remains close to 0.20.

13.6.2 Twenty-one additional tests are made and the 26 counts computed together;

13.6.2.1 The new average count $\bar{N}$ turns out to be 101, corresponding to an ASTM size = 7.40 and an intercept size $\bar{l} = 0.0248$ mm (see 13.6.1.1).

13.6.2.2 The new C.V. value is 0.19, for which Fig. 8 indicates a C.L. of 0.22 size numbers for 26 tests. The final size number determination thus is 7.40 ± 0.22 (95 % C.L.) and is within the specified precision, with 7.5 being the nearest half grain size, rather than 7.0 uncertainly indicated by the first 5 tests (see 13.6.1.7).



NOTE—The small circle has a diameter of 79.8 mm and an area of 5 000 mm². The large circle has a diameter of 159.6 mm and an area of 20 000 mm².

FIG. 11 Test Pattern for Planimetric (Jeffries') Method

13.6.2.3 As the coefficient of variation changed only from 0.20 to 0.19, the specimen is still indicated to be variable, and we should indicate the size range. The limits are slightly revised to −0.61 and +0.50 number and with the corrected mean size now yields ASTM number: range 6.8 to 7.9, the width of the range being the same as found in the first 5 tests (see 13.6.1.9), but the entire band being raised 0.2 numbers by the improved mean value.

13.6.2.4 To complete the revised calculations, the C.L. for $\bar{l}$ is now found to be 0.08 × $\bar{l}$ or 0.002 mm, giving $\bar{l}$ = 0.025 ± 0.002 for the intercept size. The range of $\bar{l}$ at a C.V. of 0.19 is −16 and +27·% making the range statement $\bar{l}$ = 0.021 to 0.031 mm (see 13.6.1.8).

14. Effective Grain Size in Metals Containing Two or More Phases

14.1 *Scope:*

14.1.1 When a metal contains grains or particles of phases in addition to the matrix phase, the normal grain structure is modified or distorted and caution is required in applying grain size concepts. This section sets forth acceptable procedures for such cases.

14.1.2 The term *second phase particle* includes both phases deliberately formed in the microstructure and those accidentally present (inclusions). For the purpose of determining the effective average grain size of the matrix this distinction is to be ignored and all interruptions of the matrix treated equally.

14.1.3 The qualifying word *effective* is to be included to indicate that intercepts other than those due to normal grain boundaries are included in the determination. Unless otherwise indicated, the effective average grain size shall be presumed to be the size of the matrix phase. The term *effective particle size* is allowable as a condensation of effective grain size of . . . particles.

14.1.4 A second phase island in the microstructure may be known to have an internal structure, in some cases containing portions of the matrix phase. In determining the effective average grain size of the matrix, each such island shall be treated as a unit, either by measurement at a low magnification where the internal structure is not resolved or by omitting internal measurements from computations.

14.1.5 Where islands in the general microstructure are found to have an internal structure, the sizes of components of this internal structure may be determined or estimated (in the same manner as for the general structure) and reported separately. An appropriate higher magnification should be used, and measurements must be confined to the internal structure.

14.1.6 The identity of each measured phase, and the percentage of field area occupied by each phase, shall be included in the information reported.

14.2 *Comparison Procedure*—The comparison chart procedure may often be used with sufficient precision for most commercial purposes provided that: (*a*) the second phase is confined to islands having essentially the same size as the matrix grains; or (*b*) the concentration and particle size of the second phase are both small and the particles are located primarily at grain boundaries. The comparison procedure is not applicable if the second phase has caused appreciable distortion of the matrix grains from equiaxed shape.

14.3 *Planimetric Procedure*—The planimetric procedure may be applied provided that the second phase particles are located between matrix grains and do not occur as islands within matrix grains. The percentage of the test area occupied by the second phase must be separately determined and deducted from the test area. The effective average grain size then is determined from the number of grains per unit net area of the matrix phase. (See Practice E 562.)

14.4 *Modified Intercept (or Lineal Analysis) Procedure:*

14.4.1 The effective average grain size of a phase in a material containing two or more phases may, in all cases, be determined by a modified intercept procedure which includes the determination of the fraction of the field area occupied by this phase. The area fraction shall be determined as the fraction of test line length contributed by intercepts on this phase.

14.4.2 The use of manual lineal analysis in this application is entirely valid. However, the added effort of determining length increments for each phase usually dictates use of mechanical aids or of automated equipment. Use of integrating stage micrometer systems including at least 2 μm whose motions are additive, together with at least two mechanical counters, will allow manual operations at approximately the same speed as for the Heyn procedure (Section 11) for single phase materials. If fully automated

equipment is used, adequate precautions must be taken to ensure that: (*a*) all intersections are correctly counted and the intercept credited to the proper phases, and (*b*) the correct area, or line length in phase, is determined for each phase. The machine adjustments to meet these two requirements are not necessarily the same. When accuracies consistent with the required precision in size determination are not obtained with a single machine adjustment, successive scans of the same field using successive appropriate adjustments may be necessary for the different measurements.

14.4.3 The procedures to be used are similar to those given in Sections 10 and 11, with the additional provision that the test line is to be graduated in equal increments of a size resolvable under the selected conditions of observation. Increments of 1 mm are recommended for direct visual observations. A line of equally and closely spaced point observations may be used interchangeably. Each time the test line intercepts a grain, or portion thereof, of the phase being measured, one intercept shall be tallied and also the line length of this intercept shall be observed and accumulated. Separate tallies and length accumulations shall be made for each phase and may be made for each class of intersection if desired. At the end of each test, the primary size information shall be computed as follows: n_l = number of intersections per millimetre of test line on this phase at the specimen surface. The value of n_l or of $\bar{n}_l$, obtained by averaging the result of several tests, may be converted to effective ASTM average grain size number by use of Fig. 6, using the $500\times = n_l$ graph line. Conversion to effective intercept distance may be made using Fig. 7. Alternatively, the conversion may be found in Tables 2, 4, or 7, or computed by the equations in Annex A1.2. The total of intercept lengths divided by the total length of test lines gives the concentration of the measured phase.

14.4.4 An arbitrary choice must be made to use either the leading or trailing intersection of each intercept line as the control point which determines the phase to which the intercept tally and length increment shall be credited. When fractional intercepts occur at the ends of a test line, or at the edges of the scanned field, all fractional length increments shall be credited to the proper phase, but an intercept count shall be tallied only when this control point falls within the test line or field. Counts shall be tallied for intersections at grain boundaries and at the edges of all added phase particles. Counts normally are not tallied at twin boundaries, unless it has been specifically stated that the effective size of twin units is to be determined. Length increments on all second phase islands shall be credited to the proper phase. If it has been shown that a layer or film of an added phase exists at the grain boundary, the length increments corresponding to the apparent width of grain boundaries should be credited to this added phase. If the grain boundaries are judged free of added phase the apparent boundary width should be considered an artifact of etching and this apparent width included in the length credits to the matrix phase. If an unacceptable error arises from this cause, a separate determination of the area fraction arising from artificial grain boundary width may be made and used as a blank correction.

14.4.5 Knowledge of the distribution of actual intercept distances may sometimes be required, either for its own value or to allow separation of short intercepts with complex second phase islands. Two methods are available for making reasonable allowance for fractional intercepts at the ends of test lines. In the first method, all fractional intercepts at the ends of test lines are scored as ½ tallies, twice the measured length. This method yields the correct average intercept size, but may indicate a few intercepts longer than any actually present. An alternative system is available in which fractional intercepts whose control point falls within the measured field are measured and tallied in full by outward extension of the test line, using an otherwise unmeasured area called a guard band. Fractional intercepts at the opposite side of the field are discarded. Measurements in this method are made on an irregularly shaped field whose exact area is unknown and which may tend to be selective for longer objects. For this reason, the guard band method should never be used in determining mean intercept size or phase area percent.

14.5 The number of intercepts counted in each determination must in each case be sufficient to obtain statistical stability within the precision required by the application. Increased variability due to added phases will generally require that the minimum intercept count must be higher than the count values indicated in Sections 11 and 12, which apply to single phase metals only. As a minimum requirement, the customarily sufficient number of counts must be obtained for each phase measured. The required number of separate tests on different fields may also be increased, particularly if the second phase concentration is not uniform.

14.6 To combine the results of tests on several fields, the result of each test must be used in the form of n_l counts per millimetre on phase at the specimen. A worksheet similar to Fig. 10[9] may be used, using a separate worksheet for each phase measured. Statistical validation should be performed in accordance with the procedure of Section 13. This validation is independent of change of size, providing the fractional portions that will appear in n_l are carried in the computation of C.V. It should be noted that the number of tests adequate to give the required size precision for one phase may be insufficient to give the same precision for another phase.

14.7 *Use of a Parallel Array of Test Lines:*

14.7.1 Determination of the effective grain size by use of a parallel array of test lines, as usually necessary with automated equipment, is adequate provided the material has been demonstrated to be isotropic. When the structure is visibly anisotropic, two separate tests should be made on each field, applying the array in two mutually perpendicular principal directions. If the material is suspected to be anisotropic, but the principal directions are not obvious, the array should be measured while applied in each of several orientations. Tests in the third principal direction, on a surface perpendicular to the original, are required for complete size determination of an anisotropic material.

14.7.2 For each phase measured, the average count per unit length should be determined for each direction ($\bar{n}_l$, $\bar{n}_t$, $\bar{n}_n$), using the corresponding measurements from as many fields as have been found necessary. The average count in all directions is then determined by averaging $\bar{n}_l$, $\bar{n}_t$, and $\bar{n}_n$, as in 11.6.3. The final average effective grain size shall be determined from the final average $\bar{n}$. Subscripts showing effective

shape should be added, or the ratios of $\bar{n}$'s or of $\bar{l}$'s stated. Averaging by the method of 11.6.2 is not appropriate for effective grain size, because meaningful values of grains per cubic millimetre or per square millimetre are not produced for structures other than for an equiaxed single phase.

14.8 The effective intercept distance, sometimes designated as the mean free path ($\bar{l}_\alpha$) when for the matrix phase, or the mean intercept width ($\bar{l}_\beta$) or mean chord length when for dispersed particles, is an unbiased measurement of these distances in the solid body. Therefore, $\bar{l}$ should be reported for all structural types. The effective ASTM size number is primarily of interest for reasonably equiaxed shapes and need not necessarily be stated for other structures, such as eutectics or eutectoids. The effective ASTM size number is, however, useful for correlation with properties when a rational relation to the logarithm of actual size is expected. Use of this number, as the preferred logarithmic scale, will eliminate ambiguities which otherwise arise from use of differing measurement units. The micro size number scale may be extended upward indefinitely by use of equations in Annex A1.2.

14.9 The value obtained for effective average grain size will normally indicate a dimensionally smaller size than the grain size that would be obtained for the same material when treated as a single phase. Thus, the two types of size measurements cannot be freely interchanged in practical applications, and the distinction must be maintained. While beneficial effects on some properties may be found to correspond to the smaller effective size, possible adverse effects of added phases must also be considered, particularly when these are of incoherent types. The concentration and size information obtained for the added phases may be useful in this consideration. Additional information obtained by other evaluations, for example Test Method E 45 (for inclusions) may also be required. The effective size measurement procedure is provided purely as a potentially useful extension of geometrical methods, with no implication that these measurements can be substituted in any specific application.

15. Numerical Expressions of Grain Size

15.1 The average grain size, as estimated by any of the foregoing numerical methods, is originally indicated by counts of grain sections per unit area (n_a) or grain intercepts per unit length (n_l). These values are usually inconvenient for subsequent use. Hence, they are normally reexpressed as quantities such as nominal diameter, Feret's diameter, intercept size, specific surface, grains per unit volume, or ASTM microsize or macro-size numbers (see Annexes A1 and A2). Both customary and metric measuring units of varying magnitude are in use. Of these quantities, only the ASTM size numbers are independent of the units in which the measurements were made. To facilitate comparison of published size data in terms of a single scale, it is suggested that, whenever dimensional size units are employed as the initial statement, the ASTM grain size numbers be added in parentheses following the selected designation. The microsize number scale may be extended upward indefinitely and is not limited to the range shown in the tables and figures.

15.2 If it is desirable to express the average grain size representative of a group of specimens, the average of the individual values normally cannot be used. The various size expressions are related by reciprocal and logarithmic terms. Therefore, if the size of each specimen is represented on several different scales and the various representations averaged for the group, the resulting averages no longer are convertible from one to another. If there is a large number of specimens in the group, the mode or peak of the frequency distribution curve may be considered most characteristic. For fewer specimens, the size at the median of the group may be used. If an arithmetical average appears justified, it should be assumed that the original count densities are nearest to a normal or symmetrical distribution, and the average obtained by averaging the values of $\bar{n}_l$ or $\bar{n}_a$ for each specimen.

15.3 Mixed grain sizes sometimes are encountered, particularly in hot-worked metal. Any average of two distinctly different sizes, or size ranges, will usually result in a size that does not in fact exist in the specimen. Methods for characterizing mixed grain size are described in Test Methods E 1181.

16. Precision and Bias

16.1 For the precision and bias of the various methods see Sections 3, 5, 8, 10 to 14, and A5.

ANNEXES

(Mandatory Information)

A1. BASIS OF ASTM GRAIN SIZE NUMBERS

A1.1 Descriptions of Terms and Symbols

A1.1.1 The general term *grain size* is commonly used to designate size estimates or measurements made in several ways, employing various units of length, area, or volume. Of the various systems, only the ASTM grain size number, G, is essentially independent of the estimating system and measurement units used. The equations used to determine G from recommended measurements, as illustrated in Fig. 6 and Tables 2 and 4, are given in A1.2 and A1.3. The nominal relationships between commonly used measurements are given in Annex A2. Measurements that appear in these equations, or in equations in the text, are as follows:

A1.1.1.1 N = Number of grain sections counted on a known test area, A, or number of intercepts counted on a known test array of length = L, at some stated magnification, M. The average of counts on several fields is designated as $\bar{N}$.

A1.1.1.2 n = Number of grain sections or intercepts on a unit test area or length when corrected to unit magnification ($M = 1\times$) (see A2.1). After magnification correction, but for various test areas or lengths, $n_a = n/a$ = number of grain

APÉNDICE E

TABLA 1 DEL SAE J1123 NOV92

CROSS-SECTION TOLERANCES FOR LEAF SPRING FOR MOTOR VEHICLE SUSPENSION

the distance between the lines where load is applied under the specified conditions. Tolerance, ±3.0 mm.

5.5 Loaded Fixed End Length—Distance from the center of the fixed end eye to the projection on the datum line of the point where the centerline of the center bolt intersects the spring surface in contact with the spring seat. Tolerance, ±1.5 mm.

5.6 Straight Length—Distance between eye centers when the tension surface of the main leaf at the center bolt centerline is in the plane of the seat angle base line. The distance is measured parallel to the seat angle base line. Tolerance, ±3.0 mm.

5.7 Seat Length—Length of spring that is in actual engagement with the spring seat when installed on a vehicle at design height. It is always greater than the inactive length.

5.8 Inactive Length—Length of spring rendered inactive by the action of the U-bolts or clamping bolts.

5.9 Seat Angle (see Figure 1)—Angle between the tangent to the center of the spring seat and the seat angle base line. When the spring is viewed with the fixed end of the spring to the left as shown, and the load is applied to the shortest leaf from above, the seat angle may be specified as either positive (counterclockwise) or negative (clockwise), depending upon the angular direction in which the tangent to the center of the spring seat is disposed from the seat angle base line.

Consequently, with the spring in normal vehicle position so that the load is applied from below as shown in Figures 2, 4, 5, 6, and 7 and again with the fixed end of the spring to the left of the drawing, the seat angle is defined as positive when that tangent is disposed clockwise; and as negative when the tangent is disposed counterclockwise.

