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“ENSAYOS MECÁNICOS DE FUNDICIONES GRISES SOMETIDAS A TRATAMIENTOS TÉRMICOS”

Tesis para optar el título profesional de:

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*A Dios, por estar conmigo en cada paso que
doy, por fortalecer mi corazón e iluminar mi
mente.*

*A mis padres Leo y Rosana, por darme la
vida, creer en mí y por sus sacrificios e
incondicional apoyo.*

*A mis hermanos Edward y Jorge por todos
los momentos que compartimos juntos.*

*A toda mi familia ya que gracias a ellos
alcanzare mis metas.*

Elder Roy Escalante Escobedo



*Le agradezco a Dios y a mis padres los
éxitos de mi vida.*

Diego Alonso Bustinza Martínez

INTRODUCCIÓN

Esta investigación tiene como principal propósito el estudio del comportamiento de las propiedades de las fundiciones grises al ser sometidas a diferentes tratamientos térmicos, a través de ensayos mecánicos y análisis metalográficos.

En la elaboración del presente proyecto de tesis se ha visto en la necesidad de implementar un equipo moderno para la realización de tratamientos térmicos que se encuentre al desarrollo con la tecnología actual. Con el horno de mufla se conseguirá que los alumnos puedan realizar sus prácticas de una manera más sencilla y rápida desechando todos los procedimientos anteriores para realizar estos procedimientos.

Toda preparación de probetas y ensayos se ha realizado estrictamente bajo las normas ASTM. Del mismo modo los resultados obtenidos en las múltiples pruebas se han corroborado que cumplan con las exigencias de estas normas.

Después de realizada la investigación en donde se evaluó la microestructura y las propiedades mecánicas de la fundición gris, se llegó a concluir que realizando un proceso de recocido se logro ablandar la matriz y mejorar la maquinabilidad, mientras que; con el tratamiento de normalizado se logró mejorar las propiedades mecánicas de la fundición.

En conclusión de todo lo expuesto se afirma visiblemente que la implementación de un horno de mufla para realizar tratamientos térmicos ha sido de gran utilidad para todos los beneficiarios que utilicen de él como son: Ingenieros, técnicos y primordialmente los alumnos de futuras promociones que necesiten de su apoyo en diferentes actividades propuestas por dichos entes.

RESUMEN

El presente, es un trabajo de aplicación práctica de los conocimientos adquiridos en las aulas Universitarias, en el cual se busca caracterizar la fundición gris sometida a diferentes tratamientos térmicos utilizando un horno de mufla; ya que este equipo nos permite lograr una uniformidad durante el proceso de tratamiento.

Se ha realizado una serie de ensayos mecánicos y metalográficos antes y después del tratamiento térmico, para analizar la microestructura y las propiedades de la fundición gris.

En el Capítulo Primero, se enfocan las generalidades, en el cual se describen los objetivos, los alcances, las limitaciones, y la justificación del estudio.

En el Capítulo Segundo, se hace referencia al marco teórico que viene a ser el sustento y guía del presente trabajo, en el cual se describen las principales características y propiedades de la fundición gris, así como también los principales tratamientos térmicos aplicados a este tipo de material.

Los Capítulos Tercero y Cuarto, tratan exclusivamente del desarrollo experimental realizado en el Laboratorio Materiales de la Universidad y los resultados de todas las pruebas obtenidas a partir de los ensayos practicados; para finalmente en el Capítulo Quinto analizar estos resultados y caracterizar así la fundición gris antes y después de ser sometida a algunos tratamientos térmicos.

ABSTRACT

The present investigation is a work of practical application of the knowledge acquired in university classrooms, which seeks to characterize the grey cast iron subjected to different thermal treatments using a muffle furnace; considering that this equipment allows us to achieve uniformity during the treatment process.

We were able to complete a series of mechanical and metallographic tests before and after the thermal treatment, to analyze the microstructures and the properties of grey cast iron.

In the first chapter, the generalities are focused. There we describe the objectives, scopes and limitations and the justification of the study.

The second chapter refers to the theoretical framework that comes to be the sustenance and guide of this investigation. There we describe the main features and properties of grey cast iron as well as the main thermal treatments applied to this type of material.

The third and fourth chapters are exclusively about the experimental development carried out in the University's laboratory and of the results of all the proves obtained from the test that were done; Finally in the fifth chapter we analyze these results and thus characterize grey cast iron before and after being subjected to some thermal treatments.

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CAPÍTULO I

GENERALIDADES

1.1 TÍTULO DE LA TESIS

“ENSAYOS MECÁNICOS DE FUNDICIONES GRISES SOMETIDAS A
TRATAMIENTOS TÉRMICOS”

1.2 DESCRIPCIÓN

En el presente trabajo se busca evaluar las propiedades de las fundiciones grises antes y después de ser sometidas a diferentes tratamientos térmicos, esto utilizando un horno de mufla y los instrumentos de ensayo con los cuales cuenta actualmente el Laboratorio de Materiales del programa profesional de Ingeniería Mecánica, Mecánica – Eléctrica y Mecatrónica.

1.3 JUSTIFICACIÓN

- El presente trabajo es realizado ya que en el mercado actual existe una gran variedad de piezas hechas por fundición para las cuales se necesitan procesos de tratamientos térmicos adecuados, que aseguren la modificación de sus propiedades y así de esta manera conseguir la optimización en su desempeño.
- Anteriormente no se ha realizado estudios en fundiciones grises al ser modificadas en su estructura cristalina mediante un calentamiento uniforme y constante, como el que se consigue utilizando un horno de mufla.
- Finalmente buscamos ampliar la capacidad de las prácticas realizadas en el laboratorio, para que futuras promociones cuenten con una base para el estudio de los tratamientos térmicos y así fomentar en ellas el desarrollo y la investigación.

1.4 OBJETIVOS DE LA INVESTIGACIÓN

1.4.1. Objetivo General

Analizar el comportamiento de la fundición gris al ser tratada térmicamente utilizando un horno de mufla.

1.4.2. Objetivos Específicos

- Evaluar las propiedades de la fundición gris una vez culminado el proceso de colado.

- Aplicar diferentes tratamientos térmicos a la fundición gris para modificar la estructura cristalina de estos, y así obtener variaciones en sus propiedades físicas y mecánicas.
- Analizar las propiedades de los materiales tratados térmicamente.
- Identificar los cambios encontrados en las fundiciones grises mediante los resultados obtenidos en el laboratorio.

1.5 ALCANCES Y LIMITACIONES

Se realizarán los tratamientos térmicos de las fundiciones grises utilizando una Mufla Digital de 1200°C, por lo cual los límites que se presentan en la siguiente investigación son:

- El rango de temperatura con el cual se podrá trabajar para los tratamientos térmicos, va desde 100 °C hasta 1200 °C.
- Las dimensiones de las probetas deberán ser menores que 18 x 25 x 13 cms (Ancho x Profundidad x Altura), las cuales son las medidas internas de la cámara de la mufla.
- El proceso de tratamiento térmico de las fundiciones se complica ya que durante el calentamiento de la fundición se puede desarrollar el proceso de grafitización lo cual podría cambiar la estructura y las propiedades de la fundición.
- Las pruebas a realizar en las probetas se verán limitadas por los instrumentos con los cuales cuenta actualmente el laboratorio.

CAPITULO II

MARCO TEÓRICO

2.1 FUNDICIONES FERROSAS

Las fundiciones son básicamente aleaciones hierro- carbono, con una alto porcentaje de carbono mayor que los aceros. Su concentración esta entre 1.76% y 6.67% de carbono. En la práctica, el contenido de carbono varía de 2,5 a 4 %, siendo lo más frecuente que oscile de 2,75 a 3,5 %. El contenido en silicio suele oscilar de 1 a 3,8 % y el de manganeso de 0,4 a 1,5 %. Muy raras veces los contenidos de silicio y manganeso llegan al 4 %, y en ocasiones se fabrican fundiciones especiales hasta el 15 % de silicio. Los porcentajes de azufre suelen oscilar de 0,01 a 0,12 %, los de fósforo de 0,020 a 0,10 % y en algunos casos llega a 1,5 %. Para conseguir ciertas características especiales, se fabrican fundiciones aleadas que, además de los elementos citados, contienen también porcentajes variables de cobre, níquel, cromo, molibdeno, etc.

El mejor método para clasificar las fundiciones es de acuerdo con su estructura metalográfica.

Las variables para definir los tipos de fundiciones son:

- El porcentaje de carbono.
- El contenido de aleación y de impurezas.
- La velocidad de enfriamiento.
- El tratamiento térmico después de la fusión en donde es posible observar grandes diferencias en la microestructura la cual define su forma física.

El carbono puede estar libre, es decir en forma de grafito o puede estar combinado en forma de carburo de hierro en la cementita. La distribución del carbono sin combinar influirá en gran medida en las propiedades físicas de las fundiciones.

2.2 CLASIFICACIÓN DE LAS FUNDICIONES

Por ser muchos y muy diferentes los factores que hay que tener en cuenta para la clasificación y selección de las fundiciones, es difícil establecer una clasificación simple y clara de las mismas. La más antigua y conocida de las clasificaciones establece cuatro grupos: fundición blanca, gris, maleable y nodulada.

2.2.1. Fundición blanca

Si la velocidad de extracción de calor durante el paso del líquido a sólido, en una fundición de hierro es alta a raíz de un enfriamiento rápido, la solidificación del material se completa con la formación de un eutéctico Fe – Fe₃C llamado ledeburita. El producto final se denomina Fundición blanca; siendo éste un material que se caracteriza por su

color blanco en la fractura y por ser bastante dura y resistente al desgaste, por su gran cantidad de cementita, sin embargo es extremadamente frágil y difícil de mecanizar.

Aplicaciones: Es usada en casos en que la resistencia al desgaste es lo más importante y la aplicación a la cual está destinada no requiere buena ductilidad ni maleabilidad como es el caso de las camisas para mezcladoras de cemento, bolas de trituración para acería.

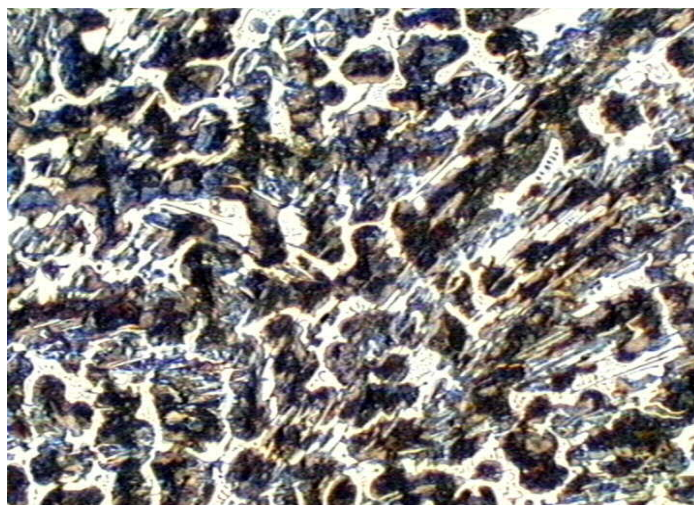


Fig. N° 2.1 Fundición Blanca en bruto tomada a 100 aumentos.
Fuente: <http://www.esi2.us.es/IMM2/Pract-html/y1.html>

2.2.2. Fundición gris

Se llama así por el aspecto de su fractura, que es de color gris. Es una aleación hierro-carbono hipoeutéctica con un porcentaje entre 2.5 y 4.0 % y de silicio entre 1 y 3 %. El grafito suele aparecer como hilos dentro de una matriz de ferrita o perlita. Desde un punto de vista mecánico las fundiciones grises son frágiles y poco resistentes a la tracción, su resistencia y ductilidad a los esfuerzos de compresión son mayores.

Cuando no se requieren unas características mecánicas muy exigentes, las condiciones más interesantes que en general conviene que cumplan estas fundiciones son:

- Que tengan buena colabilidad.

- Facilidad de mecanizado.
- Que no queden poros, para ello la temperatura de fusión debe ser baja y el contenido de carbono debe ser alto, aproximadamente de 3 a 3,75% y los contenidos de silicio entre 1,25 y 2,5% de tal forma que el CE= 4,3%.

Aplicaciones: Estas fundiciones amortiguan de forma óptima las vibraciones y en un mayor grado que los aceros, por lo que en sistemas de transmisión de potencia y mecanismos son muy utilizadas. A la temperatura de colada tienen mucha fluidez por lo que permite moldear piezas de formas complejas. Es además, uno de los materiales metálicos más baratos. Se utiliza en bloque de motores, tambores de freno, cilindros y pistones de motores.



Fig. N° 2.2 Fundición Gris en bruto tomada a 100 aumentos.
Fuente: <http://www.esi2.us.es/IMM2/Pract-html/y2.html>

2.2.3. Fundición maleable

Esta fundición apareció del afán de ablandar la fundición blanca y convertirla en un material tenaz. Se obtiene a partir de la fundición blanca por calentamiento prolongado en atmósfera inerte (para prevenir la oxidación) a temperaturas entre 800 y

900 °C. Bajo estas condiciones la cementita se descompone para dar grafito en forma de racimos o rosetas dentro de la matriz ferrítica o perlítica de modo similar a la de la fundición esferoidal.

Aplicaciones: Se suele emplear en tubos de dirección y engranajes de transmisión, muelles tubulares y partes de válvulas.

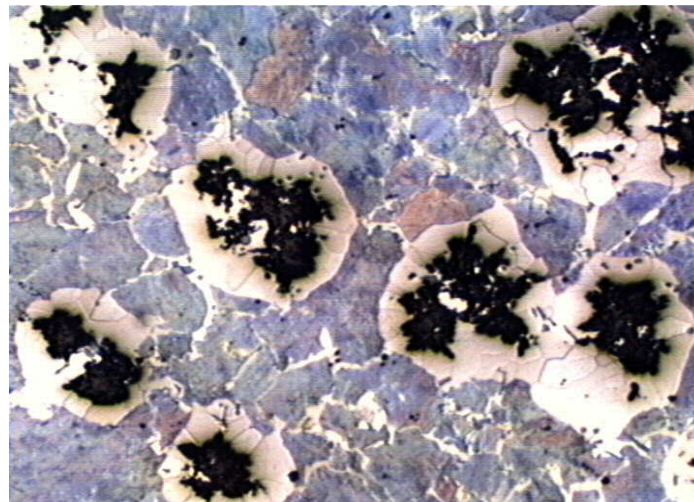


Fig. N° 2.3 Fundición Maleable en bruto tomada a 50 aumentos.
Fuente: <http://www.esi2.us.es/IMM2/Pract-html/y5.html>

2.2.4. Fundición nodular

Es una aleación Fe, C y Si, cuya microestructura está conformada por una matriz metálica y una cantidad del 10 al 15% de grafito en forma de esferas. La presencia de grafito afecta ciertas propiedades entre ellas la disminución de la dureza y la resistencia mecánica, pero por otro lado, incrementa la maquinabilidad.

- Ferríticas: Posee maquinabilidad, ductilidad y límite elástico moderado.
- Perlíticas: Buen límite elástico y ductilidad pero baja maquinabilidad, se pueden temprar superficialmente.

- Tratadas térmicamente: Con tratamientos térmicos como normalizados, templados y revenidos o austemperadas, presentan alta resistencia a la tracción y alto límite elástico.

Aplicaciones: Presenta una mayor resistencia a la tracción que la fundición gris y se suele utilizar para la fabricación de válvulas y engranajes de alta resistencia, cuerpos de bomba, cigüeñales y pistones. Se diferencia de la maleable porque generalmente se obtiene como resultado de la solidificación y no requiere tratamiento térmico.

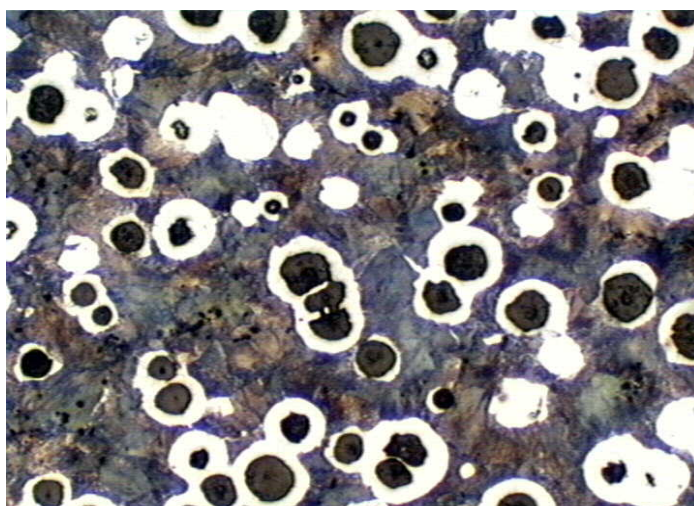


Fig. N° 2.4 Fundición Nodular en bruto tomada a 100 aumentos.
Fuente: <http://www.esi2.us.es/IMM2/Pract-html/y3.html>

2.2.5. Otras clases de fundiciones

2.2.5.1. Fundición grafito compacto

Presenta propiedades intermedias entre la gris y la nodular; el grafito dentro de la matriz se presenta tanto en nódulos como en láminas en forma interconectada. Su resistencia a la tracción varía entre 40 y 85Ksi y el límite elástico entre 30 y 60Ksi con alargamientos entre 1 y 5%.

2.2.5.2. Fundiciones chiliadas

En fundiciones grises, nodulares y de grafito compacto, se pueden inducir durante la solidificación la formación de fundición blanca en la superficie de las piezas recibe el nombre de chill y la fundición recibe el nombre de fundición chiliada.