5.10 Finished Width—Width to which the spring leaves are ground or milled to give the edges a flat bearing surface. If the spring ends have a finished width, the required length of the finished edge must also be indicated. The usual tolerances for finished widths are as in Table 3.

5.11 Assembled Spring Width—Where more than one leaf constitutes a spring assembly, the overall width tolerance of the assembly within the spring seat length shall be as follows as in Table 4.

5.12 Stack Thickness—Aggregate of the nominal thicknesses of all leaves of the spring including any spacer plates which are part of the spring at the seat.

5.13 Leaf Ends—The leaf ends used most generally are:

a. Square as sheared
b. Trimmed to a shape
c. Taper rolled
d. Taper rolled; trimmed or forged to a shape or both

5.14 Surface Finish—Condition of the surface of the spring leaves after the steel has been heat treated and prior to coating.

5.14.1 "AS HEAT TREATED" FINISH—The surface of the spring leaves is in the condition as taken from the heat treating furnace where generally the leaves have a finish of oxide coating.

5.14.2 "SHOT PEENED" FINISH—The tension surface of the spring leaves has been exposed to the shot peening operation where the oxide coating and scale are removed and a matte luster finish is produced.

5.14.3 "GROUND OR POLISHED LEAF ENDS"—The bearing areas of leaves are ground or polished to produce a smooth surface for reduced friction. The distance or length to be ground or polished should be specified.

5.15 Protective Coating—Material added to surface of spring leaves or exposed areas of assembled springs. For additional information, see HS-J788.

5.16 Leaf Numbers (see Figure 1)—Leaves are designated by numbers, starting with the main leaf which is No. 1, the adjoining leaf is No. 2, and so on. If rebound leaves are used, the rebound leaf adjoining the main leaf is rebound leaf No. 1, the next one rebound leaf No. 2, and so on. (Rebound leaves are assembled adjacent to the side opposite the load bearing leaves.) Helper springs are considered as separate units.

5.17 Opening and Overall Height (see Figure 1)—Distance from the datum line to the point where the center bolt centerline intersects the surface of the spring that is in contact with the spring seat.

If the surface in contact with the seat is on the main leaf or a rebound leaf (as on underslung springs), this distance is called "opening."

If the surface in contact with the seat is on the shortest leaf (as on overslung springs), this distance is called "overall height."

TABLE 1—CROSS-SECTION TOLERANCES, mm

Width	Width Tolerance Minus 0.00	Tolerance In Thickness (±)[1] and In Flatness (-)[2] For Thickness 5.00-9.50	Tolerance In Thickness (±)[1] and In Flatness (-)[2] For Thickness 10.00-21.20	Tolerance In Thickness (±)[2] and In Flatness (-)[2] For Thickness 22.40-37.50	Maximum Difference In Thickness[3] For Thickness 5.00-9.50	Maximum Difference In Thickness[3] For Thickness 10.00-21.20	Maximum Difference In Thickness[3] For Thickness 22.40-37.50
40.0	+0.75	0.13	0.15	-	0.05	0.05	-
45.0	+0.75	0.13	0.15	-	0.05	0.05	-
50.0	+0.75	0.13	0.15	-	0.05	0.05	-
56.0	+0.75	0.13	0.15	-	0.05	0.05	-
63.0	+0.75	0.13	0.15	-	0.05	0.05	-
75.0	+1.15	0.15	0.20	0.30	0.08	0.10	0.15
90.0	+1.15	0.15	0.20	0.30	0.08	0.10	0.15
100.0	+1.15	0.15	0.20	0.30	0.08	0.10	0.15
125.0	+1.85	0.18	0.25	0.40	0.10	0.13	0.20
150.0	+2.30	-	0.30	0.50	-	0.15	0.25

1 Thickness measurements shall be taken at the edge of the bar where the flat surfaces intersect the rounded edge.
2 This tolerance represents the maximum amount by which the thickness at the center of the bar may be less than the thickness at the edges. Thickness at the center may never exceed the thickness at the edges.
3 Maximum difference in thickness between the two edges of each bar.

TABLE 2—SPECIFIED WIDTHS AND THICKNESSES OF ALLOY STEEL BARS, mm

Widths	Widths	Thicknesses	Thicknesses	Thicknesses	Thicknesses	Thicknesses	Thicknesses
40.0	75.0	5.00	7.10	10.00	14.00	20.00	28.00
45.0	80.0	5.30	7.50	10.60	15.00	21.20	30.00
50.0	100.0	5.60	8.00	11.20	16.00	22.40	31.50
56.0	125.0	6.00	8.50	11.80	17.00	23.60	33.50
63.0	150.0	6.30	9.00	12.50	18.00	25.00	35.50
		6.70	9.50	13.20	19.00	26.50	37.50

APÉNDICE F

SAE J406 FEB95

METHODS OF DETERMINING HARDENABILITY OF STEELS

1.22

(R) METHODS OF DETERMINING HARDENABILITY OF STEELS—SAE J406 FEB95

SAE Standard

Report of the Iron and Steel Division approved January 1942. Completely revised by the Iron and Steel Technical Committee—Division 8—Hardenability of Carbon and Alloy Steels, May 1985, November 1990, June 1993, and February 1995. Rationale statements available.

1. Scope—This SAE Standard prescribes the procedure for making hardenability tests and recording results on shallow and medium hardening steels, but not deep hardening steels that will normally air harden.

Included are procedures using the 25 mm (1 in) standard hardenability end-quench specimen for both medium and shallow hardening steels and subsize method for bars less than 32 mm (1-1/4 in) in diameter. Methods for determining case hardenability of carburized steels are given in SAE J1975.

Any hardenability test made under other conditions than those given in this document will not be deemed standard and will be subject to agreement between supplier and user. Whenever check tests are made, all laboratories concerned must arrange to use the same alternate procedure with reference to test specimen and method of grinding for hardness testing.

For routine testing of the hardenability of successive heats of steel required to have hardenability within certain limits, it is sufficient to designate hardenability simply in terms of distance from the quenched end to the point at which a certain hardness is obtained. This designation may also be adequate for comparing steels of different compositions to see whether they have similar hardenability.

Hardenability limits for specifying steel in this manner are obtained by measuring the hardenability of a steel which has proved satisfactory for the use intended. The hardenability test may be used in this way as an empirical test.

For new components where manufacturing experience is lacking, hardenability data may be effectively used to estimate the hardness profile provided by any given steel. Attendantly, the ability to predict hardenability from chemical composition has become increasingly important when comparing various steel grades or developing new steels for specific applications. One such procedure is described in Appendix A. Other hardenability prediction methods are available from the selected references in Section 2. However, it should be emphasized that the use of any hardenability prediction procedure does not preclude the importance of conducting Jominy end-quench tests to determine the actual hardenability of any specific grade of steel.

Hardenability data may be used to estimate hardnesses obtainable with any steel in new machine parts not yet in production and not similar to any parts on which production experience is available. Various hardenability application methods are described in the selected references, Section 2.1, 23 to 25. It appears none of these methods are precise, but these are often useful for estimation purposes. Final correlation on actual parts is necessary.

2. References

2.1 Applicable Documents—The following publications form a part of this specification to the extent specified herein. The latest issue of SAE Publications shall apply.

1. SAE J417 Hardness Test and Hardness Number Conversion
2. SAE EA 406 Hardenability Prediction Calculator
3. W. E. Jominy and A. L. Boegehold, "A Hardenability Test for Carburizing Steel," ASM Transactions, Vol. 26 (1938, No. 2, pp 574-599)
4. J. L. Burns, T. L. Moore, and R. S. Archer, "Quantitative Hardenability," ASM Transactions, Vol 26 (1938), No. 1, pp 1-33
5. W. E. Jominy, "A Hardenability Test for Shallow Hardening Steels," ASM Transactions, Vol. 27 (1939) pp 1072-1085
6. Symposium on Hardenability of Alloy Steels, ASM 1939
7. M. Asimow and M. A. Grossmann, "Hardening Characteristics of Various Shapes," AMS Transactions, Vol. 28 (1940) pp 949-977
8. "Standardization Sought in Determining the Hardenability of Steels" (A symposium), SAE Journal, Vol. 49, No. 1 (July 1941) pp 265-293
9. A. E. Focke, "Hardenability of Steel," Iron Age, Aug. 20, 1942 pp 37-40: Aug. 27, 1942, pp. 43-51; Sept. 3, 1942, pp 56-59
10. Morse Hill "The End-Quench Test: Reproducibility," ASM Transactions, Vol. 31 (1943), P 923 ff.
11. Symposium on the Hardenability of Steel, Special Report No. 36, British Iron and Steel Institute, 1946
12. G. K. Manning, "End Quench Hardenability Versus Hardness of Quenched Rounds," Metal Progress, Vol. 50, No. 4 (October 1946) pp 674-650
13. E. W. Wienman, R. F. Thomson, and A. L. Boegehold, "Correlation of End Quenched Test Bars and Rounds in Terms of Hardness and Cooling Characteristics," ASM Transactions, Vol. 44 (1952) pp 802-834
14. G. K. Manning, " Comparison of Tests of Hardenability of Shallow Hardening Steels," SAE Journal, Vol. 61, July 1953, pp 30-36
15. D. J. Carney, "Another Look at Quenchants, Cooling Rates and Hardenability," ASM Transactions, Vol. 46 (1954), pp 882-925
16. John Birtalan, R. G. Henley, Jr., and A. L. Christenson, "Thermal Reproducibility of the End-Quench Test," ASM Transactions, Vol. 46 (1954), P 928 ff
17. M. A. Grossman and R. L. Stephenson, "The Effect of Grain Size on Hardenability," ASM Transactions, Vol. 29 (1941), pp 1-19
18. M. A. Grossmann, "Hardenability Calculated from Chemical Compositions," AIME Transactions, Vol. 150 (1942) pp 227-259
19. I. R. Kramer, S. Siegel, and J. Brooks, "Factors for the Calculation of Hardenability," ASM Transactions, Vol. 163 (1946), p 670 ff
20. C. F. Jatczak and D. J. Girardi, "Multiplying Factors for the Calculation of Hardenability of Hypereutectoid Steels Hardened from 1700 F," ASM Transactions Vol. 51 (1960) p 335 ff
21. E. Just, "New Formulas for Calculating Hardenability Curves," Metal Progress, November 1969, pp 87-88
22. C. F. Jatczak, "Determining Hardenability from Composition," Metal Progress, Vol. 100, No. 3 (September 1971), p 60
23. D. H. Breen, G. H. Walter, C. J. Keith, and J. T. Sponzilli, "Computer-Based System Selects Optimum Cost Steels." Metal Progress, I: Dec. 1972, p. 42; II: Feb. 1973, p. 76; III: April 1973, p. 105; IV: June 1973, p. 83; V: Nov. 1973, p. 43
24. C. S. Siebert, D. V. Doane, and D. H. Breen, "The Hardenability of Steels," American Society for Metals, Metals Park, OH 1977, p 64 ff
25. D. V. Doane, J. S. Kirkaldy, "Hardenability Concepts with Applications to Steel," The Metallurgical Society of AIME, Warrendale, PA 1978
26. C. T. Kunze and G. Keil," A New Look at Boron Effectiveness in Heat Treated Steels," Symposium on Boron Steels, TMS-AIME, Milwaukee, WI Sept. 18, 1979
27. W. Hewitt, "Hardenability - Its Prediction form Chemical Compositions," Heat Treatment of Metals, Vol. 8, 1981, pp 33-38
28. Deb. M. C. Chaturvedi and A. K. Jena, "Analytical Representation of Hardenability Data for Steels," Metals Technology, 1982, Vol 9, p 76
29. J. M. Tartaglia and G. T. Eldis, "Core Hardenability Calculations for Carburizing Steels," Met. Trans., Vol. 15A, No. 6, June 1984, pp. 1173-1183

2.2 Related Documents—The following publications are provided for information purposes only and are not a required part of this document.

ASTM A 255, "End-quench Test for Hardenability of Steel"

JIS G 0561, "Method of Hardenability Testing (End-Quenching Method)"

DIN 50191, "Hardenability Testing of Steel by End Quenching"

3. Hardenability Test for Medium Hardening Steels

3.1 Introduction—This method covers the procedure for determining the hardenability of steel by the end-quench test for both the 25 mm (1 in) standard specimen and the subsize test specimen. Also included are charts for plotting hardenability test results and for predicting hardness U curves in various sizes of rounds.

Please note that in this revision the metric dimensions are shown to the nearest whole millimeter. Tolerances, where not indicated, are assumed to be ±0.5 mm or ±1/32 in (0.03 in).

3.2 Test Specimen—The test specimen is a 25 mm (1 in) diameter cylinder 102 mm (4 in) long with means for hanging it in a vertical position for end-quenching. Figure 1 shows a test specimen in the fixture ready for quenching illustrating the preferred form of specimen. Figure 2 gives the details of the preferred test specimen. Figure 3 is an example of an optional specimen which provides the same diameter and approximately the same length and which will provide satisfactory heat transfer characteristics.

The bar from which the specimen is machined shall be a forged or rolled 29 to 32 mm (1-1/8 to 1-1/4 in) round representing the full cross section of the product (or rolled 26 mm, 1-1/16 in, round if optional test specimen, Figure 3, is used). A cast specimen may be used in lieu of a rolled or forged specimen, except in the case of boron-treated steel; experience has shown that cast specimens of boron-treated steels give erratic results. The option of using as-cast specimens for non-boron steels, deletion of normalizing prior to heating for end-quenching or modification of other testing details shall be negotiated between supplier and user. It is of primary

importance that the specimen represent the full cross section of the ingot, cast bloom or cast billet since test specimens from a portion of the bloom, billet, or bar may introduce factors tending to affect the reproducibility of test results. The condition of this hot formed bar shall be such that there is no decarburization on the 25 mm (1 in) specimen machined from it. If any test specimen shows obvious defects or flaws, the specimen should be discarded and a new specimen obtained.

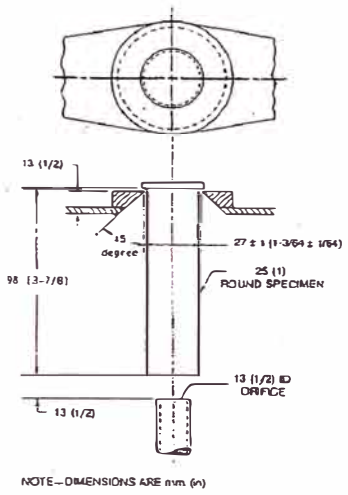


FIGURE 1—HARDENABILITY TEST SPECIMEN IN FIXTURE FOR WATER QUENCHING

3.3 Optional Specimen Preparation—The following method is satisfactory for most purposes, but for check testing against specifications, the method in the preceding paragraph is mandatory.

The test specimen shall be machined from the center of the bar in the case of sections from 32 to 51 mm (1-1/4 to 2 in) round or square. In sections over 51 mm (2 in), the test specimen shall be machined from one-half of the section with the axis of the specimen located at a point halfway between the center and surface of the bar and marked to identify the position of the test bar with reference to the original bar. The hardness readings shall be made on the two sides of the test specimen corresponding to a position in the bar approximately halfway between the center and the surface.

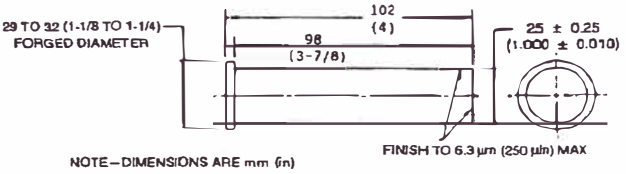


FIGURE 2—PREFERRED TEST SPECIMEN

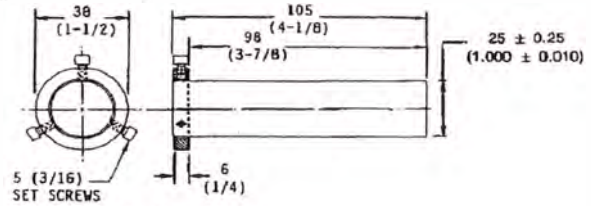


FIGURE 3—OPTIONAL TEST SPECIMEN

3.4 Normalizing Prior to Heating for End-Quenching—The forged or rolled round shall be normalized prior to machining the test specimen. This is of importance since the structure of material before the final austenitizing treatment may materially affect the hardening characteristics. In order that variations in prior structure may be controlled as much as possible, the normalizing temperature listed in Table 1 should be used. The steel shall be held at such temperature for 1 h and cooled to ambient in still air. If the normalized specimen is too hard, it may be given a short time temper at about 55 °C (100 °F) below the Ac_1 to improve machinability. *Cast specimens usually are not normalized before machining.* The record of hardenability test results must always state the prior thermal history of the specimen tested.

3.5 Heating for End-Quenching—The specimen shall be heated to the austenitizing temperature shown in Table 1. The specimen shall be placed in a furnace which is at the specified temperature and shall be held at this temperature for 30 to 35 min. It is necessary to determine by means of a thermocouple the time required for a test specimen to come to the required temperature.

While heating the test specimen it is important to insure that practically no scaling or decarburization takes place on the end to be quenched. This may be achieved through the use of protective furnace atmospheres or by placing the specimen in a container which maintains a non-oxidizing atmosphere, e.g., by placing fine graphite powder or cast iron chips in the base of the container.

Figure 4 illustrates a type of container which has been used with success. However, any similar type will be satisfactory.

TABLE 1—NORMALIZING AND QUENCHING TEMPERATURES[1,2]

APPLICABLE TO STEEL ORDERED TO END-QUENCH HARDENABILITY REQUIREMENTS

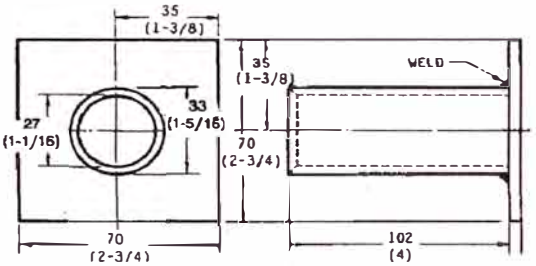
Maximum Ordered Carbon Content, %	Normalizing Temperature °C	Normalizing Temperature °F	Austenitizing Temperature °C	Austenitizing Temperature °F
Steel Series 1000, 1300, 1500, 4000, 4100, 4300, 4600, 4700, 5000, 5100, 6100[3], 8100, 8600, 8700, 8800, 9400				
Up to 0.25 incl	925	1700	825	1700
0.26 to 0.36 incl	900	1650	870	1600
0.37 and over[3]	870	1600	845	1550
Steel Series 4800, 9300				
Up to 0.25 incl	925	1700	845	1550
Steel Series 9200				
0.50 and over	900	1650	870	1600

[1] A variation of ±5 °C (±10 °F) from the above temperature is permissible.

[2] When testing H steels, the normalizing and austenitizing should be the same as for the equivalent standard steels. EXAMPLES: For 8622 H, the normalizing and austenitizing temperature should be the same as for SAE 8622; for 4032 H (carbon 0.30/0.37), the temperature should be the same as for SAE 4032 (carbon 0.30/0.35).

[3] Normalizing and austenitizing temperatures shall be 30 °C (50 °F) higher for the 6100 series.

1.24



NOTE—DIMENSIONS ARE mm (in)

FIGURE 4—SPECIMEN PROTECTING FIXTURE TO BE CONSTRUCTED OF HEAT-RESISTING ALLOY

3.6 **Quenching**—The test specimen shall be placed on a fixture so that a column of water at a temperature of 5 to 30 °C (40 to 85 °F) may be directed against the bottom face of the specimen. The column of water passing through an orifice 13 mm (1/2 in) in diameter shall rise to a free height of 63 mm (2-1/2 in) above the orifice. The fixture shall be dry at the beginning of each test.

In performing the test, the water supply shall be shut off with a quick-opening valve and the hot specimen placed over the water pipe so that the bottom of the specimen is 13 mm (1/2 in) from the opening of the water pipe and the water shall then be turned on. A preferred alternate procedure is to keep the water flowing, but impose a deflecting plate above the water pipe while transferring the test specimen from the furnace to the fixture, and quickly removing the plate to start the end-quench. The time between removal of the specimen from the furnace and the beginning of the quench shall be not more than 5 s. The sample shall remain on the fixture for at least 10 min. A condition of still air shall be maintained around the specimen during cooling. (If the quenched end of the specimen is not cool when removed from the fixture, investigate whether water temperature or water flow is within specification.)

3.7 **Hardness Measurement**—Two flats 180 degrees apart shall be ground to a minimum depth of 0.38 mm (0.015 in) along the entire length of the bar and Rockwell C hardness measurements made along the length of the bar. Deviation from the standard depth can affect reproducibility of test results, and correlation with cooling rates in quenched bars.

The preparation of the two flats must be carried out with considerable care. They should be mutually parallel and the grinding done in such a manner that no change of the quenched structure takes place. Very light passes (less than 0.013 mm (0.0005 in)) with water cooling and a coarse, soft grinding wheel are recommended to avoid overheating the specimen. To detect tempering due to grinding, the flats may be etched as follows:

Two etchant solutions are used:

No. 1—5% nitric acid (concentrated) and 95% water by volume.

No. 2—50% hydrochloric acid (concentrated) and 50% water by volume.

Wash the sample in hot water. Etch in solution No. 1 until black. Wash in hot water. Immerse in solution No. 2 for 3 s and wash in hot water. Dry in air blast.

The presence of lighter or darker areas indicates that hardness and structure have been altered in grinding. All structural changes caused by grinding shall be removed before hardness tests are made. This may be accomplished by resurfacing and again etching, or new flats may be prepared.

When hardness indentations are made, the test specimen must rest on one of its flats on an anvil firmly attached to the hardness machine. It is important that no vertical movement be allowed when the major load is applied. The fixture must be constructed to move the test specimen past the penetrator in accurate steps of 0.5 mm (for metric fixture) or 1/16 in (for U.S. customary fixture). (Resting specimen on a V-block is not permitted.)

Figure 5 is an example of a commercially available fixture which provides for the controlled movement of the specimen.

The Rockwell tester should be checked against standard test blocks before testing the hardenability specimen. It is recommended that the test block be interposed between the specimen and the indenter to check the seating of the indenter and the specimen simultaneously.

Care must be exercised in registering the point of the indenter with the hardened end of the specimen, as well as providing for accurate spacing between indentations. A low power measuring microscope is suitable for use in determining the distance from the quenched end to the center of the first indentation and in checking the distance from center to center of the succeeding indentation. It has been found that with reasonable operating care and a well-built fixture, it is practical to locate the center of the first indentation 1.5 mm ± 0.075 mm (0.0625 in ± 0.003 in) from the quenched end. The variations between spacings should be even smaller. Obviously, it is more important to position the indenter accurately when testing shallow hardenability steels than when testing medium hardenability steels. The positioning of the indenter should be checked with sufficient frequency to provide assurance that accuracy requirements are being met. In cases of lack of reproducibility or of differences between laboratories, indenter spacing should be measured immediately.

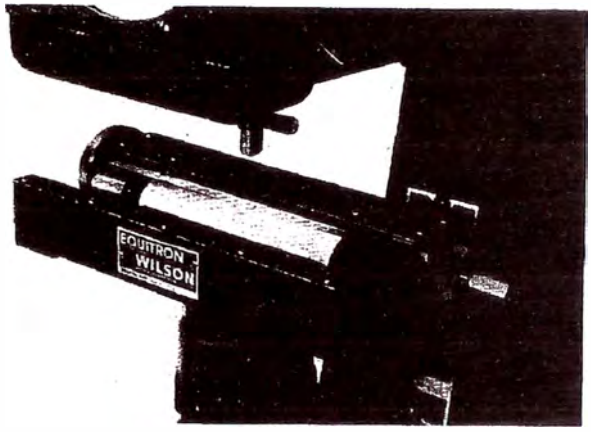


FIGURE 5—COMMERCIALLY AVAILABLE FIXTURE FOR POSITIONING SPECIMEN FOR HARDNESS INDENTATIONS

3.7.1 METRIC DISTANCES BETWEEN READINGS—Readings shall be taken at 1.5, 3, 5, 7, 9, 11, 13, and 15 mm, then at5 mm intervals to 50 mm, or until 20 HRC is reached (if less than 50 mm).

3.7.2 DISTANCES BETWEEN READINGS IN SIXTEENTHS OF AN INCH—Readings shall be taken at intervals of 1/16 in for the first inch. Distances between readings beyond 1 in may be at the discretion of the tester, but usually are taken at intervals of 1/8 in until 20 HRC is reached. (Less frequent intervals may be agreed upon between supplier and user.)

Hardness readings should be made on one flat, or preferably, two flats 180 degrees apart. When a flat on which readings have been made is used as a base, the ridges around the hardness indentations shall be removed by grinding unless a fixture is used which has been relieved to accommodate the irregularities due to the indentations. Testing on two flats will assist in the detection of errors in specimen preparation and hardness measurement. If the two probes on opposite sides differ by more than 4 HRC points at any one position, the test should be repeated on new flats, 90 degrees from the first two flats. If the retest also has greater than 4 HRC points spread, a new specimen should be tested.

For reporting purposes, hardness readings should be recorded to the nearest integer, with 0.5 HRC values rounded to the next higher integer.

3.8 **Plotting of Tests**—Tests should be plotted on a standard chart prepared for this purpose (Figure 6A or 6B) in which the ordinates represent hardness and the abscissas represent distance from the quenched end. Readings at identical distances should be averaged and the resultant values used for plotting.

Figures 6A and 6B are Standard Forms for Plotting Hardenability Curves.

3.9 **Construction of Hardness U Curves**—Charts are provided for using the hardenability curve to predict hardness U curves in various sized rounds when oil or water quenched. Figure 7 shows these charts. The curves show the locations in various sizes of rounds where the cooling rates are the same as at various positions along the end-quenched hardenability test bar. It should be noted that these curves assume good heat treatment practice—separation of parts in the quench, good agitation, and good control of temperature and cleanliness of the quenchant. The ranges given reflect variations found under laboratory conditions. Under production conditions, even wider variations may be found.

1.25

DATE _____
LABORATORY _____
TYPE SPECIMEN _____
TEST NO. _____

TYPE	HEAT NO.	GRAIN SIZE	C	Mn	P	S	Si	Ni	Cr	Mo		NORMAL, TEMP. °C	QUENCH TEMP. °C

REMARKS _____

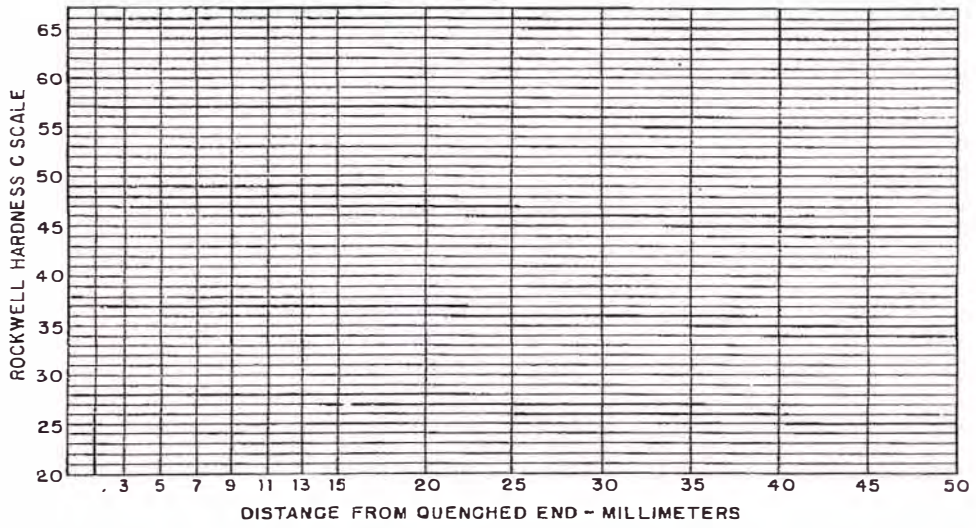


FIGURE 6A—STANDARD FORM FOR PLOTTING HARDENABILITY CURVES (MILLIMETER DISTANCES)

3.10 Subsize Test Specimen—For determining hardenability of steel received in bars less than 26 mm (1-1/16 in) in diameter, the test bar may be made 19, 13, or 6 mm (3/4, 1/2, or 1/4 in) in diameter, as desired, and end-quenched as prescribed for the 25 mm (1 in) round. Modifications in the water orifice are required for quenching cylinders of less than 25 mm (1 in) diameter. The details of orifices for quenching specimens less than 25 mm (1 in) diameter are given in Table 2.

Because of the greater air-cooling effect on test specimens less than 25 mm (1 in) diameter and especially in specimens smaller than 19 mm (3/4 in) diameter, the cooling rates at various distances from the quenched end will not be the same as in the standard test specimen.

Hardenability curves obtained from smaller specimens are not comparable with curves obtained from the 25 mm (1 in) round specimen. If the standard hardenability curve is needed from subsize specimens, it becomes necessary to determine the actual cooling rates on the subsize specimens.

4. Hardenability Tests for Shallow Hardening Steels—The 25 mm (1 in) standard hardenability specimen may be used to determine the hardenability of shallow hardening steels other than the carbon tool steels by a modification in the hardness survey. The procedure for preparing the specimen prior to hardness measurement is specified in 3.1 to 3.9 for standard 25 mm (1 in) hardenability specimens. An anvil providing a means of very accurately measuring the distance from the quenched end is essential.

Only two flats 180 degrees apart need be ground if the mechanical fixture has a grooved bed which will accommodate the indentations on the flat surveyed first. The second hardness traverse is made after turning the bar over. If the fixture does not have such a grooved bed, two pairs of flats should be ground, the flats of each pair being 180 degrees apart. The two hardness surveys are made on adjacent flats.

4.1 Procedure for Distance from the Quenched End in Millimeters—Hardness values are obtained from 1 to 15 mm in intervals of 1 mm. For this distance, two hardness traverses are made, each with hardness indentations 2 mm apart, one traverse starting at 1 mm from the quenched end, the other starting at 2 mm from the quenched end. Beyond 15 mm from the quenched end, intervals can be increased to 5 mm until 20 HRC is reached.

4.2 Procedure for Distance from the Quenched End in Sixteenths of an Inch—Hardness values are obtained from 1/16 to 8/16 in from the quenched end in intervals of 1/32 in. For this distance, two hardness traverses are made, each with hardness indentations 1/16 in apart, one traverse starting at 1/16 in from the quenched end, the other starting at 3/32 in from the quenched end. Beyond 8/16 in from the quenched end, intervals can be increased to a minimum of 2/16 in until 20 HRC is reached.

For plotting test results, the Standard Form for Plotting Hardenability Curves (Figure 6A or 6B) should be used.