2.2.5.3. Fundición moteada

Una fundición que solidifique a velocidades intermedias entre blanca y gris contendrá en su estructura grafito y cementita y se denomina fundición moteada o atruchada.

2.3 FUNDICIÓN GRIS

La fundición gris es un tipo de fundición que contiene carbono precipitado como grafito en forma de hojuelas. Ésta es la fundición de hierro de más amplio uso y debe su nombre al color gris mate de la superficie fracturada. La fundición de hierro gris contiene muchos racimos, es decir celdas eutécticas, de hojuelas de grafito interconectadas. El punto en el cual se conectan estas hojuelas es el núcleo original de grafito. Las hojuelas de grafito aparecen durante la solidificación y posterior enfriamiento de la fundición.

La mayoría de las aleaciones grises son aleaciones hipoeutécticas que contienen entre 2.5% y 4% de carbono. El proceso de grafitización se realiza con mayor facilidad si el contenido de carbono es elevado, las temperaturas elevadas y si la cantidad de elementos grafitizantes presentes, especialmente el silicio es la adecuada. Para que grafiticen la cementita eutéctica y la proeutectoide, aunque no la eutectoide, y así

obtener una estructura final perlítica hay que controlar cuidadosamente el contenido de silicio y la velocidad de enfriamiento.



Corresponden de izquierda a derecha a:

- Matriz de perlita con cementita esferoidizada para trabajo a altas temperaturas.
- Gris aleada, y consta de grafito tipo A con carburos libres (zonas blancas).
- Templada y revenida, su microestructura consta de grafito en una matriz de martensita revenida.

Fig. N° 2.5 Clases de fundiciones grises

Fuente: HandBook Metals

2.3.1. Clasificación de las fundiciones grises

Las fundiciones grises se pueden clasificar de varias formas, pero una de las más usuales es la clasificación por la estructura de la matriz:

2.3.1.1. Fundición gris Perlítica o Eutectoide

Su estructura está formada de perlita con inclusiones de grafito (en la Figura N° 2.6 a, el grafito se ve en forma de vetas pequeñas). Como se sabe, la perlita contiene un 0,8 % de C, por consiguiente, esta unidad de carbono se halla en la fundición perlítica gris en estado ligado (es decir, en forma de cementita). La cantidad restante se encuentra en estado libre, o sea, en forma de grafito.

2.3.1.2. Fundición gris Ferrítica o Hipoeutectoide

En esta fundición la matriz es ferrita y todo el carbono que hay en la aleación está en forma de grafito (Figura N° 2.6 c).

2.3.1.3. Fundición gris Ferrito-perlítica

La estructura de esta fundición está formada por ferrita y perlita e inclusiones de grafito. En esta fundición la cantidad de carbono ligado es menor que el 0,8 % de C (Fig. N° 2.6 b).



a) Fundición perlítica, tomada a 200 aumentos; b) Fundición ferrito - perlítica, tomada a 100 aumentos; c) Fundición ferrítica, tomada a 100 aumentos.

Fig. N° 2.6 Microestructura de la fundición gris.

Fuente: Gulyavev, A., "Physical Metallurgy", Mir Publishers, 1980, Volumen 1, p. 204

2.3.2. Propiedades de las fundiciones grises

2.3.2.1. Propiedades generales de las fundiciones grises

- Las fundiciones grises son un material compuesto de grafito, y de otro material matriz. Este material a su vez, frecuentemente está compuesto por un intermetálico "cerámico" (la cementita), y otro material (la ferrita) que es metálico.

- Requieren para su elaboración menos energía que los aceros, porque con similar capacidad calorífica su temperatura de fusión es menor. Presentan además, excelentes características de colabilidad y dan poco rechupe.

- Su colabilidad es mejor cuanto mayor es su contenido de carbono, por ser pequeño el intervalo de temperaturas entre el líquido y sólido. Algunas de ellas, las de composición eutéctica, solidifican a temperatura constante.

- Las fundiciones grises dan poco rechupe, 1 % de contracción lineal aproximadamente, inferior al de los aceros y fundiciones blancas, como puede verse en la Tabla N° 2.1. La pequeña contracción al solidificar se debe a que su densidad (entre 6,95 y 7,35 g/cm³, menor cuanto más carbono) es inferior a la de las fundiciones blancas (7,7 g/cm³) y a la de los aceros (densidad del hierro 7,97 g/cm³).

Tabla N° 2.1 Contracción durante la solidificación (A.S.M.)

Tipo de Fundicion	% Contracción
Fundición dúctil	0.0 - 0.7
Fundición gris	1.0
Fundición maleable	1.0
Fundición austenítica	1.3 - 1.5
Fundición blanca	2.0
Acero al carbono	2.0
Acero aleado	2.5

Fuente: José Antonio Pero-Sanz Elorz, Materiales para ingeniería Fundiciones Férricas, 1994, pg. 50

Esta menor densidad de las fundiciones grises se justifica por la presencia del grafito cuya densidad es 2,2 g/cm³. En las fundiciones grises el grafito suele ocupar un volumen (o un área de los campos observados al microscopio) entre 6 y 10 % del volumen total.

- La característica radical de las fundiciones grises es que no presentan ledeburita. En su estructura micrográfica aparece grafito que puede ser de diversos tipos, disperso en una matriz similar a un acero.

El comportamiento mecánico de una fundición gris resulta parecido al de un acero con numerosas microfisuras taponada por grafito. La cohesión entre el grafito y la matriz metálica es casi nula. Debido a la gran diferencia entre los coeficientes de dilatación del hierro y del grafito, éste se despegará fácilmente de la matriz. Esto explica varias propiedades de estas fundiciones: el color gris que presentan las fracturas, la capacidad para amortiguar vibraciones, mayor cuanto más grafito. Además de su maquinabilidad, generalmente buena, las moderadas resistencias a tracción y bajos alargamientos, la dispersión habitual en valores de microdureza, etc.

- La conductividad térmica de las fundiciones grises es aproximadamente 46 w/m.K; superior a la de los aceros. En ello influye el grafito, buen conductor. La capacidad para disipar calor es, por tanto, mayor en las fundiciones grises - mayor cuanto más cantidad de grafito, y mejor si el grafito es laminar que esferoidal - que en los aceros. Para aprovechar esta propiedad, las lingoteras para acero líquido se fabrican de fundición gris hipereutéctica.

- La resistencia de las fundiciones grises al choque térmico resulta, también, mejor para contenidos altos en carbono.

- El coeficiente de dilatación de las fundiciones grises es, aproximadamente, de 13 $\mu\text{m/m}$. entre 0 °C y 500 °C, y de 10,5 $\mu\text{m/m}$ en el rango de 0 °C y 100 °C. Aunque parecido al del hierro, resulta algo menor que este (11 $\mu\text{m/m}$ para el Fe alfa y 18 $\mu\text{m/m}$ para el Fe gamma).

- La tenacidad de las fundiciones grises, es mayor que las de las fundiciones blancas; pero, por el efecto de entalla debido al grafito laminar, resulta insuficiente. Por ello, cuando se requiere un material tenaz no debe utilizarse fundición blanca, ni tampoco fundición gris laminar.

- Las medidas de dureza son interesantes para predeterminar la resistencia al desgaste de una fundición gris. Además, proporcionan un primer criterio sobre su comportamiento al mecanizado o maquinabilidad. A diferencia de los aceros, las fundiciones no tienen una proporcionalidad directa entre dureza y resistencia a la tracción.

- La resistencia a tracción, R , depende del tipo de grafito, de su cantidad, y de la estructura matriz. Puede señalarse, con carácter general, que la resistencia a tracción disminuye al aumentar el contenido en carbono de las fundiciones. El grafito disminuye la sección real del constituyente matriz, que es quien aguanta el esfuerzo de tracción, y por otra parte el efecto de entalla del grafito laminar, disminuye la tenacidad.

- Una misma fundición gris perlítica puede presentar distintos valores de R según sea el tamaño de la pieza. Así, para un mismo contenido de carbono, lo cual determina la cantidad de grafito en la fundición solidificada establemente, un aumento del módulo de masividad (volumen / área) equivale a disminuir la velocidad de solidificación. Por ello las rosetas eutécticas serán más grandes, el grafito A resultará más grueso y de mayor longitud, la perlita matriz tendrá mayor espaciado interlaminar, y resultará más blanda y menos resistente.

- La resistencia a compresión de las fundiciones grises es alta: 3 ó 4 veces superior a la resistencia a la tracción. Ello se debe a que, en compresión, apenas influye

el efecto de entalla del grafito y, por tanto, la contribución negativa de este se reduce simplemente a disminuir la sección eficaz del constituyente matriz.

- Gracias a la buena colabilidad de las fundiciones grises es posible moldear piezas de paredes delgadas, tales como tubos con aletas para radiadores, rodetes para bombas, anillos para columnas, calderas, compresores, etc.

- Las fundiciones grises ordinarias presentan buena resistencia a la corrosión, superior a la de los aceros. Los productos de corrosión quedan apresados por el esqueleto de grafito y dificultan el deterioro de zonas más profundas.

- En general, las fundiciones grises resultan fácilmente mecanizables, aunque ocasionalmente, pueden presentar dificultades de mecanizado derivadas de defectos externos tales como arena adherida a superficie, o bien por factores ligados al diseño o a la práctica del moldeo.

- En cuanto a resistencia al desgaste el comportamiento de las fundiciones, tanto blancas como grises, es excelente.

2.3.2.2. Características mecánicas de las fundiciones grises

Cada día se tiene más en cuenta la resistencia a la tracción de las fundiciones grises, y es frecuente clasificar las fundiciones por la resistencia a la tracción que con ella se obtiene en barras fundidas de 30 mm de diámetro. Las fundiciones normales de baja calidad que se fabrican sin precauciones o especificaciones especiales, suelen tener de 10 a 15 kg/mm² de resistencia a la tracción.

Al realizarse el ensayo de tracción de una fundición gris, se observa que el módulo de elasticidad no es constante como en los aceros, sino que disminuye a medida que aumenta la carga que actúa sobre el material. No hay, por lo tanto, como en los

aceros una zona en la que haya rigurosa proporcionalidad entre las cargas y las deformaciones. Por ello, a cada carga que actúa sobre el material corresponde un módulo de elasticidad, siendo frecuente que en la práctica se de cómo valor del módulo de elasticidad de una fundición, el que corresponde a una carga de un 75 % de la máxima de rotura. Durante el ensayo, en un momento determinado del mismo, tendremos:

$$\text{Módulo de elasticidad} = \text{Carga que está actuando/alargamiento que ha producido.} \\ [\text{kg/mm}^2]$$

En general, el módulo de elasticidad varía entre 7000 y 13000 kg/mm². Al disminuir el tamaño y cantidad de las láminas de grafito, aumenta el módulo de elasticidad y también la resistencia a la tracción de las fundiciones. En general, el alargamiento plástico y permanente de las probetas en la mayoría de las fundiciones ordinarias es muy pequeño, puede decirse casi nulo, ya que no suelen llegar al 1 %, mientras en los aceros son normales los alargamientos que oscilan entre 10 y 20 %.

La presencia de numerosas discontinuidades en la estructura, debido a las líneas de grafito, hace que las fundiciones grises sean mucho menos sensibles al efecto de entalla que los aceros, lo cual también es muy ventajoso. Por ello, no hay que temer tanto como en los aceros, el peligro de rotura en las piezas o rayas de mecanizado, ángulos vivos, etc.

Una propiedad importante de las fundiciones, debida precisamente a la presencia de láminas de grafito, es su gran capacidad de amortiguación a las vibraciones, muy superior a las de los aceros.

En la Figura N° 2.7 se representan esquemáticamente las vibraciones que se producen ensayando en las mismas condiciones, varillas de fundición, de acero y de

aleación de aluminio. Se observa que las vibraciones se amortiguan en la fundición mucho antes que el acero y que en la aleación de aluminio, lo cual, en general, es muy ventajoso cuando se emplea este material para la fabricación de bancadas de máquinas, motores, etc.

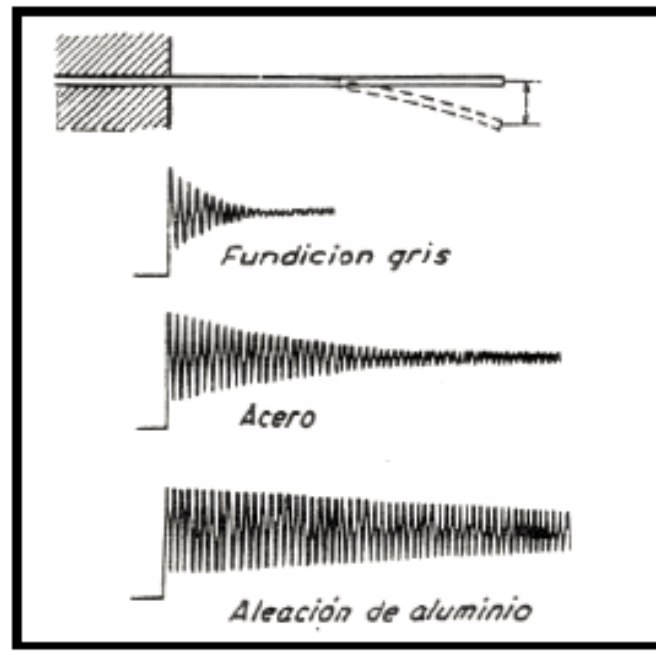


Fig. N° 2.7 Representación gráfica de la forma de amortiguarse las vibraciones que se pueden producir en las piezas de fundición, acero y aluminio.

Fuente: José Apraiz Barreiro, Fundiciones, 6ta Edición, 1998, p.41

En las figuras 2.8 y 2.9 se señalan las resistencias, durezas y módulos de elasticidad que se obtienen en piezas de diferentes espesores con las fundiciones de 15, 20, 30, etc. kg/mm² (es decir, fundiciones que en probeta de 30 mm dan 15, 20, 30 kg/mm² de resistencia).

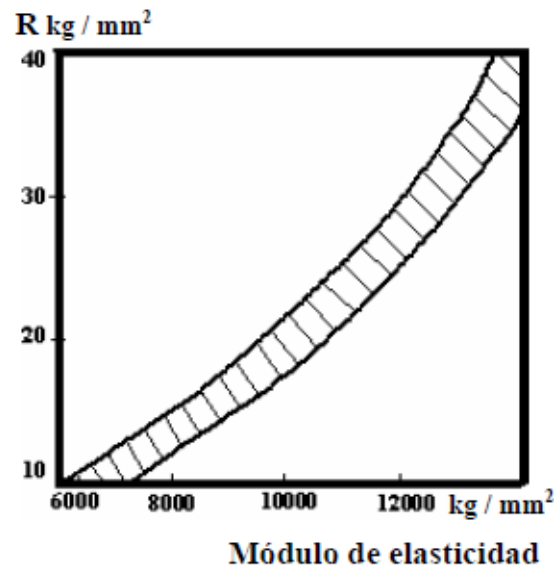


Figura N° 2.8 Relación aproximada entre la resistencia de las fundiciones y su módulo de elasticidad.

Fuente: José Apraiz Barreiro, *Fundiciones*, 6ta Edición, 1998, p.42.

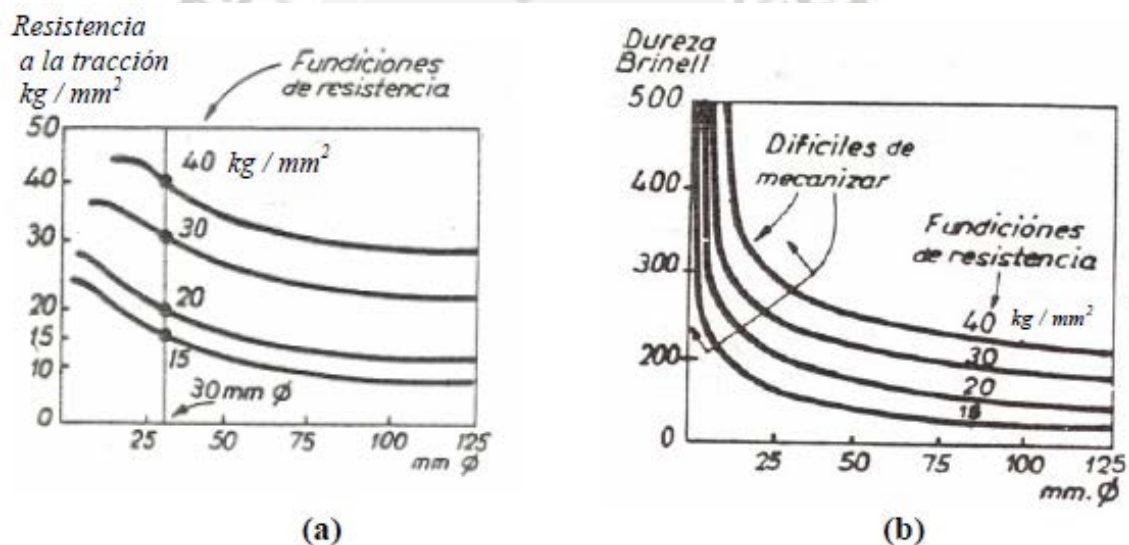


Figura N° 2.9 a) Indica la influencia del espesor de las piezas en la variación de la resistencia a la tracción de fundiciones de diferentes resistencias; b) Indica la influencia del espesor de las piezas en la variación de la dureza de las fundiciones de diferentes resistencias a la tracción.

Fuente: José Apraiz Barreiro, *Fundiciones*, 6ta Edición, 1998, p.41 y 42.

Para las fundiciones de resistencia relativamente elevadas que en la actualidad se emplean en la industria, a continuación señalamos las características principales de los 5 grupos de fundiciones más importantes.