1.26

DATE _____
LABORATORY _____
TYPE SPECIMEN _____
TEST NO. _____

TYPE	HEAT NO.	GRAIN SIZE	C	Mn	P	S	Si	Ni	Cr	Mo		NORMAL. TEMP. °F	QUENCH TEMP. °F

REMARKS _____

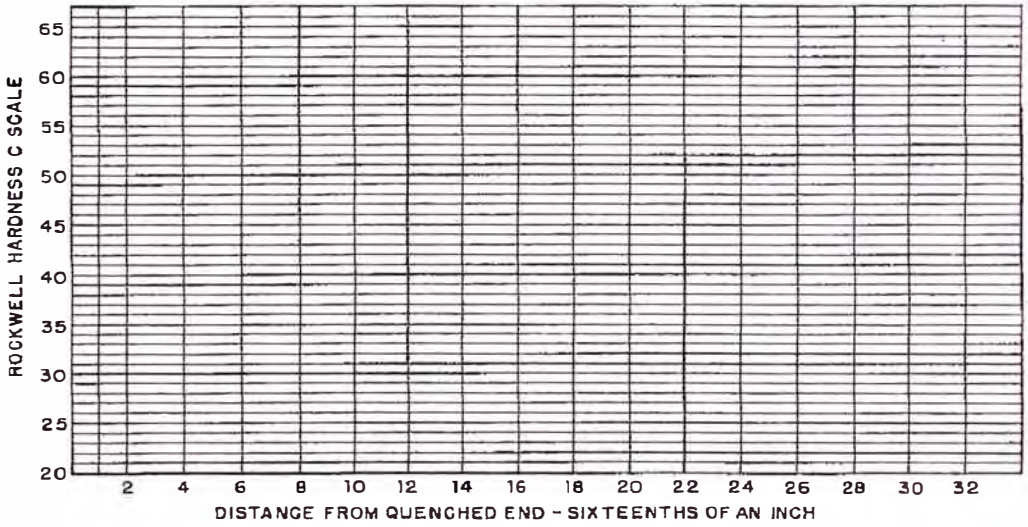


FIGURE 6B—STANDARD FORM FOR PLOTTING HARDENABILITY CURVES (SIXTEENTHS OF AN INCH DISTANCES)

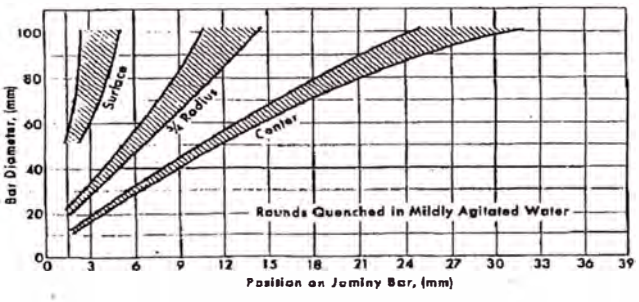


FIGURE 7A—CORRELATION OF COOLING RATES IN JOMINY BAR AND QUENCHED ROUND BARS

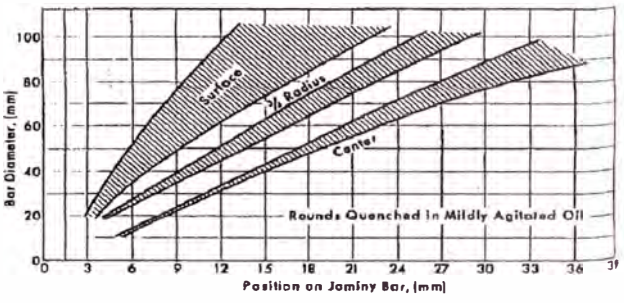


FIGURE 7B—CORRELATION OF COOLING RATES IN JOMINY BAR AND QUENCHED ROUND BARS

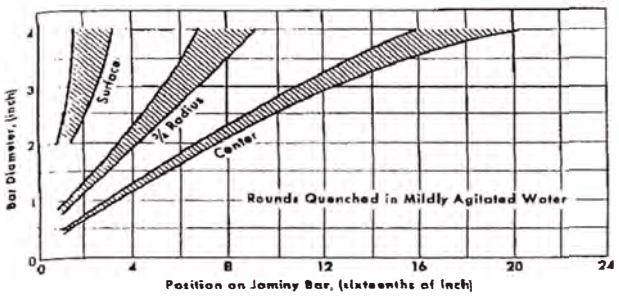


FIGURE 7C—CORRELATION OF COOLING RATES IN JOMINY BAR AND QUENCHED ROUND BARS

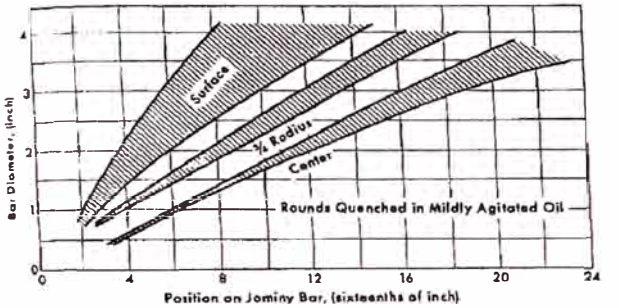


FIGURE 7D—CORRELATION OF COOLING RATES IN JOMINY BAR AND QUENCHED ROUND BARS

TABLE 2—ORIFICES FOR QUENCHING SUBSIZE SPECIMENS

Test Specimen Diameter mm (in)	Orifice Size mm (in)	Distance from Orifice to Quenched End of Specimen mm (in)	Free Height of Water Column mm (in)
19 (3/4)	13 (1/2)	13 (1/2)	63 (2-1/2)
13 (1/2)	6 (1/4)	10 (3/8)	102 (4)
6 (1/4)	3 (1/8)	6 (1/4)	203 (8)

APPENDIX A
METHOD FOR CALCULATING HARDENABILITY FROM COMPOSITION

A.1 Introduction—This method of Jominy hardenability calculation from the chemical ideal diameter[1] (D_I) of a steel is based on the original work of M. A. Grossman, Reference 18, and provides increased accuracy by refinement of the carbon multiplying factors and the correlation of a boron factor (B.F.) with carbon and alloy content. These refinements were based on analysis of thousands of heats of boron and non-boron 1500, 4100, 5000, and 8600 series steels encompassing a range of compositions as shown in Table A1 and a range of D_I as contained in Tables A9 to A12. The accuracy of this method and the techniques used to develop it have been documented, Reference 26. For comparison of this method to others, or for steel compositions outside the above-mentioned grades, the user should refer to other articles listed in Section 2.1. 17 to 29.

The succeeding paragraphs outline this method for calculating hardenability from chemical composition. The calculation method and data tables are also embodied in a computer program, BA406 "Hardenability Prediction Calculator" available through SAE. The program runs on an IBM compatible PC with a 3-1/2 in disc drive. It provides both tabular and graphical output of end-quench hardenability data calculated from chemical composition. To obtain a copy of the program, contact the SAE Customer Service Department, 400 Commonwealth Drive, Warrendale, PA 15096.

[1] D_I (or DI in some computer programs) represents the diameter of a round steel bar that will harden at the center to 50% martensite when subjected to an ideal quench (i.e., a Grossman quench severity H = infinity).

TABLE A1—COMPOSITION RANGE USED TO DEVELOP THE HARDENABILITY CALCULATION METHOD DESCRIBED IN THIS APPENDIX

Element[1]	Range (%)[1]
Carbon	0.10-0.70
Manganese	0.50-1.65
Silicon	0.15-0.60
Chromium	1.35 max
Nickel	1.50 max
Molybdenum	0.55 max

[1] For element percentages outside the ranges shown, and for elements not shown (copper and vanadium), the original Grossman factors are shown in Table A2.

A.2 D_I Calculation for Non-Boron Steels—This calculation relies on a series of hardenability factors (Table A2) for each alloying element in the composition which multiplied together give a D_I value. (For simplicity, only multiplying factors for D_I in inch units are given. For D_I in mm, the D_I in inches should be converted.) The effects of phosphorus and sulfur are not considered since they tend to cancel one another. A No. 7 austenitic grain size is assumed since most steels with hardenability control are melted to a fine grain practice where experience has demonstrated that an extremely high percentage of heats conform to this grain size. For austenitic grain sizes other than No. 7, Grossman's data suggest that the calculated D_I be increased about 8% for each grain size number less than 7 and decreased by about 8% for each grain size number greater than 7. Specific suggestions are:

a. For grain size 6 multiply D_I by 1.083
b. For grain size 5 multiply D_I by 1.172
c. For grain size 4 multiply D_I by 1.270

An example of D_I calculation is given in Table A3 for an SAE 4118 modified steel.

A.3 D_I Calculation for Boron Steels—With an effective steelmaking process, the boron factor (signifying the contribution of boron to increased hardenability) is an inverse function of the carbon and alloy content. The higher the carbon and/or alloy content the lower the boron factor.

A.3.1 Actual Boron Factor—The actual boron factor is expressed by the following relationship:

$$\text{B.F.} = \frac{\text{Measured } D_I \text{ from Jominy Data and Carbon Content}}{\text{Calculated } D_I \text{ from Composition Excluding Boron}} \qquad \text{(Eq.A1)}$$

Data for an actual boron factor determination are given in Table A4 for an SAE 15B30 modified steel.

A.3.1.1 STEP 1—Using Table A5, determine the nearest location on the end-quench curve where a hardness corresponding to 50% martensite occurs for the actual carbon content. For the example heat with 0.29% carbon this hardness is 37 HRC occurring at a "J" distance of 13 mm or 8/16 in from the quenched end.

A.3.1.2 STEP 2—From Table A6 (mm) or Table A7 (in), a "J" distance of 13 mm or 8/16 in equates to a measured DI of 76.4 mm or 2.97 in (interpolation may be required).

A.3.1.3 STEP 3

$$\text{Boron Factor} = \frac{76.4 \text{ mm}}{31.5 \text{ mm}} = 2.43 \qquad \text{(Eq.A2)}$$

or

$$\text{Boron Factor} = \frac{2.97 \text{ in}}{1.24 \text{ in}} = 2.4$$

NOTE—Difference in B.F. using inch versus mm is due to the use of nearest standard "J" distance. Use of exact "J" distances would resolve this difference.

A.3.2 Calculation of D_I with Boron (D_{I_B})

A.3.2.1 STEP 1—Calculate the D_I without boron. For the previous example, this D_I is 31.5 mm (1.24 in).

A.3.2.2 STEP 2—Calculate the alloy factor (the product of all the multiplying factors from Table A2 excluding carbon). For the previous example:

$$\text{Alloy Factor} = \frac{\text{Calculated } D_I \text{ (without Boron)}}{\text{Carbon Multiplying Factor}} = \frac{1.24 \text{ in}}{0.157 \text{ in}} = 8.0 \qquad \text{(Eq.A3)}$$

or

$$\text{Alloy Factor} = \frac{31.5 \text{ mm}}{0.157 \text{ in} \times 25.4 \text{ mm/in}} = 8.0 \qquad \text{(Eq.A4)}$$

APÉNDICE G

SAE J827 JUL94, SAE J2175 JUN91, SAE J444 MAY 93

NORMAS PARA LA GRANALLA DE ACERO FUNDIDO

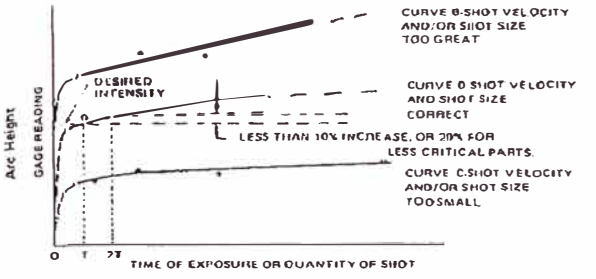


FIG. 2—INTENSITY DETERMINATION CURVES B, C, AND D

height between 10A and 14A as measured on a standard test strip "A" with 98% of part covered by dimples. Production parts are then peened for a time equivalent to that required to create this arc height—as determined on the saturation curve, and to visual coverage inspection. Because the shape and hardness of many parts differ from that of the test strip, peening time to achieve complete coverage may vary from the time required to saturate the test strip. Harder parts will require more time, softer parts will require less time. For optimum results, always peen a part with shot as hard or harder than the part to be peened.

7. Determination of surface area coverage—Full surface area coverage on part or test strip may be determined by using any one or combination of the following optional procedures:

(a) Inspect all (100%) surfaces of fillets, cavities, grooves, and holes using 10X magnification. A fully covered surface is indicated when it is covered by overlapping dimples which obliterate all prior surface definition.

(b)[1] Coat set-up part with fluorescent sensitive tracer. Peen part to intensity and exposure time determined in Step 6, then visually examine using ultra-violet light to view fluorescent tracer. Any indication of continuous residual fluorescent tracer on surface (minute flecks are acceptable) indicates that full coverage has not been obtained.

(c) Coat set-up part with dye marker ink. Peen part to intensity and exposure time determined in Step 6, then visually examine with white light for remains of dye marker ink. Any indication of continuous dye marker ink on surface (minute flecks are acceptable) indicates that full coverage has not been maintained.

(d) After a part has been shot peened, a transparent replica of the surface can be made. This replica can be compared with other replicas, having various degrees of coverage, by projection on a screen.

(e) Expose polished test strip to shot peening stream, identical to that used to determine arc height. Place in the field of metallurgical camera. Using transparent paper, and a magnification of approximately 50 diameters, outline the dented areas which can be identified by the contrast of the polished strip and the inclined surfaces of the indentations. Measure the area of all the indentations with a planimeter. The ratio of indented area to the total area is the percentage of coverage.

General Process Control—The process of peening, in common with many other processes, cannot at present be adequately controlled by nondestructive inspection of the peened parts, therefore, it is necessary to control the process itself to achieve consistent, reliable results. Measurements of surface residual stresses by X-ray diffraction (SAE J784a) can be a useful tool, where applicable, to monitor variations in shot peening process.

Shot—Shot should be initially inspected before using and also controlled throughout the peening cycle. The actual amount of sampling and inspection required will vary with each operation and with requirements for shot quality, cleanliness, etc. This control should serve as a check on the effectiveness of equipment, including the shot separator. The same reasoning applies to other peening media such as glass beads, slurries, etc.

Unless otherwise specified on the drawings, if only a minimum intensity is specified, the maximum intensity should not exceed the minimum intensity by more than 2C for C strip, 4A for A strip, and 6N for N strips. At all times, intensity is assumed to be at 98% coverage. The maximum intensity shall not cause undue warpage of the part and shall be below the threshold of erosion of the base material.

SAE Manuals on Shot Peening—SAE Manual on Shot Peening J808a, and Mechanical Prestressing Report SP 181, are recommended for supplementary information on the process.

[1] If a comparison of the sample test strip or part is made to previously prepared control specimens, the one making the comparison may be in violation of U. S. Pat. No. 3,950,642.

(R) HIGH CARBON CAST STEEL SHOT —SAE J827 JUL94

SAE Recommended Practice

Report of the Iron and Steel Technical Committee approved June 1962. Reaffirmed with editorial change January1969. Completely revised by the Fatigue, Design, and Evaluation Committee March 1990. Completely revised by the Surface Enhancement Division of the SAE Fatigue, Design, and Evaluation Committee July 1994.

1. Scope—This SAE Recommended Practice describes chemical composition, hardness, microstructure, and physical characteristic requirements for high carbon cast steel shot to be used for shot peening or blast cleaning operations.

2. References

2.1 **Applicable Documents**—The following publications form a part of this specification to the extent specified herein. The latest issue of SAE publications shall apply.

2.1.1 SAE PUBLICATIONS—Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

SAE J444—Cast Shot and Grit Size Specifications for Peening and Cleaning

SAE J445—Metallic Shot and Grit Mechanical Testing

2.1.2 ASTM PUBLICATIONS—Available from ASTM, 1916 Race Street, Philadelphia, PA 19103-1187.

ASTM B 215, Method B—Methods of Sampling Finished Lots of Metal Powders

ASTM E 140—Hardness Conversion Tables for Metals (Relationship Between Brinell Hardness, Vickers Hardness Rockwell Hardness, Rockwell Superficial Hardness, and Knoop Hardness)

ASTM E 384—Test Method for Microhardness of Materials

3. Description—High carbon cast steel shot is obtained by atomizing molten steel. The shot is heat treated and screened to produce a range of sizes from HCS70 to HCS1320 or larger as described in SAE J444.