1° - Fundiciones de menos de 15 kg/mm². Son en general, fundiciones con menos de 0,5 % de carbono combinado.

2° - Fundiciones de 20 kg/mm², aproximadamente (15 a 20 kg/mm²). Son, en general, perlíticas con grafito laminar.

3° - Fundiciones de 30 kg/mm², aproximadamente (25 a 35 kg/mm²). Son fundiciones perlíticas de propiedades muy parecidas a las anteriores, aunque con frecuencia suelen ser aleadas.

4° - Fundiciones de 40 kg/mm², aproximadamente (35 a 50 kg/mm²). Son, en general, fundiciones aciculares con grafito laminar muy fino.

5° - Fundiciones de 60 kg/mm², aproximadamente (50 a 70 kg/mm²). Son, en general, fundiciones con grafito esferoidal.

2.4 HORNOS UTILIZADOS EN TRATAMIENTOS TÉRMICOS

Un horno es un dispositivo que genera calor y que lo mantiene dentro de un compartimiento cerrado. En la industria metalúrgica, se lo utiliza para realizar tratamientos térmicos sobre los materiales, de modo de obtener propiedades mecánicas y microestructuras deseadas para algún uso particular (mediante el agregado de aleantes y/o el método de enfriado). Según su principio de funcionamiento, se los puede agrupar en 3 tipos:

1. Calentamiento por efecto Joule, entre los cuales se encuentran los hornos de inducción eléctrica y arco eléctrico.
2. Calentamiento por elevación de la temperatura del medio circundante, como los hornos de calentamiento por resistencia eléctrica y los de calentamiento por combustión.
3. Calentamiento por interacción de radiación con la muestra, entre ellos, los que emplean radiación láser y los de haces de electrones.

2.4.1. Horno de calentamiento por efecto Joule

Se conoce como efecto Joule al fenómeno por el cual si en un conductor circula corriente eléctrica, parte de la energía cinética de los electrones se transforma en calor debido a los choques que sufren con los átomos del material conductor por el que circulan, elevando la temperatura del mismo. El nombre es en honor a su descubridor, el físico británico James Prescott Joule.

El movimiento de los electrones en un cable es desordenado, esto provoca continuos choques entre ellos y como consecuencia un aumento de la temperatura en el propio cable.

En este efecto se basa el funcionamiento de diferentes electrodomésticos como los hornos, las tostadoras y las calefacciones eléctricas, y algunos aparatos empleados industrialmente como soldadoras, etc., en los que el efecto útil buscado es, precisamente, el calor que desprende el conductor por el paso de la corriente. Sin embargo, en la mayoría de las aplicaciones es un efecto indeseado y la razón por la que los aparatos eléctricos y electrónicos necesitan un ventilador que disminuya el calor generado y evite el calentamiento excesivo de los diferentes dispositivos como podían

ser los circuitos integrados. E inclusive las lámparas incandescentes que producen más energía calorífica que lumínica.

2.4.1.1. Horno Inducción eléctrica



Fig. N° 2.10 Horno de inducción eléctrica

Fuente: <http://www.directindustry.es/prod/ambrell/fuentes-de-alimentacion-electrica-de-radio-frecuencias-para-calentamiento-por-induccion-7238-399771.html>

El horno de inducción está formado por el convertidor de frecuencia, horno, horno de explosión de control estas varias partes. SCR fuente de alimentación es convertir la electricidad trifásico de corriente alterna de frecuencia a través del circuito rectificador en un DC, y después de otro circuito de salida de inversor, ofrece la frecuencia intermedia horno de inducción sin núcleo a SI AC monofásica. Aprovechando la inducción electromagnética, deja la pieza de trabajo entre el campo magnético alterno. Se produce el remolino y hace calor, logran la fundición, temple, calefacción y otras necesidades de calentamiento.

Las características del horno de inducción.

- Central tablero de control es diseñado optimizado por el ordenador. El circuito de la célula combina optimizada mente con la instalación. Este horno tiene el funcionamiento estable, calidad confiable y fuerte anti interferencias.

- Los componentes tienen la distribución razonable, coordinativa y fácil de mantenimiento.
- Sobre la base de comenzar de cero presión, y añadido la función de barrido automático y la repita de inicios, la tensión y el circuito de lazo de corriente siguen de cerca. Este equipo inicia y detiene lisa y estable, sin el impacto de corriente.
- Circuito de disparo de señal individual es altamente sensible, aumenta más la función de empezar, para lograr la tasa de éxito de empezar del equipo hasta 100 por ciento.
- El circuito de potencia constante controla el sistema, con el rápido cambio de carga controla la tensión y el corriente en una perfecta situación durante el proceso de producción. No se necesita ajustar manualmente.
- Posee un perfecto sistema de sobre voltaje, sobre corriente, voltaje, la escasez de agua, falta de fase, límite de tensión y de corriente y otros sistemas de protección.
- Posee altamente integrado programa de circuito, ajusta y maneja rápido, fácil y conveniente.

Las ventajas del horno de inducción.

- Calentamiento rápido, menos contaminación. Como el principio de calentamiento de SI horno es inducción electromagnética, su calor generado por la propia pieza de trabajo. Este método de calentamiento calienta rápido, hace muy poco de oxidación, alto rendimiento térmico, buena repetitividad de tecnología, sólo un blanqueo muy leve en superficies de metales. Muy menor de pulido se puede recuperar el brillante para tener constante función de materiales.

- Alto grado de automatización. Permite el funcionamiento automático sin vigilancia, aumenta la productividad laboral.
- Un uniforme calentamiento, una alta precisión de control de la temperatura. Con el calentamiento uniforme se puede garantizar los núcleos de pieza de trabajo tienen pequeñas diferencias de temperaturas. Controla precisamente la temperatura a través del sistema de control de temperatura, garantiza la repetibilidad de productos.
- Simple sustitución del horno de inducción. De acuerdo con los diferentes tamaños de piezas de trabajo, se necesitan instalar diferentes especies de hornos de inducción. Cada horno se diseña conectores de agua y electricidad que cambian rápido. Lo cual hace el horno más rápido y conveniente de cambiar.
- Bajo consumo de energía, no hay contaminación. Alto rendimiento de calentamiento. En comparación con otros métodos de calentamiento, reducir eficiente el consumo energético, tiene mayor productividad de trabajo, no hay contaminación. Cumplen con los requisitos ambientales.

2.4.1.2. Horno de calentamiento por arco eléctrico

En este tipo de hornos se introduce una corriente eléctrica en la muestra a través de su superficie, provista por un electrodo no consumible adecuadamente elegido. El crisol debe ser seleccionado de tal forma que sea conductor eléctrico, resista las condiciones de trabajo y no reaccione químicamente con el material a fundir.

Es el reactor principal que se usa para la fabricación de los aceros especiales. Utiliza el calor generado por un arco eléctrico para fundir la carga que se encuentra depositado en el crisol. Tiene ventajas respecto a otros hornos como son:

1. Instalación más sencilla y menos costosa que la que cualquier horno utilizados para fabricar aceros.
2. Se obtienen temperaturas más elevadas, del orden de los 3500 °C.
3. No se producen gases de combustión, polvos ni humos ni son necesarios chimeneas, recuperadores, etc.
4. El aprovisionamiento de materia prima es más fácil y libre. Es menor también la absorción de gases por la masa líquida.

Hay dos tipos de hornos eléctricos de arco son:

1. Horno eléctrico de arco indirecto.
2. Horno eléctrico de arco directo.

2.4.1.2.1. Horno eléctrico de Arco Indirecto (electrodo x electrodo)

En estos hornos el calentamiento directo es por radiación. Los hornos pueden ser del tipo Basculante rotativo o Basculante oscilante, siendo el más común el oscilante. Debido al esfuerzo de flexión y choques mecánicos a que están sujetos los electrodos, estos hornos tienen una capacidad limitada a un máximo de 2000 Kg. carga sólida a 4000 Kg. carga líquida.

2.4.1.2.2. Horno eléctrico de Arco Directo (electrodo x baño x electrodo)

Son los hornos de arco más usados en la industria del acero y fundición. Existen dos tipos:

1. Horno eléctrico de arco directo trifásico
2. Horno eléctrico de arco directo monofásico.

2.4.2. Horno de calentamiento del medio circundante

2.4.2.1. Horno de calentamiento por resistencia eléctrica

Esta clase de hornos produce la elevación de temperatura de un ambiente en donde se introduce el material a fundir. Tal elevación de temperatura es realizada por el paso de altas densidades de corriente eléctrica a través de una resistencia elegida para tal fin. El calor llega desde la resistencia al material a través de radiación y convección. Se debe aislar adecuadamente el ambiente de calentamiento para no perder eficiencia calorífica. La mayoría de estos hornos suelen llegar hasta los 1100. En un horno de este tipo fue donde se realizó el calentamiento de las probetas para realizar, con ellas, la comparación de los distintos métodos de endurecimiento.

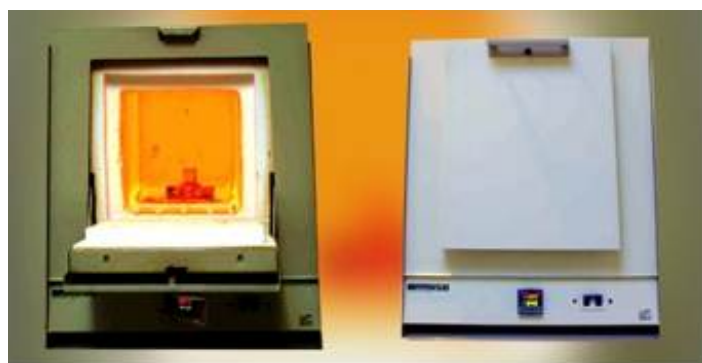


Fig. N° 2.11 Horno de calentamiento por resistencia eléctrica
Fuente: http://www.cyti.com.mx/equipos_laboratorio.asp

2.4.2.2. Horno de calentamiento por combustión

Estos hornos generan calor a través de la combustión de ciertas sustancias con poderes caloríficos altos, este calor se transmite al material a través del medio circundante o por contacto directo. Existen hornos por combustión que producen una llama, a la cual se expone al material y otros donde el material combustionante no genera llama.



Fig. N° 2.12 Horno por combustión

Fuente: <http://www.valesdedescuentos.com.ar/cinstalacionaguagasd/escalderasventar.html>

2.4.3. Horno por calentamiento interacción de radiación

2.4.3.1. Calentamiento láser

Los hornos láser, como su nombre lo indica, hacen incidir uno o varios haces láser en la superficie del material a fundir, con lo que se eleva la temperatura del mismo hasta la condición deseada. Las configuraciones son diversas, pero en general se trabaja con atmósfera controlada de gases inertes, o vacío. Tiene la gran ventaja de ser altamente preciso en la focalización del calentamiento producido y las altas temperaturas logradas.

2.4.3.2. Calentamiento por haz de electrones

Este horno trabaja con condiciones similares al horno láser, con la diferencia que en este caso se hacen incidir electrones sobre la superficie de la muestra, lo cual permite mayor penetración y permite derretir mayor volumen de material. Este tipo de hornos funden en atmósfera de vacío dado. El bajo camino libre medio de los electrones en pequeñas presiones Absolutas de gas.

2.5 TRATAMIENTOS TÉRMICOS

Se conoce como tratamiento térmico el proceso que comprende el calentamiento de los metales o las aleaciones en estado sólido a temperaturas definidas, manteniéndolas a esa temperatura por suficiente tiempo, seguido de un enfriamiento a las velocidades adecuadas con el fin de mejorar sus propiedades físicas y mecánicas, especialmente la dureza, la resistencia y la elasticidad. Los materiales a los que se aplica el tratamiento térmico son, básicamente, el acero y la fundición, formados por hierro y carbono. También se aplican tratamientos térmicos diversos a los sólidos cerámicos.

Las características mecánicas de un material dependen tanto de su composición química como de la estructura cristalina que tenga. Los tratamientos térmicos modifican esa estructura cristalina sin alterar la composición química, dando a los materiales unas características mecánicas concretas, mediante un proceso de calentamientos y enfriamientos sucesivos hasta conseguir la estructura cristalina deseada.

Entre estas características están:

1. Resistencia al desgaste: Es la resistencia que ofrece un material a dejarse erosionar cuando está en contacto de fricción con otro material.
2. Tenacidad: Es la capacidad que tiene un material de absorber energía sin producir fisuras (resistencia al impacto).
3. Maquinabilidad: Es la facilidad que posee un material de permitir el proceso de mecanizado por arranque de viruta.

4. Dureza: Es la resistencia que ofrece un acero para dejarse penetrar. Se mide en unidades BRINELL (HB) o unidades ROCKWEL C (HRC), mediante el test del mismo nombre.
5. Las propiedades mecánicas de las aleaciones de un mismo metal, y en particular de los aceros, reside en la composición química de la aleación que los forma y el tipo de tratamiento térmico a los que se les somete. Los tratamientos térmicos modifican la estructura cristalina que forman los aceros sin variar la composición química de los mismos.

Esta propiedad de tener diferentes estructuras de grano con la misma composición química se llama polimorfismo y es la que justifica los térmicos. Técnicamente el polimorfismo es la capacidad de algunos materiales de presentar distintas estructuras cristalinas, con una única composición química, el diamante y el grafito son polimorfismos del carbono. La α -ferrita, la austenita y la δ -ferrita son polimorfismos del hierro. Esta propiedad en un elemento químico puro se denomina alotropía.

Por lo tanto las diferentes estructuras de grano pueden ser modificadas, obteniendo así aceros con nuevas propiedades mecánicas, pero siempre manteniendo la composición química. Estas propiedades varían de acuerdo al tratamiento que se le dé al acero dependiendo de la temperatura hasta la cual se lo caliente y de cómo se enfría el mismo. La forma que tendrá el grano y los micro constituyentes que compondrán al acero, sabiendo la composición química del mismo (esto es porcentaje de Carbono y Hierro (Fe_3)) y la temperatura a la que se encuentra, se puede ver en el Diagrama Hierro Carbono.

2.5.1. Tratamientos térmicos de las fundiciones de hierro

El tratamiento térmico de las fundiciones de hierro se realiza fundamentalmente para eliminar las tensiones internas que surgen durante el proceso de fundido. Estas tensiones conducen con el tiempo, a la variación de las dimensiones y forma de la fundición, disminución de la dureza y mejoramiento de la maquinabilidad por corte y una elevación de las propiedades mecánicas.

En el proceso de tratamiento térmico de la fundición ocurren las mismas transformaciones que en el acero. Sin embargo, éstas se complican por el hecho de que durante el calentamiento de la fundición se puede desarrollar el proceso de grafitización que cambia complementariamente la estructura y, por lo tanto, las propiedades de la fundición.

2.5.1.1. Recocidos de las Fundiciones de Hierro

El término recocido cubre una variedad de tratamientos térmicos de fundiciones grises o nodulares aplicados con el propósito de reducir la dureza y mejorar la maquinabilidad, y que puede, simultáneamente, producir cambios en otras propiedades. Comprende los procesos de alivio de tensiones residuales, disminución de la resistencia mecánica y, en el caso del hierro nodular, incremento en la ductilidad y resistencia al impacto. Metalúrgicamente, el recocido representa un cambio en la microestructura de la fundición hacia una condición de equilibrio más estable, esto es, una estructura más uniforme.

En general, períodos de calentamiento largos, altas temperaturas de recocido y velocidades de enfriamiento muy lentas tienden a favorecer el alcance del equilibrio y máximo efecto de ablandamiento.

El recocido de la fundición incluye un aspecto no presente en el acero. Por un enfriamiento lento, el contenido de carbono de la matriz, el carbono combinado, se reduce a cero de manera que sólo ferrita y grafito quedan remanentes en la microestructura. El Si en la fundición causa precipitación del C que se deposita en el grafito presente.

El recocido, en sus variadas formas, provee un medio controlado de alcanzar el máximo de ablandamiento y maquinabilidad, o un ablandamiento parcial con retención de altos niveles de resistencia. A continuación se detallan los diferentes tipos de tratamientos de recocido en fundiciones de hierro.

2.5.1.1.1. Recocido de alta temperatura o de grafitización

Se logra la descomposición de los carburos junto a un efecto de ablandamiento debido al calentamiento a una temperatura bastante superior al rango crítico, con suficiente tiempo para homogeneizar y disolver o descomponer todos los carburos, seguido por un enfriamiento lento bastante por debajo del rango crítico. Como resultado de la completa descomposición o grafitización de los carburos, resulta una microestructura final de grafito, ferrita y algo de perlita.

Este proceso está fuertemente afectado por la composición y estructura de la fundición previa al recocido. Por ejemplo, en presencia de 1,5 a 2,5 % de Si, es normal encontrar en la fundición gris o nodular, carburo de hierro en forma de perlita, que sólo se grafitiza a temperaturas cercanas al rango crítico.

El carburo de hierro en la forma de cementita libre puede ser grafitizado sólo después de haber sido completamente solubilizado en la austenita. En la mayoría de las fundiciones grises y nodulares no aleadas, la austenización se realiza a 870 – 900° C. La

presencia de pequeños porcentajes de estabilizantes de carburos tales como Cr, Mo o V, inhiben el proceso de grafitización, y la completa descomposición de los carburos libres requieren temperaturas más altas, 900 - 930° C, y tiempos más prolongados. El inconveniente de utilizar temperaturas tan altas como 930 - 960°C, es que el eutéctico del fósforo (steadita), presente en la fundición con más de 0,10 % P, puede fundirse con el consecuente deterioro de la fundición. Además el recocido para eliminar carburos libres en presencia de cantidades significativas de Cr, Mo o V, no es práctico desde el punto de vista del costo y la distorsión resultante de la fundición.