4. Classification—Cast steel shot shall be identified by HCS for shot, followed by three numbers representing the size in ten thousandths of inches, in accordance with SAE J444.

EXAMPLE—HCS330 indicates a cast steel shot identified by a nominal sieve opening of 0.0331 in.

5. Chemical Composition—The finished shot shall have the chemical composition shown in Table 1:

TABLE 1—CHEMICAL COMPOSITION

Element	Weight Percent
Carbon	0.85 - 1.2%
Manganese	
HCS70 - HCS110	0.35 - 1.2%
HCS170	0.5 - 1.2%
HCS230 and up	0.6 - 1.2%
Silicon	0.4 - 1.50%
Sulfur	0.050% maximum
Phosphorous	0.050% maximum

6. Hardness

6.1 Standard Hardness—The hardness of 90% of all shot particles shall be within the range of 400 to 540 KHN (40 to 50 Rockwell C).

6.2 Special Hardnesses—Other hardnesses may be specified by the purchaser.

7. Microstructure—The microstructure of high carbon cast steel shot shall be uniform martensite, tempered to a degree consistent with the hardness range, with fine, well distributed carbides, if any.

8. General Appearance—High carbon cast steel shot is generally spherical and shall have no more than 20% of the particles with objectionable characteristics. Any one particle tested that has several different defects, shall only be counted once in the total.

8.1 Objectionable Characteristics

8.12

8.1.1 PARTICLE SHAPE—No more than 5% of the particles in a shot sample shall be elongated. An elongated particle is one whose length is in excess of twice the maximum particle width.

8.1.2 VOIDS—No more than 10% of the particles in a sample shall contain objectionable voids. Such a void is a smooth-surfaced, internal hole whose cross section is larger than 10% of the particle area.

8.1.3 SHRINKAGE—No more than 10% of the particles in a sample shall contain objectionable shrinkage. Such a shrinkage is an internal cavity with an irregular dendritic surface whose cross-sectional area is large than 40% of the particle area.

8.1.4 CRACKS—No more than 15% of the particles in a shot sample shall contain objectionable cracks. Such a crack is a linear discontinuity longer than three times its width, longer than 20% of the shortest cross section of the particle, and radial in orientation.

8.1.5 MICROSTRUCTURE—Carbide networks, partial decarburization, grain boundary segregation, and pearlite are undesirable. No more than 15% of the particles tested shall have these defects.

8.1.6 NONMAGNETIC MATERIAL—No more than 1% of the shot sample, by weight, shall be of nonmagnetic material.

9. Density—The density of high carbon cast steel shot shall be not less than 7 g/cc.

10. Mechanical Tests—To conform with pending revision of SAE J445 that supersedes REV AUG84.

11. Inspection Procedures

11.1 Sampling—Samples for testing shall be representative of each shipment or production lot. The method of sampling shall be ASTM B 215, Method B.

11.2 Sample Mounting for Testing—Shot samples used for testing for hardness, microstructure, and objectionable defects shall be mounted one layer deep in bakelite or other suitable strong metallurgical sample mounting media.

The mounted sample shall be ground to the center of the particles and polished by methods acceptable for microscopic examination. When grinding and polishing the sample, care must be taken not to overheat the sample and affect microstructure and/or hardness.

11.3 Hardness Testing—Hardness measurements shall be taken at the half radius of 10 particles in the mounted samples.

The hardness shall be determined by using ASTM E 384 and using a 4.9 N (500 gf) load for sizes HCS280 and finer, and 4.9 N or 9.8 N (500 or 1000 gf) load for sizes HCS330 and larger. Other microhardness test methods may be used as long as a reliable hardness conversion can be obtained by calibrating the test machine against known standards. Approximate conversion to Rockwell C Hardness Numbers can be obtained form ASTM 140.

11.4 Microstructure—The mounted and polished sample shall be etched with 2% Nital or other suitable etchant and examined at approximately 500X magnification.

11.5 Objectionable Characteristics—Objectionable characteristics shall be measured using a metallurgical microscope with 10X magnification. A minimum of 50 particles contained in the mount shall be evaluated.

11.6 Density—Density shall be determined by placing 50 mL of water or alcohol in a 100 mL graduate, adding 100 g of shot and recording the increase in volume. Dividing 100 g by the volume increase will give the density in g/cc. A pycnometer method may be used for more critical density measurements.

11.7 Nonmagnetic Material—A hand magnet will be used to separate the magnetic shot from the nonmagnetic contaminants. The nonmagnetic contaminants shall be weighed and their percentage of the original sample weight calculated.

11.8 Chemical Analysis—Any suitable ASTM Analytical procedure for steel may be used to test chemical composition.

SPECIFICATIONS FOR LOW CARBON CAST STEEL SHOT—SAE J2175 JUN91

SAE Recommended Practice

Report of the Surface Enhancement Subcommittee of the Fatigue, Design, and Evaluation Executive Committee approved June 1991.

1. Scope—This SAE Recommended Practice describes chemical analysis, hardness, microstructure, and physical characteristic requirements for low carbon cast steel shot to be used for shot peening or blast cleaning operations.

2. References

2.1 Applicable Documents—The following publications form a part of this specification to the extent specified herein. The latest issue of SAE publications shall apply.

2.1.1 SAE PUBLICATIONS—Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

SAE J444—Cast Shot and Grit Size Specifications for Peening and Cleaning

SAE J445—Metallic Shot and Grit Mechanical Testing

2.1.2 ASTM PUBLICATIONS—Available from ASTM, 1916 Race Street, Philadelphia, PA 19103.

ASTM A 370—Test Methods and Definitions for Mechanical Testing of Steel Products

ASTM E 384—Practice for Safeguarding Against Warpage and Distortion During Hot-Dip Galvanizing of Steel Assemblies

3. Description—Low carbon cast steel shot is the product obtained by atomizing and rapidly solidifying particles of molten steel in a controlled range of sizes. These shot particles are then screened to produce a range of sizes from LCS-70 to LCS-1320 or larger as described in SAE J444.

4. Classification—Low carbon cast steel shot shall be identified by LCS followed by the numbers representing the nominal size in ten thousandths of inches, in accordance with SAE J444, i.e., LCS-460.

5. Chemical Composition—The finished low carbon steel shot shall have the following chemical composition as listed in Table 1:

TABLE 1—CHEMICAL COMPOSITION

Low Carbon Steel Shot	Chemical Composition
Carbon	0.10 to 0.15%
Silicon	0.10 to 0.25%
Manganese	1.20 to 1.50%
Aluminum	0.05 to 0.15%
Phosphorus	0.035% maximum
Sulfur	0.035% maximum

6. Hardness—The hardness of 90% of all shot particles tested shall be within the range of 400 to 540 KHN (40 to 50 Rockwell C).

7. Microstructure—The microstructure of low carbon cast steel shot shall be an intermediate structure (bainite), a mechanical mixture of ferrite and cementite particles with random feather-like appearance (upper bainite) and accicular (lower bainite) with few or no free carbides, (see 8.1.5).

8. General Appearance—The low carbon steel shot shall be as spherical as commercially possible and no more than 20% of the shot particles shall have objectionable defects. Any one particle tested that has several different defects will only be counted once in the total. Notwithstanding the allowable percentages listed as follows, no more than a total of 20% objectionable particles are allowed.

8.1 Objectionable Defects

8.1.1 PARTICLE SHAPE—No more than 5% of the particles in a shot sample shall be elongated. An elongated particle is one whose length is in excess of twice the maximum particle width.

8.1.2 VOIDS—No more than 10% of the particles in a sample shall contain voids. A void is a smooth surfaced internal hole and must be greater than 10% of the particle to be considered harmful and counted as a void.

8.1.3 SHRINKAGE—No more than 10% of the particles in a sample shall contain shrinkage. A shrinkage area is an internal cavity with an irregular dendritic surface, and must be greater than 40% of the particle area to be considered harmful.

8.1.4 CRACKS—No more than 5% of the particles in a shot sample shall contain cracks. A crack is a linear discontinuity whose length is greater than three (3) times its width and its length is greater than 20% of the diameter or shortest dimension of the particle and radial in orientation.

8.1.5 MICROSTRUCTURE—Carbide networks, partial decarburization, and grain boundary segregation are undesirable. No more than 15% of the particles tested shall have these defects.

8.1.6 NONMAGNETIC MATERIAL—No more than 1% of the shot sample, by weight, shall be nonmagnetic material.

9. Density—The density of low carbon cast steel shot shall be not less than 7 g/cc.

10. Mechanical Tests—To conform with revised SAE J445.

11. Inspection Procedures

11.1 Sampling—Samples for chemical analysis, hardness, microstructure, density, objectionable defects, and mechanical testing shall be carefully obtained to be representative of each shipment of production lot.

11.2 Sample Mounting for Testing—Shot samples used for test-

ing for hardness, microstructure, and objectionable defects shall be mounted one layer deep in bakelite or other suitable strong metallurgical sample mounting media.

The mounted sample shall be ground to the center of the particle and polished by acceptable methods for examination using a microscope. When grinding and polishing the sample, care must be taken not to overheat the sample and affect microstructure and/or hardness.

11.3 Hardness Testing—Hardness measurements shall be taken at the half radius on a minimum of ten (10) randomly selected particles in the mounted sample.

The hardness shall be determined by using ASTM E 384 and using a 500 gf load for sizes LCS-280 and finer and 500 or 1000 gf load for sizes LCS-330 and larger. Other microhardness test methods may be used as long as a reliable hardness conversion can be obtained by calibrating various machines against known standards. Approximate conversions to Rockwell C hardness numbers are obtained from ASTM A 370.

11.4 Microstructures—The mounted and polished sample shall be etched with 2% Nital and examined at approximately 500X magnification.

11.5 Objectionable Defects—Objectionable defects shall be measured using a microscope with a 10X magnification. All of the particles contained in the mount shall be evaluated.

11.6 Density—Density shall be determined by placing 50 ml of ethanol or methanol in a 100 ml graduate, adding 100 g of shot and recording the increase in volume. Dividing 100 g by the volume increase will give the density in grams per cubic centimeter (cc). A pycnometer method may be used for more critical density measurements.

11.7 Nonmagnetic Material—A hand magnet shall be used to separate the magnetic shot from the nonmagetic contaminants. The nonmagnetic contaminants shall be weighed and the percentage of the original sample weight calculated.

11.8 Chemical Analysis—Any suitable ASTM analytical procedure for steel may be used to test chemical analysis.

(R) CAST SHOT AND GRIT SIZE SPECIFICATIONS FOR PEENING AND CLEANING—SAE J444 MAY93

SAE Recommended Practice

Report of the Production Division approved January 1946. Revised by the Mechanical Prestressing of Metals Division November 1976. Reaffirmed with change by the Fatigue, Design, and Evaluation Steering Committee August 1984. Completely revised by the Fatigue, Design, and Evaluation Committee May 1993.

1. Scope—This SAE Recommended Practice pertains to blast cleaning and shot peening and provides for standard cast shot and grit size numbers. For shot, this number corresponds with the opening of the nominal test sieve, in ten thousandths of inches[1], preceded by an S. For grit, this number corresponds with the sieve designation of the nominal test sieve with the prefix G added. These sieves are in accordance with ASTM E 11.

The accompanying shot and grit classifications and size designations were formulated by representatives of shot and grit suppliers, equipment manufacturers, and automotive users.

2. References

2.1 Applicable Document—The following publication forms a part of this specification to the extent specified herein.

2.1.1 ASTM PUBLICATION—Available from ASTM, 1916 Race Street, Philadelphia, PA 19103-1187.

ASTM E 11—Standard Specifications for Wire Cloth Sieves for Testing Purposes

2.2 Related Publications—The following publications are provided for information purposes only and are not a required part of this document. The latest issue of SAE publications shall apply.

2.2.1 SAE PUBLICATIONS—Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

SAE J445—Metallic Shot and Grit Mechanical Testing—For Information on Shot Durability Determination

SAE J827—Cast Steel Shot—For Information on Composition and Shapes

SAE J1993—Cast Steel Grit—For Information on Composition and Shapes

SAE J2175—Low Carbon Steel Shot—For Information on Composition and Shapes

3. Testing Procedure—Sieve Analysis

3.1 Equipment

3.1.1 A rotating and tapping type of testing machine shall be used.

3.1.1.1 The shaking speed shall be 275 to 295 rpm.

3.1.1.2 The taps per minute shall be 145 to 160 when tapping machines are used.

3.2 Sieves

3.2.1 The testing sieves shall be in accordance with ASTM E 11. They shall be of the 203 mm (8 in) diameter series, of either 25 mm (1 in) or 51 mm (2 in) height.

3.3 Procedure

3.3.1 A 100 g sample of the shot or grit shall be obtained from a representative quantity.

[1] Example: S-550 indicates a cast steel shot identified by a nominal sieve opening of 0.0555 in.

FIGURE 1—CAST SHOT SPECIFICATIONS FOR SHOT PEENING OR BLAST CLEANING

Sieve Opening Standard (mm)[1]	Sieve Designation	Nominal Sieve Opening (in)	Test Sieve Opening Size and Designation With Maximum and Minimum Cumulative Percentages Allowed on Corresponding Test Sieves — SAE Shot Number													
			S1320	S1110	S930	S780	S660	S550	S460	S390	S330	S280	S230	S170	S110	S70
4.75	4	(0.187)	All Pass	—	—	—	—	—	—	—	—	—	—	—	—	—
4.00	5	(0.157)	—	All Pass	—	—	—	—	—	—	—	—	—	—	—	—
3.35	6	(0.132)	90% min	—	All Pass	—	—	—	—	—	—	—	—	—	—	—
2.80	7	(0.111)	97% min	90% min	—	All Pass	—	—	—	—	—	—	—	—	—	—
2.36	8	(0.0937)	—	97% min	90% min	—	All Pass	—	—	—	—	—	—	—	—	—
2.00	10	(0.0787)	—	—	97% min	95% min	—	All Pass	All Pass	—	—	—	—	—	—	—
1.70	12	(0.0661)	—	—	—	97% min	85% min	—	5% max	All Pass	—	—	—	—	—	—
1.40	14	(0.0556)	—	—	—	—	97% min	85% min	—	5% max	All Pass	—	—	—	—	—
1.18	16	(0.0469)	—	—	—	—	—	97% min	85% min	—	5% max	All Pass	—	—	—	—
1.00	18	(0.0394)	—	—	—	—	—	—	95% min	85% min	—	5% max	All Pass	—	—	—
0.850	20	(0.0331)	—	—	—	—	—	—	—	95% min	85% min	—	10% max	All Pass	—	—
0.710	25	(0.0278)	—	—	—	—	—	—	—	—	95% min	85% min	—	10% max	—	—
0.600	30	(0.0234)	—	—	—	—	—	—	—	—	—	95% min	85% min	—	All Pass	—
0.500	35	(0.0197)	—	—	—	—	—	—	—	—	—	—	97% min	—	10% max	—
0.425	40	(0.0165)	—	—	—	—	—	—	—	—	—	—	—	85% min	—	All Pass
0.355	45	(0.0138)	—	—	—	—	—	—	—	—	—	—	—	97% min	—	10% max
0.300	50	(0.0117)	—	—	—	—	—	—	—	—	—	—	—	—	80% min	—
0.180	80	(0.0070)	—	—	—	—	—	—	—	—	—	—	—	—	90% min	80% min
0.125	120	(0.0049)	—	—	—	—	—	—	—	—	—	—	—	—	—	90% min
0.075	200	(0.0029)	—	—	—	—	—	—	—	—	—	—	—	—	—	—

[1] Corresponds to ISO Recommendations

8.14

3.3.2 The sample shall be placed on the top sieve of a stack of three or four sieves, depending on media and size (Figures 1 and 2). Nest the selected sieves and fit a pan to the bottom sieve.