La grafitización está principalmente influenciada por el tamaño y distribución de las partículas de carburos libres. Cantidades relativamente pequeñas y bien dispersas, son mucho más fácilmente grafitizables que carburos masivos asociados con zonas acoquilladas.

Las precauciones y condiciones de proceso en la grafitización para fundiciones grises y nodulares son las siguientes:

a) Velocidad de calentamiento: Para disminuir los peligros de gradientes térmicos grandes, se debe minimizar el diferencial de temperatura durante el calentamiento. Fundiciones de formas intrincadas con secciones gruesas y delgadas, deben ser precalentadas lentamente a 400 – 500° C, antes de llevarse a las temperaturas de austenización. En general la velocidad de calentamiento desde temperatura ambiente hasta la temperatura de recocido, no debería exceder de 110° C/hora.

b) Tiempo a temperatura: para la completa grafitización de los carburos libres, el tiempo de permanencia a la temperatura de recocido tiene su importancia. En una fundición gris no aleada se recomienda un tiempo de permanencia, cuando los carburos son masivos, de 1 a 3 horas, más 1 hora por 25 mm. de espesor. En las fundiciones

grises con cantidad apreciable de aleantes, especialmente estabilizadores de carburos como Cr, Mo y V, se utilizan mayores tiempos a temperaturas más elevadas; no obstante, cantidades apreciables de estos elementos pueden inhibir el proceso y no hacer recomendable el tratamiento.

c) Velocidad de enfriamiento: La velocidad de enfriamiento después de la permanencia a temperatura de recocido, afecta definitivamente las propiedades mecánicas de la fundición. Si se necesita un máximo ablandamiento para incrementar la maquinabilidad, es importante que la velocidad de enfriamiento sea lo suficientemente lenta para permitir la completa grafitización y prevenir que se produzcan tensiones residuales a causa de gradientes térmicos dentro de la fundición. En la mayoría de los casos las velocidades de enfriamiento en horno alcanzan a 50° C/hora, hasta bastante por debajo del rango crítico (300° C aprox.). El enfriamiento posterior hasta temperatura ambiente, se recomienda al aire calmo.

2.5.1.1.2. Normalizado

Los carburos masivos pueden removerse por grafitización a alta temperatura, como se describió anteriormente, pero la resistencia a la tracción y al desgaste se pueden retener por un tratamiento térmico de normalizado, enfriando al aire desde una temperatura por encima del rango crítico. El procedimiento es el mismo que para el recocido de alta temperatura, excepto que después de mantener la fundición durante un adecuado tiempo a temperatura, el enfriamiento se realiza más rápidamente, desde aire calmo hasta forzado con ventilador, dependiendo principalmente del tamaño y composición de la fundición. En espesores pequeños o fundiciones aleadas, el

enfriamiento debe ser lento, pudiendo incrementarse con el tamaño y la disminución de aleantes.

2.5.1.1.3. Recocidos de media temperatura

Cuando no se presentan carburos masivos o se hallan en cantidades pequeñas y dispersas, se puede realizar un recocido total calentando justo por encima del rango crítico, entre 815 y 890° C según el contenido de silicio (que eleva la temperatura crítica), seguido por un enfriamiento lento.

En una fundición no aleada este proceso se aplica para asegurar la grafitización de cualquier carburo accidental con el agregado de un total ferritizado de la matriz. El recocido de media temperatura se utiliza también en lugar del recocido de baja temperatura en fundiciones perlíticas con cantidad apreciable de Cr, Mo, V, o con % de Mn más alto que el valor nominal, pero sin cementita libre. El propósito es obtener una matriz totalmente ferrítica a pesar de los efectos inhibidores de los aleantes.

La diferencia esencial entre el recocido de temperatura media y los anteriores, es la temperatura de austenizado menor y un tiempo de calentamiento más corto, especialmente cuando no hay carburos libres. Es decir, se prefiere un tiempo mínimo a temperatura para lograr el resultado deseado, ya que un mantenimiento prolongado tiende a causar oxidación y calamina en la superficie y distorsión en la fundición.

2.5.1.1.4. Recocido de temperatura baja o ferritizado

Un recocido satisfactorio de la perlita en ausencia de cementita libre en una fundición gris y nodular, se puede lograr por medio de un calentamiento levemente debajo del rango crítico, seguido por un enfriamiento lento. El propósito es convertir

una matriz perlítica en ferrita y grafito por un proceso gradual de difusión, más que una transformación.

En fundiciones no aleadas, el calentamiento se realiza debajo de la temperatura crítica, de 730° C a 790° C, manteniéndola 1 hora por 25 mm. de espesor, seguido de un enfriamiento lento de aproximadamente 45° C por hora. La disminución de la dureza durante la ferritización en una fundición no aleada es afectada por el contenido de Si y la temperatura. Con un 2 % Si aprox., la ferritización se produce bastante rápidamente a 760° C y se puede lograr convertir hasta el 90 % de perlita en ferrita, en 20 a 30 minutos para una sección delgada. Sin embargo esta reacción es retardada por un contenido de manganeso mayor al nominal y puede ser inhibida por la presencia de aleantes. A medida que la temperatura disminuye, la velocidad de ferritización disminuye bruscamente, y debajo de 645° C la velocidad de conversión es tan pequeña que llega a ser económicamente prohibitiva.

2.5.1.1.5. Recocido de fundiciones aleadas

La presencia de uno o más elementos estabilizantes de carburos, tales como Cr, Mo, V y algunos otros como Mg, Ni y Cu, tiende a interferir en el proceso de ablandamiento que ocurre durante el recocido. Para contrarrestar estos efectos de inhibición, el recocido de las fundiciones con cantidad apreciable de estos elementos generalmente requiere temperaturas más altas y mayores tiempos de calentamiento que para las no aleadas. Por otro lado, el Si y el C tienen el efecto de favorecer la grafitización de los carburos. Consecuentemente, para comparar las características del recocido de varias fundiciones es importante considerar la influencia del C y Si, tanto

como la de los estabilizadores de carburos, como lo refleja la Tabla N° 2.2 para una fundición gris típica.

Si bien el Cr y otros estabilizadores de carburos interfieren en el recocido, tienen un importante rol cuando se trata de producir fundiciones de resistencia a la tracción y al desgaste superior. Como se verá más adelante, estos elementos también aumentan la templabilidad y resistencia a elevadas temperaturas de las fundiciones aleadas.

Tabla N° 2.2 Influencia del recocido de ferritización a 760°C, en la dureza y resistencia a la tracción de fundiciones grises

Fund. N°	Aleantes adicionales a la fundición base*, %					Tal cual fundidos		Recocidos	
	Cr	Mo	Cu	Ni	V	HB	R tracc, Mpa	HB	R tracc, Mpa
1	Hierro base sin adición de aleantes					217	253	143	191
2	0.6	0.56				262	318	217	307
3	0.5		0.52			241	296	201	263
4		0.54	0.65			269	361	187	258
5	0.49			1.45		255	312	156	240
6					0.12	229	282	156	215
7			1.8			235	300	143	206

* Composición química de la fundición base: C=3.26%, Si=1.92%, Mn=0.94%, S=0.03%, P=0.11%

Fuente: http://www.frro.utn.edu.ar/repositorio/catedras/mecanica/5_anio/metalografia/15-TT_Fundiciones_parte_b_v2

2.5.1.1.6. Propiedades de fundiciones grises y nodulares recocidas

El uso prioritario del recocido en las fundiciones grises y nodulares es para incrementar la maquinabilidad. Otras propiedades, como la resistencia a la tracción, dureza y resistencia al desgaste (y en fundiciones nodulares, límite elástico, resistencia al impacto y ductilidad) son afectadas, pero a menudo en menor importancia comparándolo con el efecto deseado en la maquinabilidad. La importancia de la

maquinabilidad se reconoce frecuentemente, cuando su costo en el proceso es varias veces mayor al costo de la fundición. De allí que toda mejora en la maquinabilidad reduce sustancialmente el costo total de la pieza terminada.

Las prácticas recomendadas para los recocidos de fundiciones grises se muestran a continuación en la Tabla N° 2.3.

Tabla N° 2.3 Práctica recomendada para los recocidos de fundiciones grises

Tipo de Recocido	Próposito	Temperatura	Tiempo	Valor de enfriamiento
Baja temperatura (ferritizado)	Convertir la perlita a ferrita en fundiciones no aleadas (máx. maquinabilidad)	700 a 760° C	45 minutos por 25 mm. de sección	Enfriamiento en el horno hasta 300° C (50° C por hora aprox.)
Media temperatura (recocido total)	Convertir la perlita a ferrita en fundiciones que no responden al ferritizado. Para eliminar pequeña cantidad de carburos dispersos.	815 a 900° C	1 hora por 25 mm. de espesor	Enfriamiento en el horno hasta 300° C aprox.
Alta temperatura (grafitizado)	Eliminación de carburos masivos y conversión de perlita en ferrita	900 a 955° C	1 a 3 horas por 25 mm. de sección	Enfriamiento dentro del horno hasta 300° C
Normalizado y Revenido	Eliminación de carburos masivos con retención de perlita para lograr resistencia y dureza intermedias	870 a 955° C	1 a 3 horas por 25 mm. de sección	Enfriamiento al aire desde la temperatura de normalizado

Fuente: http://www.frro.utn.edu.ar/repositorio/catedras/mecanica/5_anio/metalografia/15-TT_Fundiciones_parte_b_v2

Las prácticas recomendadas para los recocidos de fundiciones nodulares se muestran a continuación en la Tabla N° 2.4.

Tabla N° 2.4 Práctica recomendada para los recocidos de fundiciones nodulares

Tipo de Recocido	Próposito	Temperatura	Tiempo	Valor de enfriamiento
Baja temperatura (ferritizado)	En ausencia de carburos. Para obtener grados 60-45-12 y 60-40-18	720 a 732° C	1 hora por 25 mm de sección	Enfriamiento en el horno hasta 300° C aprox.
Media temperatura (para bajos % de Si)	En ausencia de carburos. Para obtener grado 60-40-18	870 a 925° C	Hasta igualar la temperatura de control	Enfriamiento en horno hasta 300° C aprox.
Alta temperatura (grafitizado)	En presencia de carburos. Para obtener los grados 60-45-12 y 60-40-18	915 a 930° C	2 horas mínimo	Enfriamiento dentro del horno hasta 700° C. Mantener 2 horas a 700° C y enfriar dentro del horno
Normalizado y Revenido	En presencia de carburos. Para obtener los grados 100-70-03 y 80-55-06	900 a 930° C	2 horas mínimo	Enfriamiento al aire y revenido a 530-600° C

Fuente: http://www.frro.utn.edu.ar/repositorio/catedras/mecanica/5_anio/metalografia/15-TT_Fundiciones_parte_b_v2

Desde el punto de vista metalúrgico, la microestructura para óptima maquinabilidad es una matriz ferrítica con láminas de grafito uniformemente dispersas, lo cual es una característica de una fundición totalmente recocida. Una fundición nodular totalmente recocida con una matriz ferrítica tiene una maquinabilidad comparable a la de una fundición gris, y ambos son superiores a cualquier fundición con otra estructura en la matriz. La cementita libre es la microestructura más perjudicial para la maquinabilidad, debido a que lo abrasivo y la elevada dureza tienen un efecto destructivo en el filo de la herramienta.

Las performances de maquinado de fundiciones grises o nodulares de matrices perlíticas, son definitivamente inferiores a aquellas con matriz ferrítica, pero en ausencia de cementita libre, las fundiciones perlíticas son realmente maquinables.

2.5.1.2. Incremento de la resistencia a la tracción y desgaste

Se puede lograr un significativo incremento en las propiedades mecánicas de las fundiciones grises y nodulares, mediante diversos tratamientos de endurecimiento, como normalizado, temple y revenido, tratamientos de transformación isotérmica (austemplado), martemplado, temple superficial o localizado usando inducción eléctrica o calentamiento por llama, y algún proceso que altere la composición superficial como el nitrurado.

Aunque por el temple la estructura cúbica de caras centradas se transforma, los átomos de carbono permanecen atrapados en un estado metaestable, anormal y forzando la solución sólida, lo que produce la profunda distorsión en la red de martensita, que posee una elevada resistencia y dureza debido a esa distorsión.

Dado que toda dureza extrema va acompañada de fragilidad, es necesario aliviar las tensiones de la martensita mediante un moderado calentamiento o revenido. El revenido causa la descomposición de la martensita por separación o precipitación de partículas de carburos desde la solución sólida metaestable provocando un ablandamiento de la estructura.

Cuanto mayor es la temperatura usada en el revenido, más elevado será el efecto de ablandamiento por la tendencia a aglomerarse de los carburos separados, con el consecuente alivio de la estructura martensítica. A medida que la temperatura de revenido se aproxima a la más baja del rango crítico, el ablandamiento se completa y la dureza se acerca a la condición de recocido.

2.5.1.2.1. Normalizado

Implica un enfriamiento al aire desde una temperatura por encima del rango crítico y se aplica a las fundiciones de hierro por dos propósitos. Uno es promover la grafitización de carburos masivos, que pueden formarse durante una rápida solidificación de la fundición, mientras se evita un ablandamiento del material, que resultaría de un recocido. Con la eliminación de los carburos por el normalizado, se logra un incremento de la maquinabilidad mientras se retiene la resistencia a la tracción y al desgaste. El segundo propósito para el normalizado es incrementar la resistencia al desgaste y a la tracción de aquellas fundiciones que contienen ferrita libre, producida a menudo por un muy lento enfriamiento en el molde. A causa de este propósito doble, el normalizado se trató en la sección anterior de recocidos de fundiciones.

2.5.1.2.2. Endurecido por temple y revenido

La operación de temple y revenido en fundiciones grises y nodulares requiere un conocimiento previo del rango de temperatura de transformación y la aplicación de precauciones razonables para evitar daños permanentes en el metal como por ejemplo, quemado o sobrecalentamiento, distorsión y posible fisuración en el temple. Una temperatura crítica apropiada se puede obtener por referencia con el diagrama de equilibrio de fases, conociendo la composición química de la fundición. O bien calcularse usando la siguiente fórmula:

$$\text{Temperatura crítica (}^{\circ}\text{C)} = 730 + 28. (\% \text{ Si}) - 25. (\% \text{ Mn})$$

Determinaciones más acertadas de las temperaturas de transformación alta y baja, pueden hacerse por análisis térmico de muestras de fundición.

2.5.1.2.2.1. Austenización

La respuesta al endurecimiento en las fundiciones grises y nodulares, depende directamente de la cantidad de carbono contenido en solución sólida en la austenita antes de templear. Esta cantidad se incrementará con la temperatura de austenización y decrecerá con el aumento del contenido de silicio en la fundición. Si el tiempo de mantenimiento a temperatura por encima del rango crítico es el adecuado para el calentamiento en horno, la microestructura de la matriz o el contenido de carbono combinado de la fundición antes del calentamiento no son significativos. Con un tiempo de mantenimiento muy corto, tal como en el temple a la llama o por inducción, la microestructura previa al calentamiento es un factor dominante, que determina el contenido de carbono combinado en la austenita en el temple, ya que la difusión del carbono desde el grafito a la matriz se dificulta y no se alcanza la dureza total.

Las fundiciones de hierro con una microestructura enteramente perlítica o de martensita revenida, responderán correctamente a una rápida austenización y temple como se produce en el temple a la llama o por inducción. Las fundiciones con matriz ferrítica también responderán al endurecimiento pero solamente si se mantiene por encima del rango crítico un tiempo suficiente para permitir la solución del carbono grafitico en la austenita. Podría requerir desde 1 a 10 minutos a temperatura, o más en algunos casos dependiendo de los espacios entre grafitos, la temperatura de austenización y la presencia de aleantes.

En la práctica, las fundiciones se austenizan a una temperatura 20 a 40° C por encima del punto crítico superior durante 20 minutos a 1 hora, por cada 25 mm. de espesor, dependiendo de la composición y microestructura inicial. El calentamiento debería ser gradual (unos 100° C por hora) desde una temperatura baja, para evitar

tensiones térmicas y minimizar la posibilidad de fisuras. Por encima de 550° C se puede aumentar la velocidad de calentamiento. Se debe evitar el sobrecalentamiento por su efecto en la oxidación, distorsión o incluso fusión localizada; en piezas maquinadas se debe proteger de la oxidación o descarbura-ción, utilizando atmósferas controladas.

2.5.1.2.2. Templado

Después de una austenización adecuada se realiza el temple con el propósito de suprimir la transformación de equilibrio y alcanzar la dureza deseada con estructura martensítica. En esta operación la velocidad de enfriamiento es muy importante, ya que existe, para cada composición o grado de la fundición, una velocidad crítica especial. Si la fundición se enfría demasiado lentamente no ocurrirá la transformación martensítica, sino que se formarán productos de transformación isotérmica.

Enfriamientos rápidos, tales como temple en agua que exceden la velocidad crítica, pueden causar distorsión o fisuras como consecuencia de que la transformación en martensita resulta con una apreciable expansión de volumen. Esta expansión puede ocurrir en el mismo momento en que porciones no transformadas adyacentes se encuentran en una normal contracción térmica.

Las fuerzas opuestas de la expansión de volumen de la martensita y la contracción térmica debida al enfriamiento, tienden a crear tensiones internas que resultarán en distorsiones y fisuras. En general un temple en aceite produce resultados correctos.

La dureza de una martensita adecuadamente templada en diferentes fundiciones puede no ser equivalente, cuando se mide con los ensayos convencionales de Rockwell o Brinell. Los ensayos de microdureza indican valores equivalentes a Rockwell C

dentro de los 60, pero con el método convencional los valores serán menores a causa del grafito en la microestructura. Fundiciones grises totalmente endurecidas, pueden estar en el rango de HRc 48 a 55 dependiendo de la cantidad y tamaño de las láminas de grafito. Las fundiciones nodulares deberían estar en el rango de HRc 53-58. La resistencia al desgaste de las fundiciones con estas durezas supera la de los aceros de alto carbono endurecidos.

2.5.1.2.2.3. Revenido

La etapa final del temple es el revenido. En este paso, el calentamiento a temperatura sub-crítica alivia la extrema fragilidad de la estructura tal cual templada. La base fundamental del revenido es la precipitación o separación de microscópicas o sub-microscópicas partículas de carburos de la estructura metaestable de la martensita, para establecer una microestructura más blanda y tenaz.

La selección del ciclo de temperatura-tiempo de revenido está basada en la respuesta que tiene cada tipo o grado de fundición y las propiedades que se desean. Algunas relaciones típicas entre temperaturas de revenido, tiempo y dureza, de fundiciones aleadas y no aleadas, se muestran en las Fig. N° 2.13, 2.14 y 2.15.

Usualmente es deseable un enfriamiento lento desde la temperatura de revenido, especialmente cuando es alta; esto minimiza las tensiones residuales en fundiciones de formas complejas. En la Fig. N° 2.16 se indica la relación que existe entre resistencia a la tracción, límite elástico, alargamiento y dureza en fundiciones nodulares.

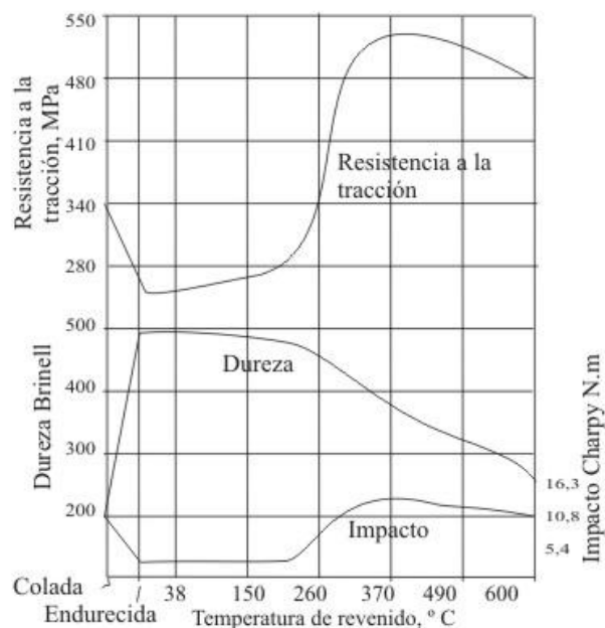


Fig. N° 2.13 Influencia por el temple y revenido en las propiedades mecánicas de una fundición gris no aleada.

Fuente: http://www.frro.utn.edu.ar/repositorio/catedras/mecanica/5_anio/metalografia/15-TT_Fundiciones_parte_b_v2

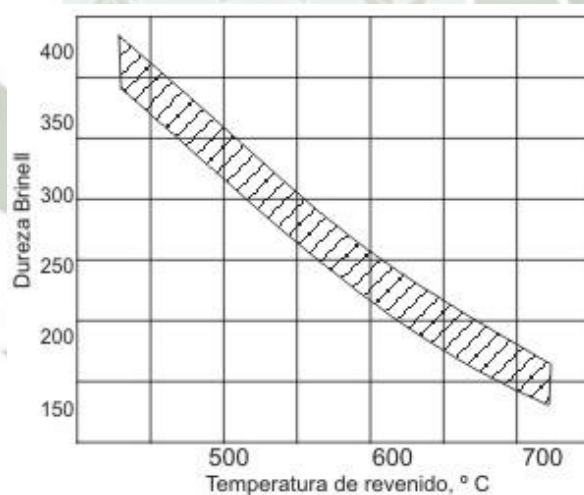


Fig. N° 2.14 Influencia del revenido de 2 hs. en la dureza de una fundición nodular templada en aceite. La dureza de temple fue de 570 HB.

Fuente: http://www.frro.utn.edu.ar/repositorio/catedras/mecanica/5_anio/metalografia/15-TT_Fundiciones_parte_b_v2

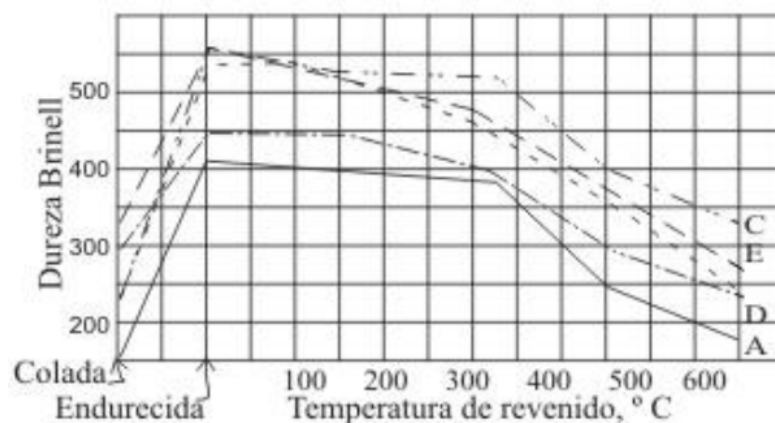


Fig. N° 2.15 Influencia de la temperatura de revenido en la dureza de fundiciones grises no aleadas y aleadas:

A: no aleada

B: 3,89 % Ni

C: 3,46 % Ni – 1,56 % Cr

D: 0,47 % Mo

E: 0,50 % Cr – 0,52 % Mo

Fuente: http://www.frro.utn.edu.ar/repositorio/catedras/mecanica/5_anio/metalografia/15-TT_Fundiciones_parte_b_v2

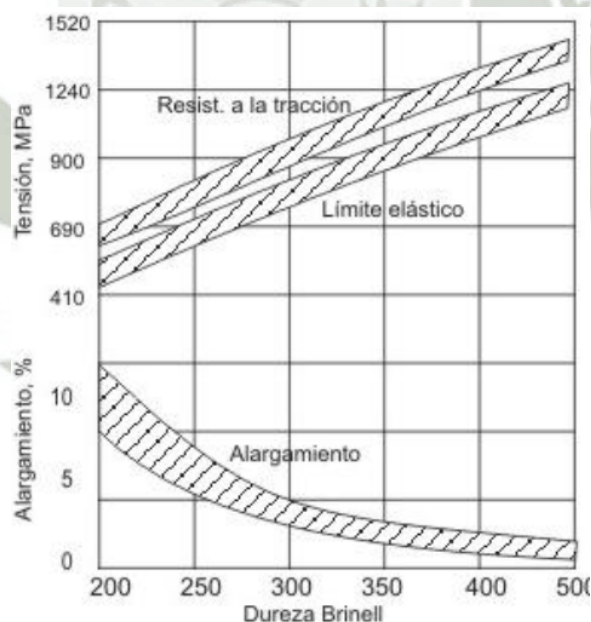


Fig. N° 2.16 Relación típica entre las propiedades mecánicas y la dureza en fundiciones nodulares templadas y revenidas.

Fuente: http://www.frro.utn.edu.ar/repositorio/catedras/mecanica/5_anio/metalografia/15-TT_Fundiciones_parte_b_v2

2.5.1.2.3. Temple en caliente

Como se indicó anteriormente la aplicación de un temple convencional y revenido en fundiciones grises y nodulares, está sujeto a ciertas dificultades, especialmente cuando las fundiciones son complejas o tienen grandes diferencias de secciones.

Para minimizar estas dificultades se puede utilizar un temple menos severo, como puede ser el uso de aceite caliente que reduciría el shock térmico del temple convencional.

Algunos efectos importantes del tiempo y temperatura en la transformación de la austenita, se muestran en el diagrama T.T.T. representado en la Fig. N° 2.17.

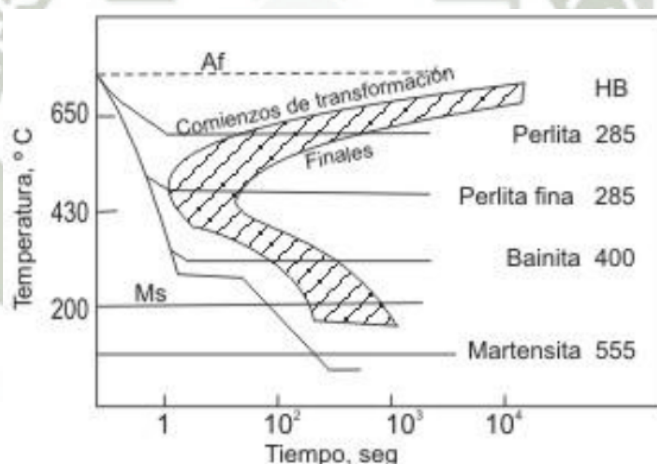


Fig. N° 2.17 Diagrama TTT de una fundición gris con bajo Si, donde se ilustran transformaciones isotérmicas a tres temperaturas. La martensita se obtiene por temple interrumpido.

Fuente: http://www.frro.utn.edu.ar/repositorio/catedras/mecanica/5_anio/metalografia/15-TT_Fundiciones_parte_b_v2

Por enfriamiento rápido desde la temperatura de austenización a 870° C dentro de un baño caliente a 320° C y mantenido aproximadamente 1 minuto, la pieza entera puede enfriarse a esa temperatura sin que se produzca ninguna transformación.

Si la pieza entonces se enfría al aire, la austenita se transformará en martensita como se indica en el diagrama por los puntos M_s y M_f . Este procedimiento producirá el máximo de dureza, que en este ejemplo es HB 555, con muy poca distorsión por la disminución del gradiente térmico. También se pueden realizar tratamientos de transformación isotérmica cuya estructura y dureza se indican en el gráfico.

Si en lugar de enfriar después del minuto de permanencia en el baño caliente, se mantiene en éste por un período largo, se produce una estructura principalmente bainítica.



CAPITULO III

DESARROLLO EXPERIMENTAL

3.1 DESCRIPCIÓN DE LOS INSTRUMENTOS A UTILIZAR

3.1.1. Pulidoras Metalográficas

Se utilizara la Desbastadora ó Pulidora Metalográfica, en su primera fase denominada Desbaste Grueso, se desbasta la superficie de la muestra con papel de lija, de manera uniforme y así sucesivamente disminuyendo el tamaño de grano hasta llegar al papel de menor tamaño de grano. Desbaste Fino, se requiere de una superficie plana libre de ralladuras la cual se obtiene mediante una rueda giratoria húmeda cubierta con un paño especial cargado con partículas abrasivas cuidadosamente seleccionadas en su tamaño para ello existen gran posibilidad de abrasivos para efectuar el ultimo pulido.

La etapa del pulimento es ejecutada en general con paños macizos colocados sobre platos giratorios circulares, sobre los cuales son depositadas pequeñas cantidades de abrasivos, en general diamante industrial en polvo fino o bien en suspensión.

En el laboratorio contamos con los siguientes equipos:

Para desbaste grueso: SPECTRUM ABRASIVE BAND GRINDING MACHINE

Modelo: TMY – 1, de la marca Beijing Time High Technology LTD.

Para desbaste fino: METALLURGICAL PREPARATION GRINDER/POLISHER

Modelo: TMP – 1A, de la marca Beijing Time High Technology LTD.

Para pulido: PULIDORA METALOGRAFICA de Tela Abrasiva.

3.1.2. Microscopio

El principal instrumento para la realización de un examen metalográfico lo constituye el microscopio metalográfico, con el cual es posible examinar una muestra con aumentos que varían entre 50X y 2000X.

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

Se cuenta con:

INVERTED METALLURGICAL MICROSCOPE Modelo DX70A, de la marca Time Group Inc.

3.1.3. Durómetro de Banco

Un durómetro es un aparato que mide la dureza de los materiales. Los más utilizados son los de Rockwell, Brinell, Vickers y Microvickers.

Se aplica una fuerza normalizada sobre un elemento penetrador, también normalizado, que produce una huella sobre el material. En función del grado de profundidad o tamaño de la huella, obtendremos la dureza.

Dentro de cada uno de estos procedimientos, hay diversas combinaciones de cargas y penetradores, que se utilizarán dependiendo de la muestra a ensayar.

En nuestro caso contamos con:

DUROMETRO DE BANCO ROCKWELL SUPERFICIAL Y NORMAL de la marca Time Group Inc.

3.1.4. Máquina Universal de Ensayos

En ingeniería se denomina máquina universal a una máquina semejante a una prensa con la que es posible someter materiales a ensayos de tracción y compresión para medir sus propiedades. La presión se logra mediante placas o mandíbulas accionadas por tornillos o un sistema hidráulico. Esta máquina es ampliamente utilizada en la caracterización de nuevos materiales.

Se realizaran las pruebas con:

MICROCOMPUTER CONTROLLED ELECTRONIC UNIVERSAL TESTING MACHINE Modelo WAW – 300E, de la marca Transcell Technology Inc.

3.1.5. Péndulo de Charpy

El péndulo de Charpy es un dispositivo a modo de péndulo ideado por Georges Charpy. Se utiliza en ensayos para determinar la tenacidad de un material. Son ensayos de impacto de una probeta entallada y ensayada a flexión en 3 puntos. El péndulo cae sobre el dorso de la probeta y la parte. La diferencia entre la altura inicial del péndulo y

la final tras el impacto permite medir la energía absorbida en el proceso de fracturar la probeta. En estricto rigor se mide la energía absorbida en el área debajo de la curva de carga, desplazamiento que se conoce como resiliencia.

Contamos con el siguiente equipo:

IMPACT TESTING MACHINE Modelo JB-W300A de la marca Time Group Inc.

3.1.6. Horno Mufla

Un horno es un dispositivo que genera calor y que lo mantiene dentro de un compartimiento cerrado. En la industria metalúrgica, se lo utiliza para realizar tratamientos térmicos sobre los materiales, de modo de obtener propiedades mecánicas y microestructuras deseadas para algún uso particular.

Se realizaran los tratamientos térmicos de las probetas con:

MUFLA DIGITAL DE 1200°C Modelo BARNF48020-33, de la marca Thermo Scientific Thermolyne.

3.2 PROCEDIMIENTO EXPERIMENTAL

3.2.1. Tratamientos térmicos

Para determinar los tratamientos térmicos a realizar en este trabajo de investigación evaluamos el costo en una pieza terminada.

La maquinabilidad de las fundiciones tiene una gran importancia, considerando que el costo en el proceso es varias veces mayor al costo de la fundición en sí. De allí que toda mejora en la maquinabilidad reduce sustancialmente el costo total de la pieza terminada.

El uso del recocido en las fundiciones grises es para incrementar la maquinabilidad; otras propiedades como la resistencia a la tracción, dureza y resistencia al desgaste son afectadas, pero a menudo en menor importancia comparándolo con el efecto deseado en la maquinabilidad.

Considerando esto, utilizaremos como referencia la Tabla N° 2.3; de la cual seleccionamos dos tipos de tratamiento térmico para las pruebas a realizar:

- Recocido de Baja Temperatura.
- Normalizado.



Fig. N° 3.1 Horno para realizar los tratamientos termicos en las probetas.

3.2.1.1. Recocido de baja temperatura

Esta prueba la realizaremos con el propósito de conseguir la máxima maquinabilidad de la fundición, esto se conseguirá ya que durante el proceso la perlita se convertirá en ferrita.

Calentaremos las probetas a una temperatura entre 700 y 760° C; durante un tiempo estimado de 45 minutos por 25 mm de sección y posteriormente se enfriaran lentamente en el interior del horno hasta una temperatura aproximada de 300° C.



Fig. N° 3.2 Tiempo de duración del recocido de baja temperatura (45 min).



Fig. N° 3.3 Probetas despues del recocido de baja temperatura.

3.2.1.1. Normalizado

Con esta prueba buscamos alcanzar una resistencia y dureza intermedias, mediante la eliminación de carburos masivos por grafitización a alta temperatura.

Calentaremos las probetas entre 780 y 955° C, por un lapso de 1 a 3 horas por 25 mm de sección, luego el enfriamiento se realizara desde aire calmo hasta aire forzado.



Fig. N° 3.4 Tiempo de duración del proceso de normalizado (1 hora).

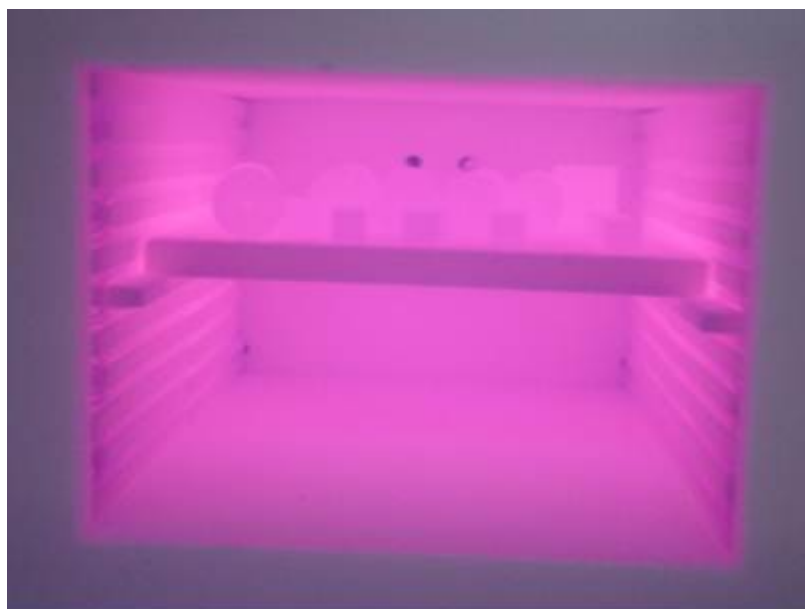


Fig. N° 3.5 Probetas despues del proceso de normalizado.