3.3.3 The sample shall be run in the testing machine for 5 min ± 5 s for sizes using sieve designation 35 or coarser and 10 min ± 5 s for sizes using sieve designation finer than 35.

3.3.4 The stack of sieves shall be removed from the testing machine and the percentage of total weight shall be recorded for the media remaining on each sieve.

3.4 Any alternate method agreed upon by the supplier and the user which gives equivalent results will be acceptable.

FIGURE 2—CAST GRIT SPECIFICATIONS FOR BLAST CLEANING

Sieve Opening Standard	Sieve Designation	Nominal Sieve Opening	Test Sieve Opening Size and Designation With Maximum and Minimum Cumulative Percentages Allowed on Corresponding Test Sieves SAE Grit Number											
(mm[1])		(in)	G10	G12	G14	G16	G18	G25	G40	G50	G80	G120	G200	G325
4.75	4	(0.187)	—	—	—	—	—	—	—	—	—	—	—	—
4.00	5	(0.157)	—	—	—	—	—	—	—	—	—	—	—	—
3.35	6	(0.132)	—	—	—	—	—	—	—	—	—	—	—	—
2.80	7	(0.111)	All Pass	—	—	—	—	—	—	—	—	—	—	—
2.36	8	(0.0937)	—	All Pass	—	—	—	—	—	—	—	—	—	—
2.00	10	(0.0787)	80%	—	All Pass	—	—	—	—	—	—	—	—	—
1.70	12	(0.0661)	90%	80%	—	All Pass	—	—	—	—	—	—	—	—
1.40	14	(0.0555)	—	90%	80%	—	All Pass	—	—	—	—	—	—	—
1.18	16	(0.0469)	—	—	90%	75%	—	All Pass	—	—	—	—	—	—
1.00	18	(0.0394)	—	—	—	85%	75%	—	All Pass	—	—	—	—	—
0.850	20	(0.0331)	—	—	—	—	—	—	—	—	—	—	—	—
0.710	25	(0.0278)	—	—	—	—	85%	70%	—	All Pass	—	—	—	—
0.600	30	(0.0234)	—	—	—	—	—	—	—	—	—	—	—	—
0.500	35	(0.0197)	—	—	—	—	—	—	—	—	—	—	—	—
0.425	40	(0.0165)	—	—	—	—	—	80%	70%	—	All Pass	—	—	—
0.355	45	(0.0139)	—	—	—	—	—	—	—	—	—	—	—	—
0.300	50	(0.0117)	—	—	—	—	—	—	80%	65%	—	All Pass	—	—
0.180	80	(0.0070)	—	—	—	—	—	—	—	75%	65%	—	All Pass	—
0.125	120	(0.0049)	—	—	—	—	—	—	—	—	75%	80%	—	All Pass
0.075	200	(0.0029)	—	—	—	—	—	—	—	—	—	70%	65%	—
0.045	325	(0.0017)	—	—	—	—	—	—	—	—	—	—	65%	20%

[1] Corresponds to ISO Recommendations

(R) METALLIC SHOT AND GRIT MECHANICAL TESTING—SAE J445 APR96

SAE Information Report

Report of the Iron and Steel Technical Committee approved January 1957, revised June 1962, and reaffirmed August 1984. Completely revised by the Surface Enhancement Subcommittee of the SAE Fatigue, Design, and Evaluation Committee April 1996.

Foreword—Shot testing machines differ in detail, but are alike in the fundamental principle that a sample of shot is subjected to repeated impacts on a target. The percentage of breakdown is readily determined by means of a screen analysis. These data can be used to check the uniformity of shipments or to determine the relative fatigue life. The results obtained from testing machines are not intended to be used in establishing consumption or cost in production machines because of other considerations not duplicated in the laboratory. However, the machines can be used to test incoming shot for consistency and comparative life with previous shipments of the same type of shot from the same manufacturer under laboratory conditions. Some machines can be fitted with standard test strips[1] to measure energy transfer.

NOTE—Shot particles may be subject to multiple impacts in a test machine. The target material of test machines are made of hard steel to resist wear during testing. Hard shot is more elastic than soft shot. Due to these considerations and their influence on shot failure, care must be exercised when analyzing results from this accelerated, laboratory testing.

1. *Scope*—This SAE Information Report is intended to provide users and producers of metallic shot and grit[2] with general information on methods of mechanically testing metal shot in the laboratory.

2. *References*

2.1 Applicable Documents—The following publications form a part of this specification to the extent specified herein. Unless otherwise specified, the latest issue of SAE publications shall apply.

2.1.1 SAE PUBLICATIONS—Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

SAE J442—Test Strip, Holder, and Gage for Shot Peening

SAE J443—Procedures for Using Standard Shot Peening Test Strip

2.1.2 ASTM PUBLICATION—Available from ASTM, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959.

ASTM B 215—Methods of Sampling Finished Lots of Metal Powders

3. *Sampling*—Samples for testing shall be representative of each shipment or production lot. The method of sampling shall be ASTM B 215, Method B.

4. *Calibration*—Because results can be influenced by the condition of a test machine, the machine must be recalibrated according to the machine manufacturer's recommendation. This may be accomplished by reserving an adequate amount of shot of known life, and comparing the results obtained on tests with that of the "standard shot." The machine must be repaired or adjusted as necessary when off-standard conditions are observed.

5. *Examples of Test Procedures*

5.1 Average Life by Measurement of the Area Under the Breakdown Curve—If a representative sample of shot is observed as it is broken down in a testing machine, and the percent of the sample retained on a control sieve is plotted against the number of cycles, on rectangular coordinate paper, a breakdown curve typical of the shot is obtained. The control sieve aperture should be approximately equal to the removal size in the blast operation. The area under this curve is a measure of the average number of cycles required to reduce the size of the shot particles which pass through the control sieve. This average number of cycles, commonly referred to as the average life of the shot, is a complete evaluation of the life of the shot under the conditions of the test.

5.1.1 EXAMPLE PROCEDURE

a. Place 50 to 100 g of the sample to be tested into the test machine.
b. Run until about 20% passes through the control sieve.
c. Screen, weigh, and plot the percent retained on the control sieve against the number of cycles, using rectangular coordinate paper.

[1] See SAE J442 and SAE J443.
[2] Shot and grit will be hereafter referred to as shot.

APÉNDICE H

SAE J441 JUN93

CUT WIRE SHOT

For faster results, the alternate procedure given below gives a close approximation of density. In cases of dispute, however, the foregoing procedure should be used.

ALTERNATE PROCEDURE—Weigh the part in air, then coat the entire part with an air-drying transparent acrylic lacquer. The part is subsequently weighed again in air, then in water.

Density is calculated as follows:

$$D = \frac{A}{B - C}$$

where: A = weight of the original part in air, g
B = weight of the part in air after coating with lacquer, g
C = weight of the part immersed in water after coating with lacquer, g
D = density, g/cm³

NOTE: The foregoing methods give the density of the part in relation to the density of water at the testing temperature, that is, specific gravity. Although it is common practice to assume density and specific gravity to be equal, this is in fact not true since the maximum density of pure water is 0.999972 g/cm³ at 39.16°F (3.98°C) and decreases with increasing temperature.

The resulting error increases to 0.5% above 90°F (32°C) and to 2.5% at 210°F (99°C). It is therefore suggested that the test temperature be held below 80°F (26° C) in order to minimize the error.

(R) CUT WIRE SHOT —SAE J441 JUN93

SAE Recommended Practice

Report of the Iron and Steel Technical Committee approved January 1952 and revised by the Mechanical Prestressing Subcommittee of the Fatigue Design and Evaluation Committee May 1987. Completely revised by the SAE Surface Enhancement Committee of the SAE Fatigue, Design, and Evaluation Division June 1993.

1. Scope—This SAE Recommended Practice is considered to be tentative and is subject to modification to meet new developments or requirements. It is offered as a guide in the selection and use of cut wire shot.

2. References

2.1 Applicable Documents—The following publications form a part of this specification to the extent specified herein.

2.1.1 ASTM PUBLICATIONS—Available from ASTM, 1916 Race Street, Philadelphia, PA 19103-1187.

ASTM A 370—Test Methods and Definitions for Mechanical Testing of Steel Products

ASTM E 384—Test Method for Microhardness of Materials

3. Description—Cut wire shot shall be the product of carbon steel wire or stainless wire Type 302, 304, Condition B, Spring Temper, cut into the form of cylinders with lengths approximately equal to the wire diameter. Conditioned cut wire shot with edges prerounded shall be required for shot peening applications.

4. Classification—All cut wire shot shall be identified according to the wire size from which it is obtained. It shall be identified by the prefix letters CW meaning cut steel wire or SCW meaning stainless cut wire. This designation shall be followed by a two-digit suffix number equivalent to the mean diameter, in inches, of the wire from which the shot is produced times 1000 (see Table 1).

TABLE 1—WIRE DIAMETER USED FOR CUT WIRE SHOT

Shot Size	Mean Wire Diameter (mm)	Mean Wire Diameter (in)
SCW/CW-62	1.6	0.062
SCW/CW-54	1.4	0.054
SCW/CW-47	1.2	0.047
SCW/CW-41	1.0	0.041
SCW/CW-35	0.9	0.035
SCW/CW-32	0.8	0.032
SCW/CW-28	0.7	0.028
SCW/CW-23	0.6	0.023
SCW/CW-20	0.5	0.020
SCW/CW-17	0.45	0.017
SCW/CW-14	0.35	0.014
SCW/CW-12	0.30	0.012

5. Chemical Composition—The chemical composition shall conform to the following specifications:

5.1 Carbon Steel

Carbon: 0.45 to 0.85

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Manganese: 0.30 to 1.30
Phosphorus: 0.040 max
Sulphur: 0.050 max
Silicon: 0.15 to 0.35

5.2 **Stainless Steel**

Carbon: 0.15 max
Manganese: 2.00 max
Phosphorus: 0.045 max
Sulphur: 0.030 max
Silicon: 1.00 max
Chromium: 17.00 to 20.00
Nickel: 8.00 to 10.50

6. Tensile Properties—Shot shall be made from wire conforming to the tensile strengths shown in Table 2. In order to meet purchaser specified hardness requirements, other tensile strengths may be permitted.

TABLE 2—TENSILE PROPERTIES OF CUT WIRE SHOT

Shot Size (mm)	Shot Size (in)	Tensile Strength Carbon Steel Wire MPa	Tensile Strength Carbon Steel Wire (ksi)	Tensile Strength Stainless Steel Wire MPa	Tensile Strength Stainless Steel Wire (ksi)
1.6	SCW/CW-62	1630/1880	(237/272)	1758/1965	(255/285)
1.4	SCW/CW-54	1680/1820	(243/279)	1793/1999	(260/290)
1.2	SCW/CW-47	1710/1970	(248/286)	1606/2013	(262/292)
1.0	SCW/CW-41	1760/2020	(255/293)	1855/2062	(269/299)
0.9	SCW/CW-35	1800/2080	(261/301)	1882/2089	(273/303)
0.8	SCW/CW-32	1830/2110	(266/306)	1910/2117	(277/307)
0.7	SCW/CW-28	1870/2140	(271/311)	1972/2178	(286/316)
0.6	SCW/CW-23	1920/2200	(279/319)	2013/2220	(292/322)
0.5	SCW/CW-20	1950/2230	(283/323)	2068/2275	(300/330)
0.45	SCW/CW-17	1980/2250	(287/327)	2095/2300	(304/334)
0.35	SCW/CW-14	2010/2280	(291/331)	2135/2341	(310/340)
0.30	SCW/CW-12	2030/2300	(294/334)	2165/2370	(314/344)

7. Hardness—Carbon steel cut wire particles shall have a minimum hardness of 426 KHN (42 HRC). Stainless cut wire shot shall have a minimum hardness of 466 KHN (45 HRC). The hardness shall be determined per ASTM E 384 and using a 500 gf load for sizes CW-28 and finer or a 1000 gf load for sizes larger than CW-28. Other microhardness test methods may be used as long as a reliable hardness conversion can be obtained by calibrating various machines against known standards. Approximate conversions to Rockwell C Hardness Numbers (HRC) from Knoop Hardness Numbers (KHN) are obtained from ASTM A 370. Other hardness values can be specified by the purchaser.

8. Size Classification—Cut wire shot shall be made from wire of the diameters shown in Table 1. The weight of random as-cut particles shall be within the limits of Table 3. The weight of random conditioned particles shall be within the limits of Table 4. Shot sizes varying from those shown are available and may be obtained by arrangement between shot manufacturer and purchaser.

TABLE 3—WEIGHT LIMITS FOR AS-CUT PARTICLES

Shot Size (mm)	Shot Size (in)	Weight of 50 Random Pieces (grams)
1.6	SCW/CW-62	1.090 - 1.330
1.4	SCW/CW-54	0.720 - 0.880
1.2	SCW/CW-47	0.480 - 0.580
1.0	SCW/CW-41	0.310 - 0.390
0.9	SCW/CW-35	0.200 - 0.240
0.8	SCW/CW-32	0.140 - 0.180
0.7	SCW/CW-28	0.100 - 0.120
0.6	SCW/CW-23	0.050 - 0.070
0.5	SCW/CW-20	0.040 - 0.050
		Weight of 100 Random Pieces (grams)
0.45	SCW/CW-17	0.040 - 0.060
0.35	SCW/CW-14	0.020 - 0.040
0.30	SCW/CW-12	0.010 - 0.025

TABLE 4—WEIGHT LIMITS FOR CONDITIONED CUT WIRE SHOT

Shot Size (mm)	Shot Size (in)	Weight of 50 Random Pieces (grams)
1.6	SCW/CW-62	1.040 - 1.260
1.4	SCW/CW-54	0.660 - 0.840
1.2	SCW/CW-47	0.460 - 0.550
1.0	SCW/CW-41	0.290 - 0.370
0.9	SCW/CW-35	0.190 - 0.230
0.8	SCW/CW-32	0.130 - 0.170
0.7	SCW/CW-28	0.095 - 0.115
0.6	SCW/CW-23	0.045 - 0.065
0.5	SCW/CW-20	0.040 - 0.050
		Weight of 100 Random Pieces (grams)
0.45	SCW/CW-17	0.035 - 0.055
0.35	SCW/CW-14	0.020 - 0.040
0.30	SCW/CW-12	0.010 - 0.025

9. Inspection Procedure—Shot particles to be checked for hardness are to be mounted, ground, and polished to the centerline.

10. Soundness—As-cut shot particles shall be free of shear cracks and laps and shall not contain excessive seams or burrs. Conditioned particles shall be free of shear cracks and shall not contain excessive seams.

11. Packaging—This material shall be packaged to prevent loss during shipping and storage.

(R) TEST STRIP, HOLDER, AND GAGE FOR SHOT PEENING—SAE J442 JAN95

SAE Standard

Report of the Iron and Steel Technical Committee approved January 1952. Revised by the Fatigue Design and Evaluation Steering Committee November 1977. Editorial change August 1979. Completely revised by the Surface Enhancement Division of the SAE Fatigue, Design, and Evaluation Committee, January 1995.