3.2.2. Análisis metalográfico

La presencia de grafito en el hierro gris limita el uso de muchas de las técnicas de preparación metalográfica, normalmente usada para otros metales. La naturaleza blanda y frágil de la fase de grafito, en combinación con la dureza de la matriz, crea durante la preparación, dificultades no experimentadas normalmente en otros metales. Las técnicas que generan una superficie libre de rasgos y distorsiones en la matriz puede no permitir la retención y pulido de la fase de grafito. Similarmente, técnicas para fases blandas y frágiles como la del grafito no se prestan fácilmente por sí mismas para una preparación buena de una matriz dura.

Si la etapa de preparación no se realiza cuidadosamente es posible que se obtenga una superficie poco representativa del metal y sus características. Una preparación incorrecta puede arrancar inclusiones no metálicas, barrer las láminas de grafito en una muestra de fundición, o modificar la distribución de fases si la muestra ha sufrido un sobrecalentamiento excesivo.

Si bien la fase más importante de la metalografía es la observación microscópica, la experiencia demuestra que poco se puede hacer si alguna de las operaciones previas se realiza deficientemente.

3.2.2.1. Preparación de la probeta

3.2.2.1.1. Extracción de la muestra

Durante la extracción de la muestra es fundamental considerar el lugar de donde se extraerá la probeta y la forma en que se hará dicha extracción.

Se debe tener en cuenta que no es indiferente el lugar de donde se extraerá la muestra, según sea el objetivo del examen. Por ejemplo cuando se trata de una pieza rota en

servicio y el objeto del examen es determinar las causas de dicha falla, la probeta debe extraerse, en la medida de lo posible, de la zona puntual donde la pieza ha fallado. Esto permitirá obtener la mayor información posible de las características del material en dicha zona y así obtener mejores conclusiones sobre las posibles causas de la falla.

En síntesis se debe lograr una muestra representativa del material a examinar. En cuanto a la forma de extracción de la probeta se debe tener en cuenta que esta operación debe realizarse en condiciones tales que no afecten la estructura superficial de la misma. Por lo tanto se debe cuidar que la temperatura del material no se eleve demasiado durante el proceso de extracción.

La extracción se puede hacer con cierras de corte manual, o en el caso de piezas muy duras con cortadoras sensitivas muy bien refrigeradas.



Fig. N° 3.6 Probetas utilizadas para el ensayo de metalografía.

3.2.2.1.2. Preparación de la muestra

La preparación de la muestra se divide en 03 etapas:

Desbaste grueso

El desbaste grueso se practica una vez extraída la probeta con la finalidad de reducir las irregularidades, producidas en la operación de extracción, hasta obtener una cara lo más plana posible. Esta operación puede realizarse con una cinta de desbaste o bien en el caso de materiales no muy duros como aceros sin temprar y fundiciones se puede hacer con lima, aunque aumente algo la distorsión que se produce en la superficie a causa de la fluencia del material.



Fig. N° 3.7 Superficie de la probeta despues del desbaste grueso.

Desbaste final

Durante la operación se debe dejar que una corriente de agua limpie los pequeños desprendimientos de material y a su vez lubrique y refrigere la zona desbastada.

Para poder reconocer esto fácilmente se opera de manera que las rayas de un papel a otro sean perpendiculares, es decir se debe rotar 90° la dirección de movimiento

de la probeta cada vez que se cambia de abrasivo. Además cada vez que se cambia de abrasivo es conveniente lavar la probeta y enjuagarse las manos para no transportar las partículas desprendidas en el abrasivo anterior, ya que esto puede provocar la aparición de rayas.

La presión que se aplica a la probeta no debe ser exagerada ya que esto aumenta la distorsión y además pueden aparecer rayas profundas. La presión debe ir disminuyendo a medida que se avanza en la operación.

En el caso práctico la operación de desbaste final comienza con un papel abrasivo de 250 o 400, para terminar con el 600 o 1000. El abrasivo está adherido sobre un disco de 220 mm de diámetro, que gira a velocidades que pueden oscilar entre 250 y 600 RPM.



Fig. N° 3.8 Tipos de papeles abrasivos utilizados para el desbaste fino.

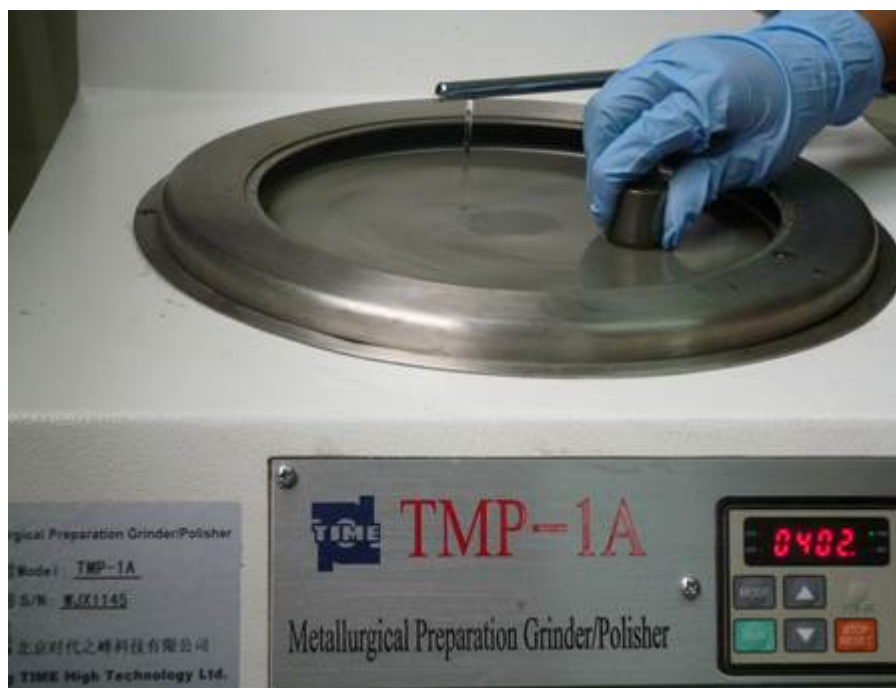


Fig. N° 3.9 Desbaste fino de la probeta.



Fig. N° 3.10 Superficie de la probeta despues del desbaste fino.

Pulido

El pulido tiene por objeto eliminar las rayas finas producidas en el desbaste final y producir una superficie con características especulares. Esta operación por lo general se realiza en forma mecánica y se utiliza un paño impregnado con partículas de algún abrasivo en solución acuosa. En general se pueden utilizar dos tipos de paños: con pelo (pana, terciopelo, lanas) y sin pelo (seda natural). Se debe elegir el que más se adapte al tipo de material a examinar. En cuanto a los abrasivos pueden ser: pasta de diamante, alúmina, alundun, etc. Se debe cuidar que la humedad del paño sea la adecuada, es decir, si la humedad es excesiva la acción abrasiva se retardará demasiado y si es escasa la probeta tiende a mancharse.

En el caso práctico se utilizara un paño de pelo corto y con un abrasivo de alúmina (óxido de aluminio en partículas).

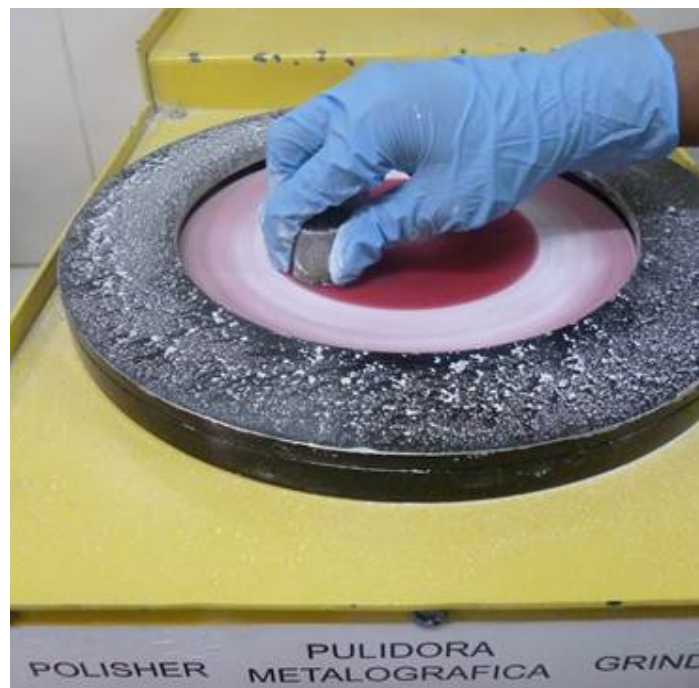


Fig. N° 3.11 Pulido de la probeta.



Fig. N° 3.12 Superficie de la probeta despues del pulido.

3.2.2.1.3. Ataque químico

El ataque químico de la cara que se observará tiene por objetivo poner en evidencia, mediante un ataque selectivo, las características estructurales de la muestra. Al aplicar el reactivo sobre la superficie a observar, las características de la estructura son reveladas como consecuencia de un ataque selectivo de la superficie. Esto se debe a que las distintas fases así como los planos cristalográficos diferentemente orientados poseen diferencias en la susceptibilidad al ataque.

Los reactivos de ataque por lo general son ácidos orgánicos disueltos en agua, alcohol, glicerina, etc. El grado de ataque de una probeta es función de la composición, temperatura y tiempo de ataque. El nital (solución acuosa o alcohólica de ácido nítrico al 2% o hasta el 5%) es uno de los reactivos más comúnmente usado en aleaciones ferrosas y aceros.

El tiempo de ataque es una variable fundamental, y en general debe ser determinado en forma práctica. Un tiempo de ataque demasiado corto (subataque), no permitirá que el reactivo actúe lo suficiente y por lo tanto no se obtendrá un buen contraste entre las fases, o los bordes de grano aun no habrán aparecido. Por otro lado, un sobre ataque proporcionará una cara oscura con bordes de grano demasiado anchos, resultando dificultoso una distinción clara de las proporciones de cada una de las fases.

En el caso práctico, antes de realizar el ataque se limpia y desengrasa con alcohol la cara de la muestra a atacar y luego se seca con aire caliente. Se sumerge la probeta en el nital al 5% de ácido nítrico, con la cara que se observará hacia arriba, transcurrido el tiempo de ataque se toma la probeta y se lava con alcohol e inmediatamente se seca con aire caliente.

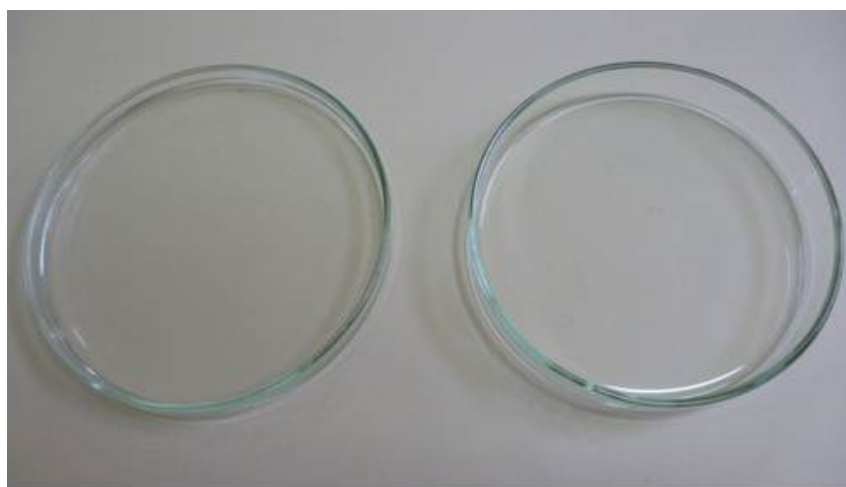


Fig. N° 3.13 Depósitos con los reactivos para el ataque químico, - Izquierda Nital al 3% de ácido nítrico – Derecha, Alcohol.

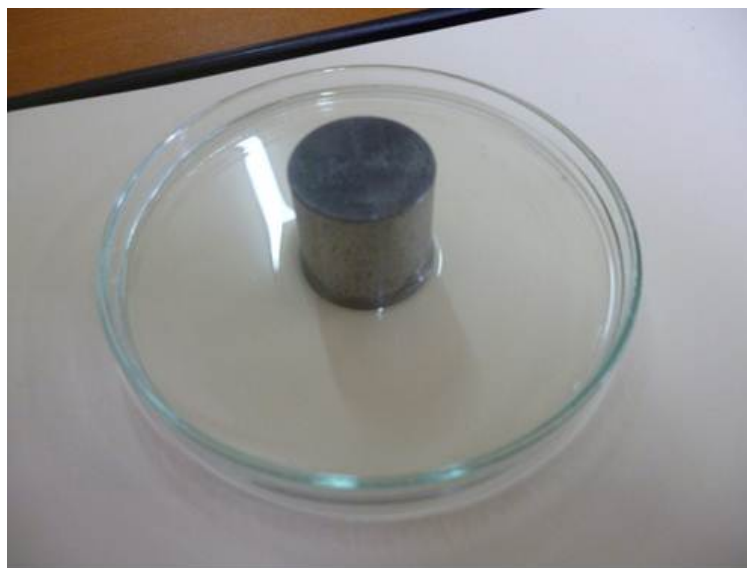


Fig. N° 3.14 Probeta siendo sometida al ataque químico.

3.2.2.1.4. Examen microscópico

Este tipo de análisis se utiliza para determinar la forma y tamaño de los granos de los cuales está constituido el metal o la aleación; para detectar los cambios de la estructura interna de la aleación operados por acción de los diferentes regímenes de tratamiento; para poner de manifiesto los microdefectos del metal, es decir, las microgrietas, microporos, etc.; para descubrir las inclusiones no metálicas: los sulfuros, los óxidos, etc.

La norma ASTM A-247 para el método de prueba estándar para la evaluación de la microestructura del grafito en fundiciones de hierro; establece la comparación de las partículas de grafito observadas con las estructuras que se muestran en los gráficos.

Esta norma brinda información puramente descriptiva sobre el tipo, la distribución y el tamaño del grafito en la muestra que está siendo evaluada. No indica excepto en una forma muy amplia el origen del grafito, o la idoneidad de la aleación de hierro-carbono para un servicio particular.



Fig. N° 3.15 Microscopio metalográfico.

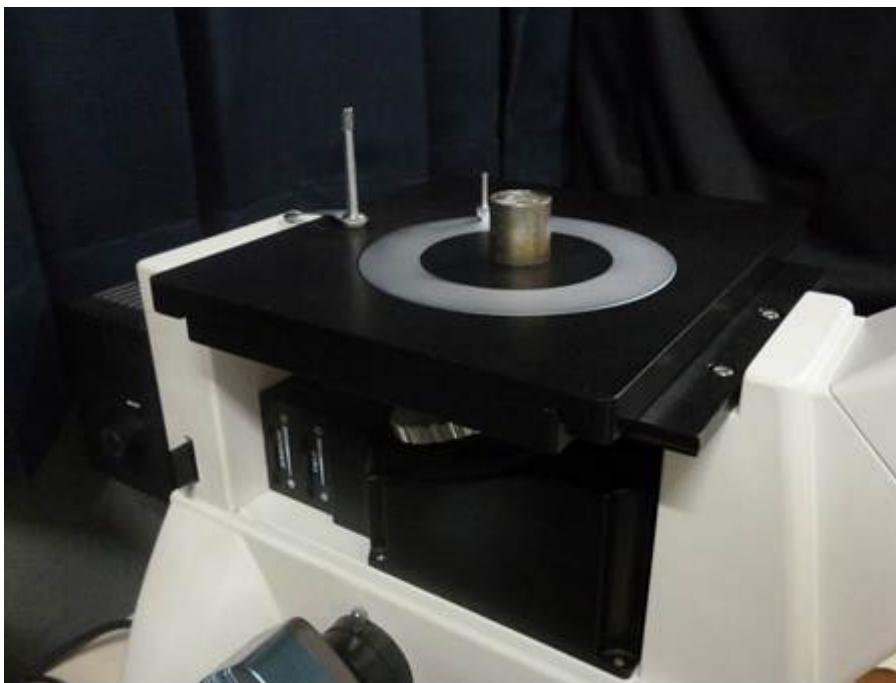


Fig. N° 3.16 Probeta lista para el examen microscopio.

3.2.3. Ensayo de tracción

El ensayo de tracción consiste en someter a una probeta (material objeto de ensayo) a una fuerza normal de tracción, progresivamente creciente, hasta producir la rotura de la misma. El ensayo se realiza en una máquina de tracción que dispone de unas mordazas para sujetar la probeta y una electrónica de medida donde se registran la fuerza y el desplazamiento.

La norma ASTM A48, para fundiciones grises laminares, hace viable la especificación de la fundición con tan sólo realizar el ensayo de tracción sobre probetas representativas del material. La ASTM A48 cubre a fundiciones de hierro gris destinadas al uso general de ingeniería donde la resistencia a la tracción es de considerable importancia.

La composición química es una de las variables decisivas en las propiedades mecánicas; pero también el tamaño, distribución del grafito y el tipo de la matriz que dependen de la velocidad de enfriamiento, pueden influir dando resultados no esperados.

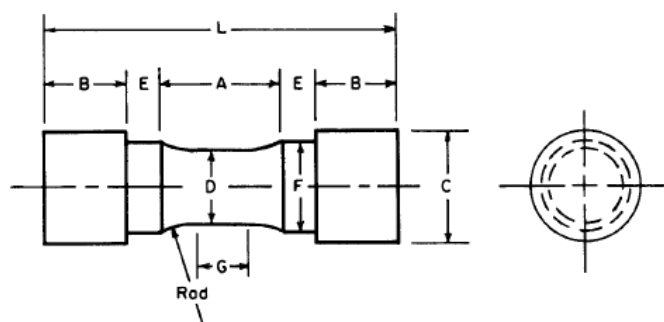
Las muestras de fundición son clasificadas en el grado a que corresponden según la ASTM, basándose en las propiedades mecánicas de las barras de prueba fundidas separadamente de la pieza. Cada clase es designada por un número seguido de una letra. El número indica la resistencia a la tracción mínima en psi o MPa de la barra de prueba fundida, y la letra indica el tamaño de la barra de prueba.

Según la norma ASTM A 48, los hierros grises se clasifican con base en la resistencia a tracción. El rango de categorías varía desde la clase 20 hasta la 60 (mínima resistencia a tracción de 138 a 414 MPa, o 20 a 60 psi, respectivamente) en una barra de ensayo de 30,5 mm de diámetro.

La resistencia a tracción disminuye con el aumento del tamaño de la sección, para todas las clases de hierros. Esta reducción en la resistencia a tracción es causada por la presencia de hojuelas más grandes de grafito y por una reducción del carbono combinado. Una disminución del carbono combinado resulta en un incremento de la cantidad de ferrita en la forma de una perlita de un mayor espaciado o con la apariencia de una fase ferrítica.

3.2.3.1. Preparación de la probeta

Las probetas para el ensayo de tracción se realizaron en base a la norma ASTM A 48, utilizaremos la probeta tipo A (ver figura). El ensayo se realizó en una máquina probadora universal de 300 KN de capacidad máxima y se empleó una probeta tipo A.



Dimensions, in. [mm]	Tension Test Specimen A	Tension Test Specimen B	Tension Test Specimen C
G—Length of parallel, min	0.50 [13]	0.75 [19]	1.25 [32]
D—Diameter	0.500 ± 0.010 [12.7 ± 0.25]	0.750 ± 0.015 [19.0 ± 0.38]	1.25 ± 0.025 [30 ± 0.65]
R—Radius of fillet, min	1 [25]	1 [25]	2 [50]
A—Length of reduced section, min	1¼ [32]	1½ [38]	2¼ [57]
L—Over-all length, min	3¼ [95]	4 [100]	6¼ [160]
C—Diameter of end section, approx	¾ [22]	1¼ [32]	1½ [48]
E—Length of shoulder, min	¼ [6]	¼ [6]	¾ [8]
F—Diameter of shoulder	⅝ ± ¼ [16 ± 0.4]	⅞ ± ¼ [25 ± 0.4]	1⅞ ± ¼ [36 ± 0.4]
B—Length of end section	A	A	A

^aOptional to fit holders on testing machine. If threaded, root diameter shall not be less than dimension F.

Fig. N° 3.17 Dimensiones de la probeta para el ensayo de tracción según la norma ASTM A-48.



Fig. N° 3.18 Probetas para el ensayo de tracción.



Fig. N° 3.19 Probeta montada en las mordazas de la maquina universal de ensayos.

3.2.4. Ensayo de dureza

En la estructura de la fundición gris encontramos fases que tienen una marcada diferencia en valores de dureza. La naturaleza blanda de la fase de grafito combinado con la dura matriz, sugiere una medida de dureza promedio que considere el efecto de la cantidad de grafito. En este ensayo un indentador se presiona contra la superficie de ensayo con una carga que se aplica en forma relativamente lenta. En general la medida de dureza en este tipo de ensayo resulta del cociente de la carga aplicada y el área de la huella que deja el indentador en la superficie, como es el caso de los métodos Brinell, Vickers y Knoop, o bien es una medida de la profundidad de la indentación como en el ensayo Rockwell.

La aplicación de la técnica de dureza Brinell para fundiciones se ajusta mejor que la medida de dureza Rockwell debido a que abarca una superficie mayor dando valores más exactos que esta técnica.

En la práctica se hace notar que la máquina del laboratorio, arroja un valor en escala Rockwell C y mediante ayuda de las tablas de conversión de dureza presentadas en la norma ASTM E140-97 se realiza la conversión a la escala Brinell. El resultado se da como un valor promedio de los valores obtenidos.



Fig. N° 3.20. Maquina utilizada para el ensayo de dureza.



Fig. N° 3.21. Probeta lista para realizar el ensayo de dureza.

3.2.5. Ensayo de resiliencia

También llamado ensayo de impacto o choque proporciona una medida de la tenacidad del material e indirectamente de su ductilidad ya que en general existe una correlación entre ambas características; el valor numérico obtenido, sin embargo, es similar al de la resiliencia. La razón de esta coincidencia se debe al hecho de que en el ensayo de impacto la carga que provoca la rotura de la probeta se aplica de forma instantánea impidiendo la deformación plástica del material provocando en la práctica la fractura frágil de materiales dúctiles.

El ensayo Charpy permite calcular cuánta energía logra disipar una probeta al ser golpeada por un pesado péndulo en caída libre. El ensayo entrega valores en Joules, y éstos pueden diferir fuertemente a diferentes temperaturas.

La probeta posee un entalle estándar para facilitar el inicio de la fisura; este entalle recibe el nombre de V-Notch. Luego de golpear la probeta, el péndulo sigue su camino alcanzando una cierta altura que depende de la cantidad de energía disipada al golpear. Las probetas que fallan en forma frágil se rompen en dos mitades, en cambio aquellas con mayor ductilidad se doblan sin romperse. Este comportamiento es muy dependiente de la temperatura y la composición química, esto obliga a realizar el ensayo con probetas a distinta temperatura, para evaluar la existencia de una "temperatura de transición dúctil-frágil".

3.2.5.1. Preparación de la probeta

Para la prueba utilizaremos probetas en base a la norma ASTM E23 o Charpy-V Tipo A, esta es de sección cuadrada de 10 mm de lado y 55 mm de longitud

colocándose con una distancia entre apoyos de 40 mm, tiene una entalla triangular formando las caras un ángulo de 45°, con una profundidad de 2mm y redondeo en el fondo de la entalla de 0,25 mm de radio (Fig. N° 3.22).

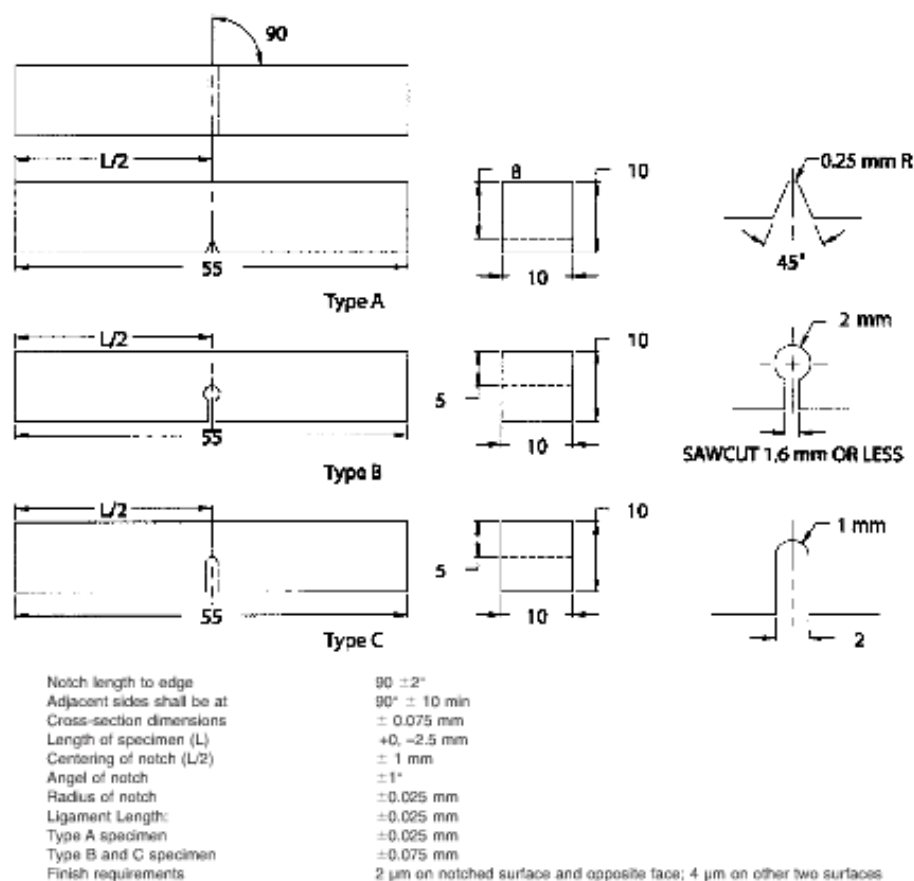


Fig. N° 3.22. Dimensiones de la probeta para el ensayo de resiliencia según la norma ASTM E23.



Fig. N° 3.23 Probeta para el ensayo de resiliencia.



Fig. N° 3.24 Probeta lista para el ensayo de resiliencia.

CAPITULO IV

RESULTADOS

4.1 PROPIEDADES MECÁNICAS DE LAS FUNDICIONES GRISES

Para poder realizar el análisis de la fundición gris con la cual estamos trabajando, es necesario tener en cuenta los valores esperados de las principales propiedades de este tipo de material.

Es por este motivo que a continuación se presentan algunas tablas que nos servirán de guía para analizar, comparar y determinar la certeza de los valores encontrados.

- En cuanto a su composición química, la fundición gris contiene entre 2.5 y 4 % de carbono y de 1 a 3 % de silicio.
- En cuanto a sus propiedades mecánicas:

Tabla N° 4.1 Características mecánicas típicas de las probetas normales de fundición gris en estado de moldeo.

Tipo ASTM	Resistencia a tracción, Kg/mm ²	Resistencia a compresión, Kg/mm ²	Resistencia al cizallamiento por torsión, kg/mm ²	Modulo de Elasticidad en miles de kg/mm ²		Limite a la fatiga por flexión alternada kg/mm ²	Resistencia transversal de una barra de 1,2 plg de diametro y 18 de longitud, en kg	BHN
				Tensión	Torsión			
20	15.40	28.10	18.20	6.72 - 9.80	2.73 - 3.92	7.00	839.90	156.00
25	18.20	67.90	22.40	8.05 - 10.36	3.22 - 4.20	8.05	987.45	174.00
30	21.70	76.30	28.00	9.10 - 11.48	3.64 - 4.62	9.80	1146.35	201.00
35	25.55	86.80	33.95	10.15 - 12.04	4.06 - 4.83	11.20	1293.90	212.00
40	29.75	98.00	39.90	11.20 - 14.00	4.48 - 5.46	12.95	1441.45	235.00
50	36.75	114.80	51.10	13.16 - 15.96	5.04 - 5.60	15.05	1634.40	362.00
60	43.75	131.25	61.95	14.28 - 16.45	5.46 - 5.95	17.15	1679.80	302.00

Fuente: F.R. Morral - E. Jimeno - P. Molera, *Metalurgia general tomo II*, Reverté 1985. Pg 1196.

Tabla N° 4.2 Composición y propiedades mecánicas de fundiciones de hierro seleccionadas.

Tipo	Composición típica, %					Resistencia a la tensión		
	Fe	C	Si	Mn	Otros	lb/plg2	Mpa	Elongación, %
Fundiciones grises								
Clase 20	93.00	3.50	2.50	0.65		20000.00	138.00	0.60
Clase 30	93.60	3.20	2.10	0.75		30000.00	207.00	0.60
Clase 40	93.80	3.10	1.90	0.85		40000.00	276.00	0.60
Clase 50	93.50	3.00	1.60	1.00	0.67 Mo	50000.00	345.00	0.60
Fundiciones dúctiles								
ASTMA395	94.40	3.00	2.50			60000.00	414.00	18.00
ASTMA476	93.80	3.00	3.00			80000.00	552.00	3.00
Fundiciones blancas								
Bajo - C	92.50	2.50	1.30	0.40	1.5 Ni, 1 Cr, 0.5Mo	40000.00	276.00	0.00
Fundiciones maleables								
Ferríticas	95.30	2.60	1.40	0.40		50000.00	345.00	10.00
Perlíticas	95.10	2.40	1.40	0.80		60000.00	414.00	10.00

Fuente: Mikell P. Groover, *Fundamentos de manufactura moderna: materiales, procesos y sistemas*, Pearson 1997. Pg. 130.

4.2 ANTES DEL TRATAMIENTO TÉRMICO

4.2.1. Análisis metalográfico

Las imágenes fueron analizadas en el microscopio modelo DX70A con un aumento de 50X; estas fueron captadas por la cámara propia del microscopio y con una cámara digital Lumix de Panasonic.

Para la obtención del porcentaje de carbono presente en la fundición, se procedió a analizar la imagen de la muestra con el software Image – Pro Plus.

Del procesamiento digital de la imagen en sus múltiples etapas y posterior binarización de esta, se obtiene las áreas que representan el carbono presente en la probeta; el software nos permite obtener la cantidad y la suma de todas estas áreas en pixeles.

$$\text{Area total} = 3230221 \text{ pixeles}$$

$$\text{Area ocupada por grafito} = 101242 \text{ pixeles}$$

Para obtener el porcentaje de grafito de la muestra de fundición gris analizada utilizamos la Ecuación 4.1, y el resultado obtenido es tal como se muestra:

Ecuación N° 4.1 Cálculo del % de grafito

$$\% \text{ grafito} = \frac{\text{Area ocupada por grafito} * 100\%}{\text{Area total}}$$

$$\% \text{ grafito} = \frac{101242 * 100}{3230221}$$

$$\% \text{ grafito} = 3.13 \%$$

Se capturaron las imágenes necesarias para realizar la evaluación de la probeta, para lo cual se utilizaron dos tipos diferentes de lentes; un lente propio del microscopio utilizado y otro de la cámara digital Lumix de Panasonic.



Fig. N° 4.1 Imagen capturada con un aumento de 50X con la cámara digital.

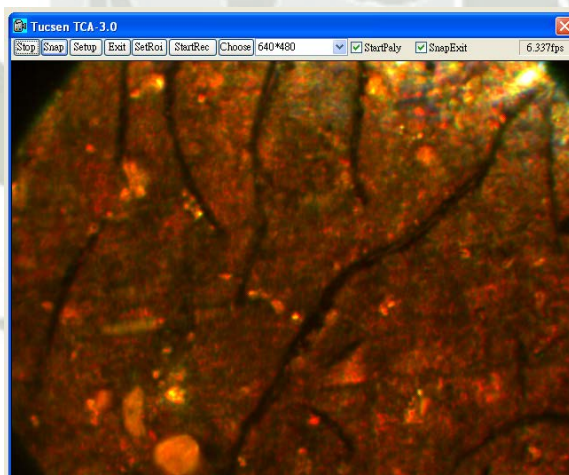
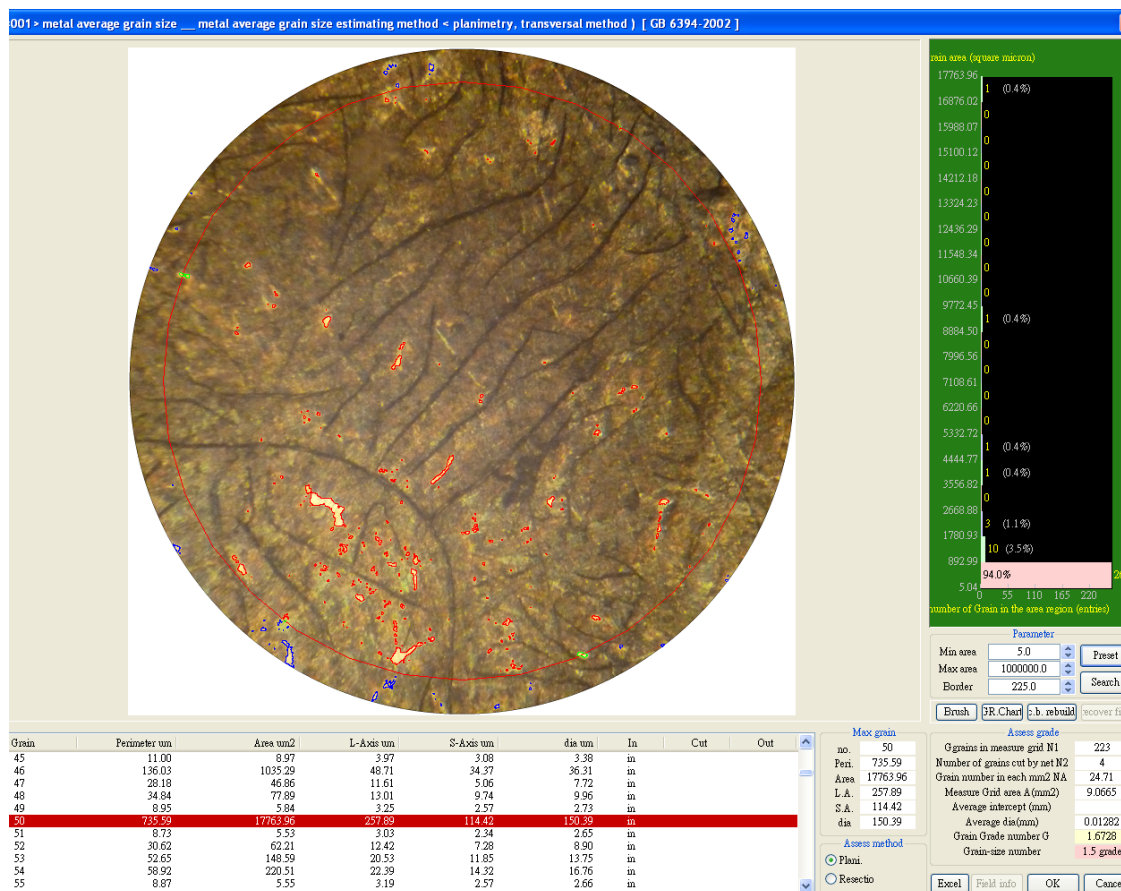


Fig. N° 4.2 Imagen capturada con un aumento de 50X con el microscopio.