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SAE J442 JAN95

TEST STRIP, HOLDER, AND GAGE FOR SHOT PEENING

8.06

Manganese: 0.30 to 1.30
Phosphorus: 0.040 max
Sulphur: 0.050 max
Silicon: 0.15 to 0.35

5.2 Stainless Steel

Carbon: 0.15 max
Manganese: 2.00 max
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Sulphur: 0.030 max
Silicon: 1.00 max
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0.35	SCW/CW-14	0.020 - 0.040
0.30	SCW/CW-12	0.010 - 0.025

TABLE 4—WEIGHT LIMITS FOR CONDITIONED CUT WIRE SHOT

Shot Size (mm)	Shot Size (in)	Weight of 50 Random Pieces (grams)
1.6	SCW/CW-62	1.040 - 1.260
1.4	SCW/CW-54	0.680 - 0.840
1.2	SCW/CW-47	0.460 - 0.550
1.0	SCW/CW-41	0.290 - 0.370
0.9	SCW/CW-35	0.190 - 0.230
0.8	SCW/CW-32	0.130 - 0.170
0.7	SCW/CW-28	0.095 - 0.115
0.6	SCW/CW-23	0.045 - 0.065
0.5	SCW/CW-20	0.040 - 0.050
		Weight of 100 Random Pieces (grams)
0.45	SCW/CW-17	0.035 - 0.055
0.35	SCW/CW-14	0.020 - 0.040
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9. Inspection Procedure—Shot particles to be checked for hardness are to be mounted, ground, and polished to the centerline.

10. Soundness—As-cut shot particles shall be free of shear cracks and laps and shall not contain excessive seams or burrs. Conditioned particles shall be free of shear cracks and shall not contain excessive seams.

11. Packaging—This material shall be packaged to prevent loss during shipping and storage.

(R) TEST STRIP, HOLDER, AND GAGE FOR SHOT PEENING—SAE J442 JAN95

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7.2 Superseded Intensity Designation
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FIGURE 2 ASSEMBLED TEST STRIP AND HOLDER
FIGURE 3 ALMEN GAGE

1. Scope—This SAE Standard defines requirements for equipment/supplies to be used in measuring shot peening intensity. Guidelines for the use of these articles (test strip, holding fixture, and gage) are also included.

2. References

2.1 **Applicable Documents**—The following publications form a part of this specification to the extent specified herein. The latest issue of SAE publications shall apply.

2.1.1 SAE PUBLICATION—Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

SAE J443—Procedures for Using Standard Shot Peening Test Strip

2.1.2 ASTM PUBLICATION—Available from ASTM, 1916 Race Street, Philadelphia, PA 19103-1187.

ASTM E 18—Standard Test Method for Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials

3. Outline of Method of Control—The control of a peening machine operation is primarily a matter of the control of the properties of a stream of shot in relation to the work being peened. The basis of measurement of these properties is as follows:

If a flat piece of steel (the test strip) is clamped to a solid block (the test strip holder) and then exposed to a stream of shot, it will be curved upon removal from the block. The curvature is due to residual compressive stresses induced by the shot impacts, causing the peened face to be convex. The curvature serves as a means of measuring the effect of the shot stream. The degree of the curvature depends upon the properties of the shot stream, the properties and mounting of the test strip, and the exposure condition.

3.1 **Properties**

3.1.1 SHOT STREAM—The properties of the shot stream are: shot material (includes chemical and physical characteristics), size, shape, velocity, directional consistency, and shot flow rate.

3.1.2 TEST STRIP—The properties of the test strip are: material (includes chemical and physical properties), hardness, physical dimensions, and the extent of any internal stresses. The properties of the test strip mounting are flatness, rigidity, and the location and force of the holding means.

3.1.3 EXPOSURE—The properties of exposure to the blast stream are length of time, angle of impact, and the degree of uniformity and consistency of the geometric relationship between the shot stream and test strip.

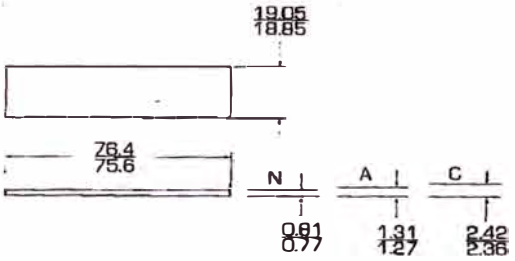
3.2 **Standards**—Based on these principles, the SAE has adopted the following standards: test strips, holding block, and gage. Specifications for these parts, the method of use, and a standard designation are presented herein.

4. Specifications of Intensity Measuring Equipment

4.1 **Test Strips and Holding Fixture**—Standard test strips, N, A, and C are shown in Figure 1 and test strip holder is shown in Figure 2. The approximate relationships between readings of test strips N, A, and C (for conditions of identical blast and exposure) are as follows:

C strip reading x 3.5 = A strip reading
A strip reading x 3.0 = N strip reading

4.2 **Gage**—The gage (Almen gage) for determining the curvature of the test strip must incorporate the elements shown in Figure 3. Curvature of the test strip is determined by a measurement of the height of the combined longitudinal and transverse arc across standard chords. This arc height is obtained by measuring the displacement of a central point on the nonpeened surface from the plane of four balls forming the corners of a particular rectangle. To use this gage, the test strip is located so that the indicator spindle bears against the center of the NONPEENED surface, one long edge of the strip bearing against the two back stops. The test strip is then centered by placing the ends even with the edges of the base, or by resting the ends against built-in end stop(s).



Flatness: Measured as the reading on the Almen gage for each strip type is as follows:
N - .025
A - .025
C - .038

Material: SAE 1070 cold rolled spring steel.

Edge Type: Number 1 round.

Finish: Plain tempered, all burrs removed.

Heat Treatment: All strips must be uniformly hardened and tempered at a minimum temperature of 371 degrees C (700 degrees F) to produce tempered martensite having a hardness, as measured on the surface, of HRC 44-50 (HRA 72.5-78.0 for the "N" strip).

Surface Carbon: Strips shall be free from alteration of surface carbon to the degree that any difference in average hardness between the surface and subsurface shall not exceed two points as measured on the Rockwell 30-N scale. The average of at least four readings in each region should be used to make the comparison. Any such determinations must be made on strips which have not been shot peened, and will preclude other use of a strip so tested. Surface hardness readings that are less than subsurface readings indicate evidence of decarburization. Surface readings which are higher than corresponding subsurface values indicate carburization.

Example:
If the average surface hardness is 62.5 on the Rockwell 30-N scale and, after careful grinding, a region below the surface is found to be 64.0 on the Rockwell 30-N scale - the strip is acceptable. If the subsurface reading had been 65.0 on the Rockwell 30-N scale, the difference (2.5 points) being over two points constitutes grounds for rejection.

FIGURE 1—TEST STRIP SPECIFICATIONS

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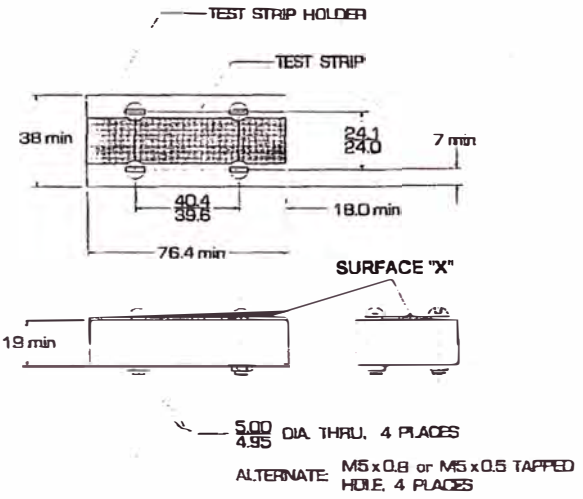


Recommended Material for Test Strip Holder - Any alloy or carbon steel, hardened to 57 HRC for a minimum depth of 0.7 mm. Alternate materials and thicknesses may be used when their wear and deformation characteristics do not adversely affect the performance of the test strip.

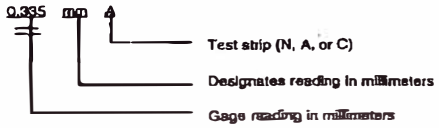
Use M 5 socket head button or pan head screws and hex or square nuts

Alternate: Use screws only in tapped holes.

FIGURE 2—ASSEMBLED TEST STRIP AND HOLDER

5. Designation Standard of Intensity Measurement

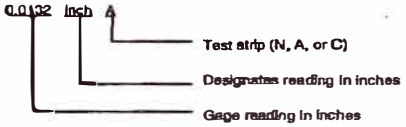
5.1 Primary Standard—The standard designation of intensity measurement includes the gage reading and the test strip used. It may be explained by the example shown in Figure 4:



This example signifies that the Almen Gage reading of the peened Almen A test strip as measured on the gage is 0.335 mm.

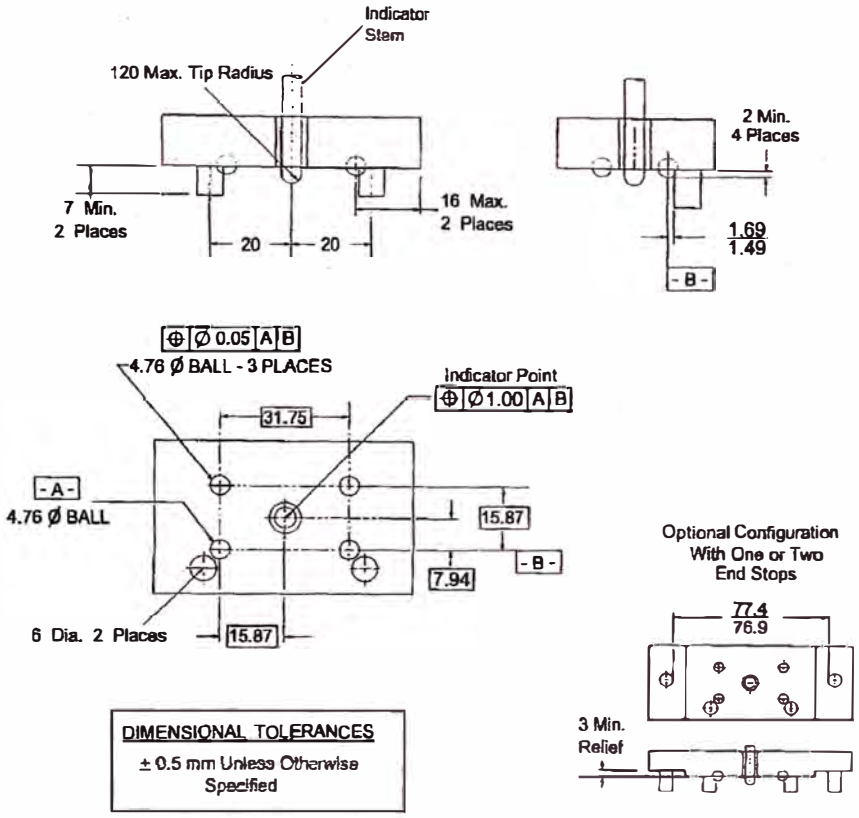
FIGURE 4—EXAMPLE OF STANDARD DESIGNATION OF INTENSITY MEASUREMENT

5.2 Transition Standard—Gages utilizing the inch-pound system (English units) may be encountered during the period of transition to SI. The designation of intensity measurement in this temporary alternate is explained in the example shown in Figure 5:



This example signifies that the Almen Gage reading of the peened A Strip as measured the gage is 0.0132 inch.

FIGURE 5—EXAMPLE OF DESIGNATION OF INTENSITY MEASUREMENT TEMPORARY ALTERNATE



Notes:

1. Four, 4.76 mm diameter, precision balls are installed in the test strip locating base. Balls must be in the same plane (perpendicular to the indicator stem) within .05 mm.
2. Digital or analog indicator must have .0025 mm graduations (maximum).
3. Maximum design indicator contact force - 25 gf.

FIGURE 3—ALMEN GAGE

6. *Maintenance, Calibration and Use*

6.1 Test Strips—After removal from the test strip holder, test strips should not be replaced, re-used, or shot peened for any additional time.

6.2 Holding Fixture—The test strip contact area of the holding fixture shall be checked for flatness on a periodic basis. Flatness of the test strip contact area shall not exceed 0.1 mm. In addition to a dimensional check for flatness, holding fixtures shall be checked visually for the following characteristics:

a. Burrs or raised material that can be caused by damage or excessive peening (particularly on the holding fixture end faces).
b. Particles of shot or beads that could become trapped under the test strip during installation.
c. Damage to threads that may prevent one or more screws from adequately holding the test strip in place.

6.3 Gage—Locating balls and indicator tip shall be checked periodically for wear. Any visual signs of wear shall be cause for repair of the gage such that new round surfaces are in contact with the test strip. The indicator shall be calibrated periodically over the range used for measuring test strips. The calibration tolerance for the indicator shall not exceed 0.005 mm. The use of calibration blocks, either flat, curved, or equipped with steps, is recommended.

7. *Notes*

7.1 Superseded Gage Designation—Two types of gages were formerly used to measure the arc height of test strips. The number 1 gage, which is obsolete, employed two knife edges to support the test strip; the number 2 gage (developed in 1943) uses four balls to locate the test strip in relation to the indicator stem. Some engineering criteria may continue to show the numeral "2" after the test strip letter, designating the use of a number 2 gage. This designation (such as A2) is neither required nor recommended. The gage defined by this SAE Standard uses the same locating scheme as the number 2 gage, and therefore will yield an equivalent reading.

7.2 Superseded Intensity Designation—The prior "dimensionless" value relating to the number of gradations read on the dial indicator has been discontinued in favor of direct reading in millimeters (inches).

APÉNDICE J

ANÁLISIS DE LA MATERIA PRIMA DE LAS PROBETAS

JIANGYIN XING CHENG SPECIAL STEEL WORKS CO LTD

NO.297 BINJIANG(E) ROAD,JIANGYIN CITY, JIANGSU PROVINCE,CHINA PC:214429

CERTIFICATE OF ANALYSIS

No. 11/33 R13-003/1-02-E

Date: OCT.27.2010

ID:1100000005814

TO: INDUSTRIA PERUANA DEL ACERO S.A..
AV, REPUBLICA DE PANAMA 4085 LIMA 34, PERU

DESCRIPT. OF GOODS: HOT ROLLED SPRING STEEL FLAT BARS

INVOICE NO.: XPE007C CONTRACT NO.:XPE007 L/C NO. 732956

Size(MM): 9.00×70.00 mm Grade: SAE5160H1

序号 No	炉号 Heat No	生产批号 Prod No	件数 bundles	重量 Net Weight (MT)	C(%) X10²	Si(%) X10²	Mn(%) X10²	P(%) X10³	S(%) X10³	Cr(%) X10²
MIN-					56	15	75	0	0	70
MAX-					65	35	110	25	25	90
4	R31004E22VX	P1011088	16	28.614	60	21	89	16	12	83

序号 No	Ni 级 Grade	Cr 级 Grade	Si 级 Grade	A细 Thin 级 Grade	A粗 Heavy 级 Grade	B细 Thin 级 Grade	B粗 Heavy 级 Grade	C细 Thin 级 Grade	C粗 Heavy 级 Grade	D细 Thin 级 Grade	D粗 Heavy 级 Grade	晶粒度 Grain Size 级 Grade	脱碳层 Decarburized Layer mm	J1.5 HRC	J3 HRC	J5 HRC	J7 HRC	J9 HRC	J11 HRC	J13 HRC	J15 HRC	硬度 Hardness HBW
MIN-														60								
MAX-														99								
4	1.0	1.0	1.0	2.0	0.0	0.5	0.0	0.0	0.0	0.5	0.5	8	0.1	62	61.5	61	60.5	59.5	57.5	56	54.5	306
	1.0	1.0	1.0	2.0	0.0	0.5	0.0	0.0	0.0	0.5	0.5		0.11									306
				1.5	0.0	0.5	0.0	0.0	0.0	0.5	0.5		0.1									304
				1.5	0.0	0.5	0.0	0.0	0.0	0.5	0.5											
				1.5	0.0	0.5	0.0	0.0	0.0	0.5	0.0											
				1.5	0.0	0.5	0.0	0.0	0.0	1.0	0.0											

说明 如发现偏析中白点、皮下气泡、宏观夹杂等标准规定不允许有的缺陷，我们均保证符合标准出厂。有异议时，来函请标明钢号、批号、规格、发货日期、原因，并将实物保管好。
No impermissible macro-structural defects, such as flakes, subsurface bubbles and macro inclusions are available. When there is any complain, you are kindly requested to mark the Steel Grade, Heat No., Size, Delivery Data, Causes and , materials in the condition. This certificate is wrritten according to EN 10204 3.1
材料的表面质量和外形尺寸均合格 Surface quality and shape size of material are all qualified *0031=0+N+H

备注

INDUSTRIA PERUANA DEL ACERO S.A.
LABORATORIO DE CONTROL DE CALIDAD

ANALISIS METALOGRAFICO

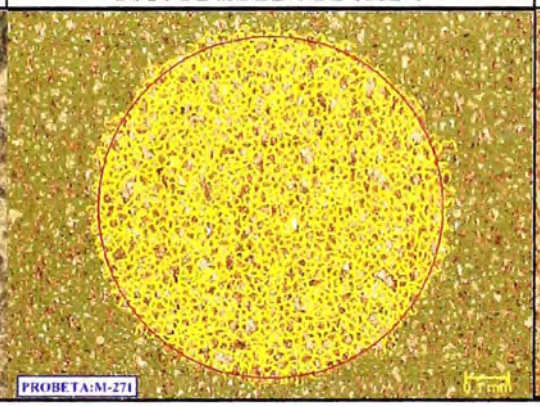
ANALISIS N°: 094/10Lab.	**FECHA:** 22/12/2010	**MUESTRA CODIGO N° :** 271
MATERIAL: 70 x 9 mm		**PROVEEDOR:** Jiangyin Xingcheng Special Steel
PROCEDENCIA: Shanghai - CHINA		**VAPOR:** LINGUE
N° COLADA: R31004822VX		**TIPO DE EVALUACION:** Evaluación de Materia Prima
O/C : 156 2010	**N° ATADO:** 822-2	**Recepción**

TRATAMIENTO TERMICO

MATERIA PRIMA : Barra Maciza de Acero SAE 5160H			**DUREZA (HB):** 301
ENSAYO DE TEMPLE	**TEMP.°C :** -	**TIEMPO PERMAN. :** -	**DUREZA (HB):**
ENSAYO DE REVENIDO	**TEMP.°C :** -	**TIEMPO PERMAN. :** -	**DUREZA (HB):**

EXAMEN METALOGRAFICO

SEGREGACIONES: No Presenta					**AUMENTO:**	100X
DESCARBURIZACIÓN: Presenta 0.051 mm de profundidad					**AUMENTO:**	100X
INCLUSIONES NO METALICAS **NORMA ASTM E-45**	**OXIDO GLOB.:**D-3 5	**SILICATOS:**C-3	**ALUMINA:** -	**SULFURO:**	**AUMENTO:**	100X
	SERIE : Fina	**SERIE :** Fina	**SERIE :** -	**SERIE :** -		
TAMAÑO DE GRANO **NORMA ASTM E-112**	8				**AUMENTO:**	100X
MICROESTRUCTURA	**%PERLITA LAM.**	**% FERRITA**	**%MARTEN.**	**%C. CALCUL.**	**R. ATAQUE**	**AUMENTO**
	73.48	26.52	-	0.59	Picral	1000X

FOTO DE MICROESTRUCTURA	FOTO DE TAMAÑO DE GRANO	FOTO DE SEGREGACIONES B.
		

OBSERVACIONES:

. La muestra para la sección longitudinal se tomo de la parte central de la barra de acero.

. Tiene como microcontituventes: Perlita Laminar y Ferrita

. No se observó presencia de segregaciones bandeadas en su microestructura.

. Resultados del analisis quimico: **%C** = 0.59 **%S** = 0.017

CONCLUSIONES:

Material cumple con especificaciones metalograficas

INSPECCIONADO POR: Ing.W. Magallanes H.	**REVISADO POR:** Bach.José Carlos Valdiviezo G.

APÉNDICE K

CERTIFICADOS DE CALIBRACIÓN DEL STAGE MICROMETER PATRON Y DE LOS PATRONES DE CARBONO Y AZUFRE

KLARMANN RULINGS, INC.
Precision Optical Patterns

480 Charles Bancroft Highway, Litchfield, New Hampshire 03052
reticles.com Email: sales@reticles.com
Phone: 603/424-2401 800/252-2401 Fax: 603/424-0970

CERTIFICATE OF CALIBRATION

CUSTOMER	Industria Peruana Del Acero S.A. Av. Republica de Panama 4085 Lima 34 - Peru
INSTRUMENT	Stage Micrometer P/N KR-851
MAKE	Klarmann Rulings, Inc.
SERIAL NUMBER	11371
TEST NUMBER	083109-01
DATE CALIBRATED	August 31, 2009
CONDITION OF INSTRUMENT	__X__ GOOD ___ FAIR ___ POOR

This is to certify that the above listed instrument has been calibrated by Klarmann Rulings, Inc.
Calibrated at 74.0 +/-2 Degrees F, Relative Humidity 56+/-5% using Cal Pro 001(edge to edge method at the vertical mid point of the shortest line group)

The Standard used is as follows:
KLARMANN RULINGS, INC. STAGE MICROMETER SERIAL NUMBER
5181 CALIBRATED BY THE N.I.S.T. TEST NUMBER 821/273087-06

The Measuring Instrument used is as follows:
OLYMPUS STM MEASURING MICROSCOPE WITH AN OVERALL ACCURACY
OF +/- .00002"/.0004MM WITH A TOTAL ESTIMATED UNCERTAINTY OF +/-.00003"/.0006MM
Our measuring instrument was last calibrated on July 8, 2009
Our next calibration is due on October 8, 2009

The Calibration Department of Klarmann Rulings, Inc. is accredited to ISO/IEC 17025:2005 "General requirements for the competence of testing and calibration laboratories". Our calibration system is reviewed and tested by our Quality Control Manager in accordance with Klarmann Rulings, Inc. Quality Procedures. Our measuring instrument is calibrated four times yearly, using standards that are calibrated by the N.I.S.T and verified twice daily.
This certificate of calibration shall not be reproduced, except in full, without the written approval of Klarmann Rulings, Inc.

The entire system is subject to review at any time by our Government Quality Assurance Representative and/or our accrediting body.

Keith Kurowski
Q. C. Manager

Date Calibrated: August 31, 2009

Serial Number: 11371

Stage Micrometer per P/N KR-851 (1mm in 100 divisions)

Glass: 1" x 3"

Actual readings are as follows:

0	10 Div. =	0.1004mm
0	20 Div. =	0.2000mm
0	30 Div. =	0.3004mm
0	40 Div. =	0.4004mm
0 -	50 Div. =	0.5004mm
0	60 Div. =	0.5996mm
0	70 Div. =	0.7000mm
0	80 Div. =	0.7996mm
0	90 Div. =	0.9000mm
0 -	100 Div. =	1.0000mm

Unless otherwise stated, each reading has a total estimated uncertainty of +/- 0.0006mm.

Keith Kurowski
Q.C. Manager

Calibration Sample Certificate of Traceability

LECO Calibration Samples are traceable to national and or international standard reference materials whenever possible. When these reference materials do not exist or are inadequate for calibration purposes, other reference materials or gas dosing methods are used. The accuracy of the LECO Calibration Sample is greatly influenced by the accuracy of the primary reference material(s) used.

The average result reported is determined from a minimum of three sets of data acquired over different days by different technicians on a variety of LECO instruments.

Part No: 502-809

Lot No: 0578

Description: 0.5 gram steel pin

Reference Materials: NIST SRM 2166, Low-Alloy Steel @ 0.015% Carbon
NIST SRM 15h, Basic Open-Hearth Steel @ 0.019% Sulfur
NIST SRM 343a, Stainless Steel @ 0.078% Nitrogen

Methods: Carbon: High Temperature Combustion – IR detection
Sulfur: High Temperature Combustion – IR detection
Nitrogen: Inert gas fusion TC detection

	weight (g)	% Carbon	% Sulfur	% Nitrogen
Average	*0.500*	*0.023*	*0.030*	*0.074*
2s	*0.003*	*0.002*	*0.001*	*0.002*
n	-	*30*	*30*	*30*

Date: September 21, 2007

Approved by: Dennis Lawrenz
Technical Services Laboratory Director

- *Additional information about this calibration sample is available upon request.*
- *These calibration samples are manufactured using a proprietary process and are suitable for use directly from the bottle without additional cleaning.*
- *No warranties of description, merchantability, or fitness for a particular purpose or any other express or implied warranties arise out of LECO's sale of this product. Remedies for any claimed defect in this product will be limited to replacement of the product or refund of the purchase price. In no event shall LECO be liable for incidental or consequential damages.*

LECO Corporation • Technical Services Laboratory • 3000 Lakeview Avenue • St. Joseph, MI 49085-2396 U.S.A.
Phone: 269-985-5496 • Fax: 269-982-8977 • info@leco.com • www.leco.com •

Calibration Sample Certificate of Traceability

LECO Calibration Samples are traceable to national and or international standard reference materials whenever possible. When these reference materials do not exist or are inadequate for calibration purposes, other reference materials or gas dosing methods are used. The accuracy of the LECO Calibration Sample is greatly influenced by the accuracy of the primary reference material(s) used.

The average result reported is determined from a minimum of three sets of data acquired over different days by different technicians on a variety of LECO instruments.

Part No: 501-678

Lot No: 0426-14

Description: 1 gram steel pin

Reference Materials: NIST SRM 13g, Carbon Steel @ 0.613% Carbon
NIST SRM 15h, Basic Open-Hearth Steel @ 0.019% Sulfur

Method: High temperature combustion – IR detection

	Weight (g)	% Carbon	% Sulfur
Average	*0.995*	*0.560*	*0.0057*
2s	*0.005*	*0.006*	*0.0005*
n	*90*	*90*	*90*

Date: February 3, 2005

Approved by: Dennis Lawrenz
Technical Services Laboratory Director

- *Additional information about this calibration sample is available upon request.*
- *No warranties of description, merchantability, or fitness for a particular purpose or any other express or implied warranties arise out of LECO's sale of this product. Remedies for any claimed defect in this product will be limited to replacement of the product or refund of the purchase price. In no event shall LECO be liable for incidental or consequential damages.*

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Phone: 269-985-5496 • Fax: 269-982-8977 • info@leco.com • www.leco.com •
Revised: 7/06

APÉNDICE L

INFORME METALOGRÁFICO DE IPASA A LA GRANALLA SAE S 330

INDUSTRIA PERUANA DEL ACERO S.A.
LABORATORIO DE CONTROL DE CALIDAD

ANALISIS METALOGRAFICO

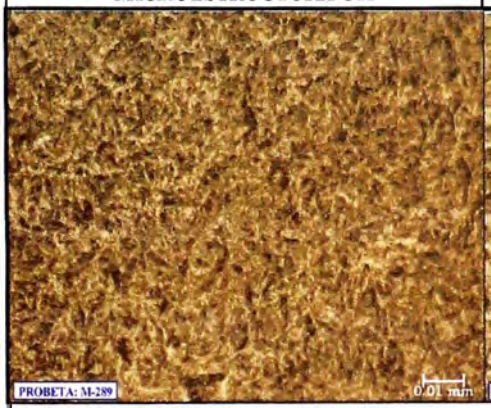
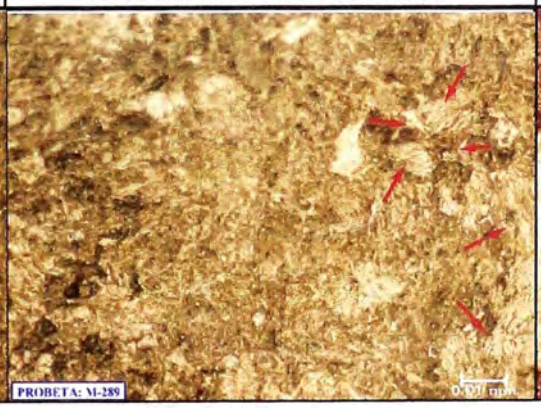
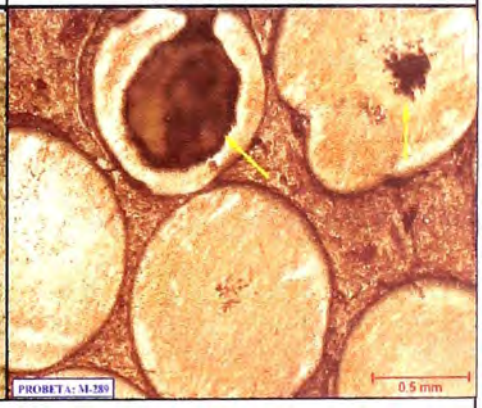
ANALISIS N°: 015/11Lab.	**FECHA:** 14/04/2011	**MUESTRA CODIGO N° :**	289
MATERIAL: GRANALLA S-330		**PROVEEDOR:** IKK - BRASIL	
PROCEDENCIA: Brasil		**LOTE:** 130211	
N° IRCC: 20892		**TIPO DE EVALUACION:** Evaluación de Granalla	
O/C : -	**N° ATADO:** -		

TRATAMIENTO TERMICO

MATERIA PRIMA : Muestra de 121 Granallas de acero			**DUREZA (HB):** -
ENSAYO DE TEMPLE	**TEMP.°C :** -	**TIEMPO PERMAN. :** -	**DUREZA (HB):**
ENSAYO DE REVENIDO	**TEMP.°C :** -	**TIEMPO PERMAN. :** -	**DUREZA (HB):**

EXAMEN METALOGRAFICO

SEGREGACIONES: -					**AUMENTO:** -	
DESCARBURIZACIÓN: -					**AUMENTO:** -	
INCLUSIONES NO METALICAS **NORMA ASTM E-45**	**OXIDO GLOB.:** - **SERIE :**	**SILICATOS:** - **SERIE :**	**ALUMINA:** - **SERIE :** -	**SULFURO:** **SERIE :**	**AUMENTO:** -	
TAMAÑO DE GRANO **NORMA ASTM E-112**	-				**AUMENTO:** -	
MICROESTRUCTURA	**%PERLITA LAM.**	**% FERRITA**	**%MARTEN.**	**%C. CALCUL.**	**R. ATAQUE** Nital 2%	**AUMENTO** 1000X

MICROESTRUCTURA OK	MICROESTRUCTURA INDESEABLE	DEFECTO INTERNO
		

ESPECIFICACIONES METALOGRAFICAS:

	ESPECIFICADO	ENCONTRADO
ORIFICIOS INTERNOS	NO MAS DEL 10%	4.13%
GRIETAS	NO MAS DEL 15%	2.50%
MICROESTRUC. DESEABLE	MARTENSITA REVENIDA	MARTENSITA REVENIDA
MICROESTRUC. INDESEABLES	NO MAS DEL 15%	4.13% (PRESENTA REDES DE CARBURO Y PERLITA LAMINAR)

CONCLUSIONES:

Granallas de acero se encuentran dentro de las especificaciones requeridas por nuestro estandar(STD IPASA 0506003)

INSPECCIONADO POR: Ing.W. Magallanes H.	**REVISADO POR:** Bach.José Carlos Valdiviezo G.