Posteriormente se procedió a analizar el tamaño de grano de la probeta, para esto se utilizó el software del microscopio DX70A; y se obtuvo lo siguiente:



Grain-size number: 1.5 grade.

Fig. N° 4.3 Obtención del tamaño de grano.

4.2.2. Prueba de tensión

Los resultados de la resistencia a la tracción se obtuvieron con el software de la maquina empleada para el ensayo, estos figuran en la Tabla N° 4.3.

Tabla N° 4.3 Resultados del ensayo de tracción, antes del tratamiento térmico.

Item	Probeta	Ø Inicial	Esfuerzo de traccion		Maxima Deform
		mm	Mpa	Psi	mm
1	A1	12.7	142.51	20669	4.483
2	A2	12.7	134.13	19454	3.172
3	A3	12.7	93.55	13568	4.764
4	A4	12.7	84.50	12256	4.449
Promedio			114	16487	

A continuación se muestran los gráficos de Carga – Deformación de todas las probetas ensayadas.

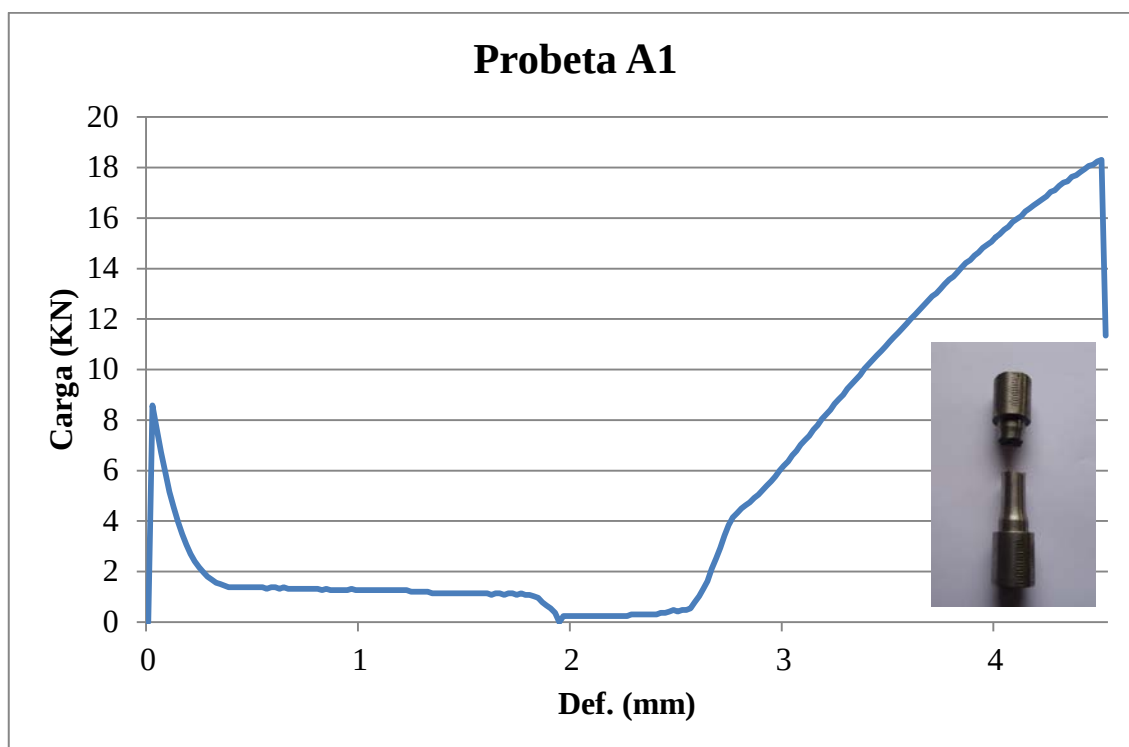


Fig. N° 4.4 Probeta A1.

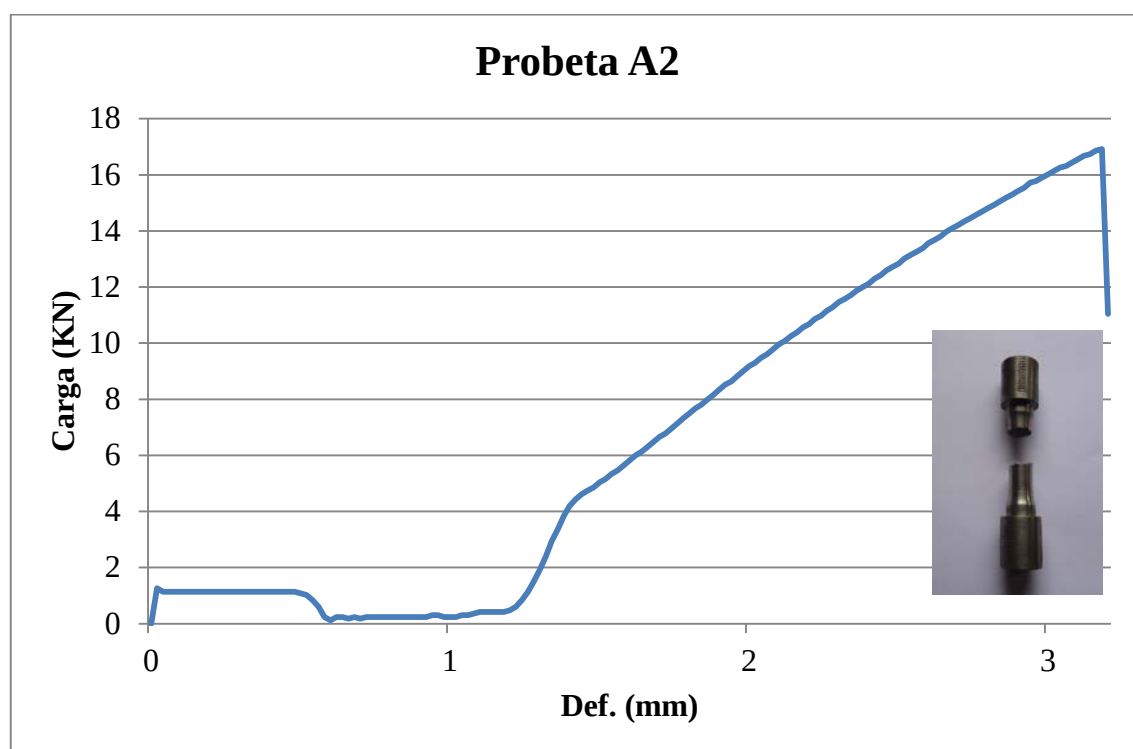


Fig. N° 4.5 Probeta A2.

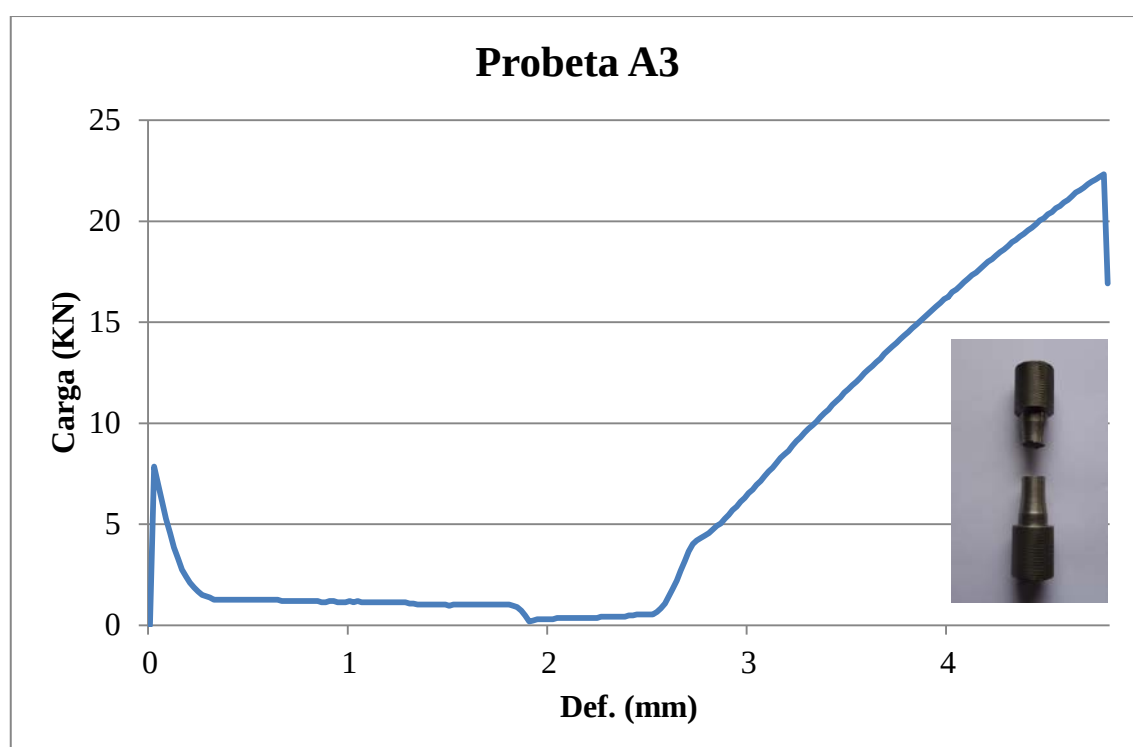


Fig. N° 4.6 Probeta A3.

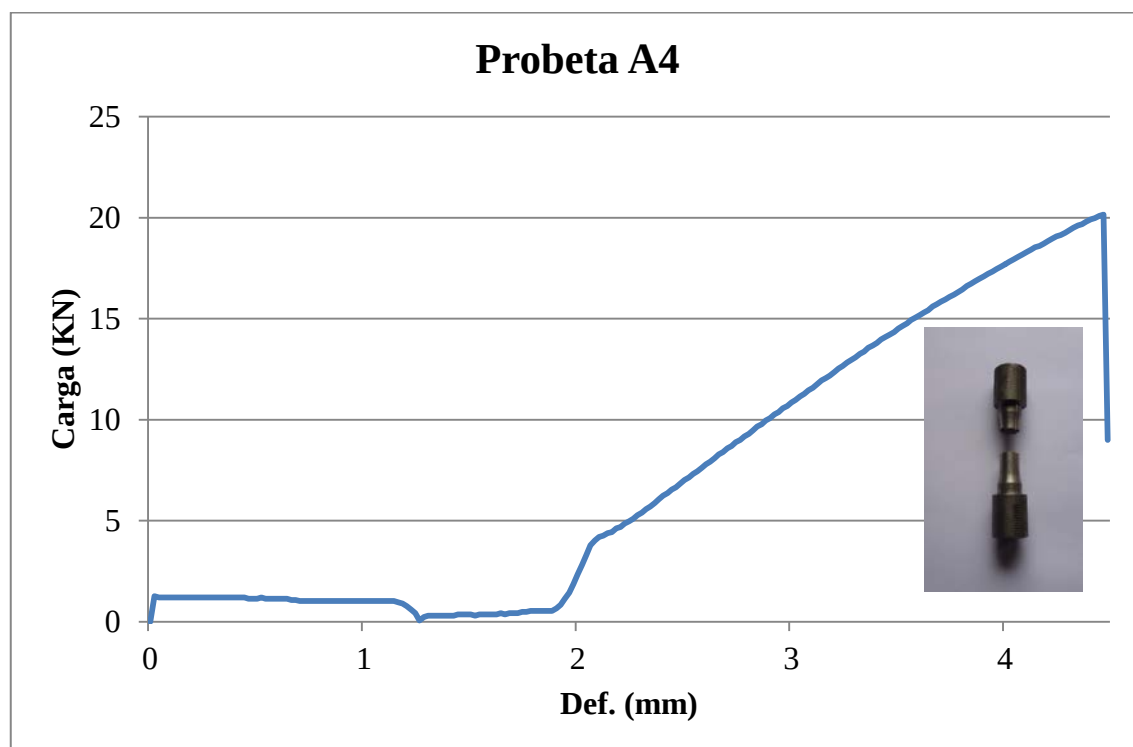


Fig. N° 4.7 Probeta A4.

4.2.3. Ensayo de dureza

Vemos los resultados de este ensayo en la Tabla N° 4.4:

Tabla N° 4.4 Resultados del ensayo de dureza, antes del tratamiento térmico.

Item	Dureza	
	HRC	HBN
1	37.10	343
2	36.90	341
3	36.60	338
4	37.50	346
5	32.40	304
6	35.30	327
7	35.80	331
8	38.00	351
Promedio		335

4.2.4. Ensayo de resiliencia

Los resultados del ensayo de resiliencia, se obtuvieron con el software de la maquina empleada para el ensayo, estos se muestran en la Tabla N° 4.5.

Tabla N° 4.5 Resultados del ensayo de resiliencia, antes del tratamiento térmico.

Item	Probeta	Resiliencia	Tenacidad
		J	J/cm2
1	CA1	4.20	5.20
2	CA2	4.70	5.90
3	CA3	3.50	4.30
4	CA4	3.60	4.50
Promedio		4.00	

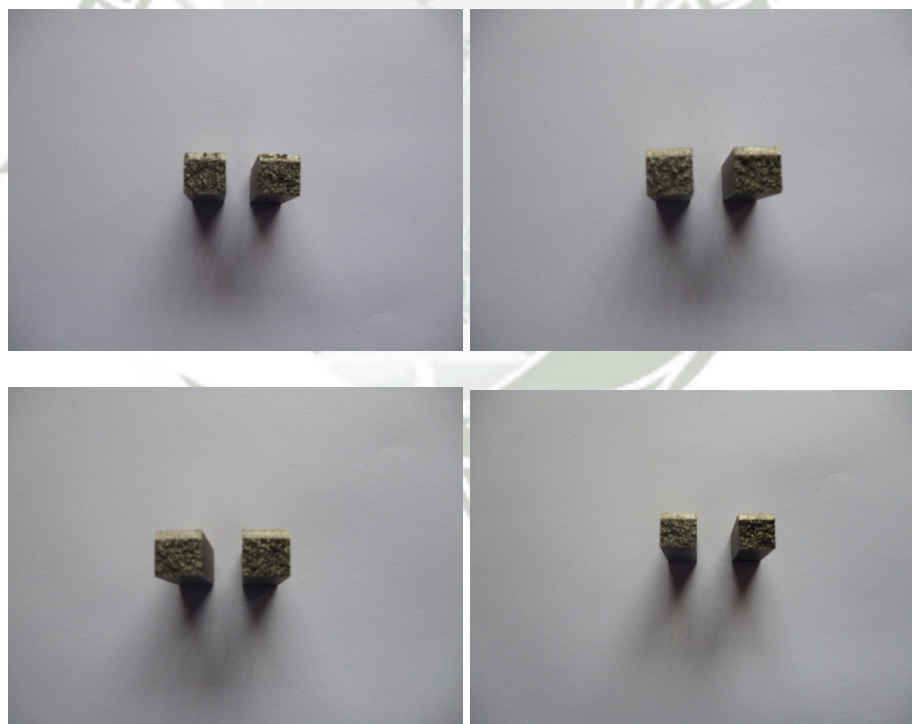


Fig. N° 4.8 Probetas de ensayo de resiliencia (izquierda a derecha): CA1, CA2, CA3 Y CA4.

4.3 DESPUÉS DEL RECOCIDO DE BAJA TEMPERATURA

4.3.1. Análisis metalográfico

Se muestran las imágenes obtenidas de la probeta utilizada para el ensayo, se ve como la ferrita (zonas de color claro) va aumentando y las zonas de perlita han ido disminuyendo después de realizado el tratamiento.

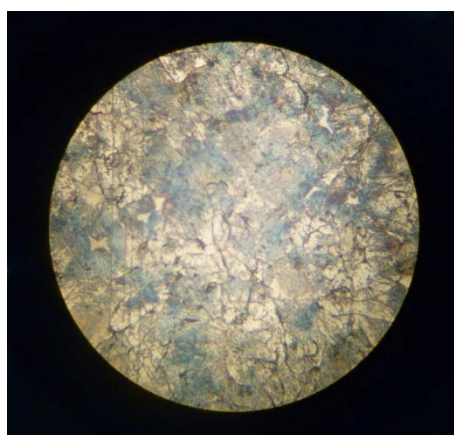


Fig. N° 4.9 Imagen capturada con un aumento de 50X con la cámara digital

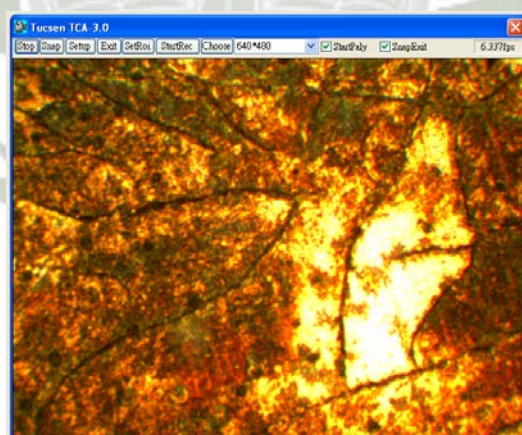
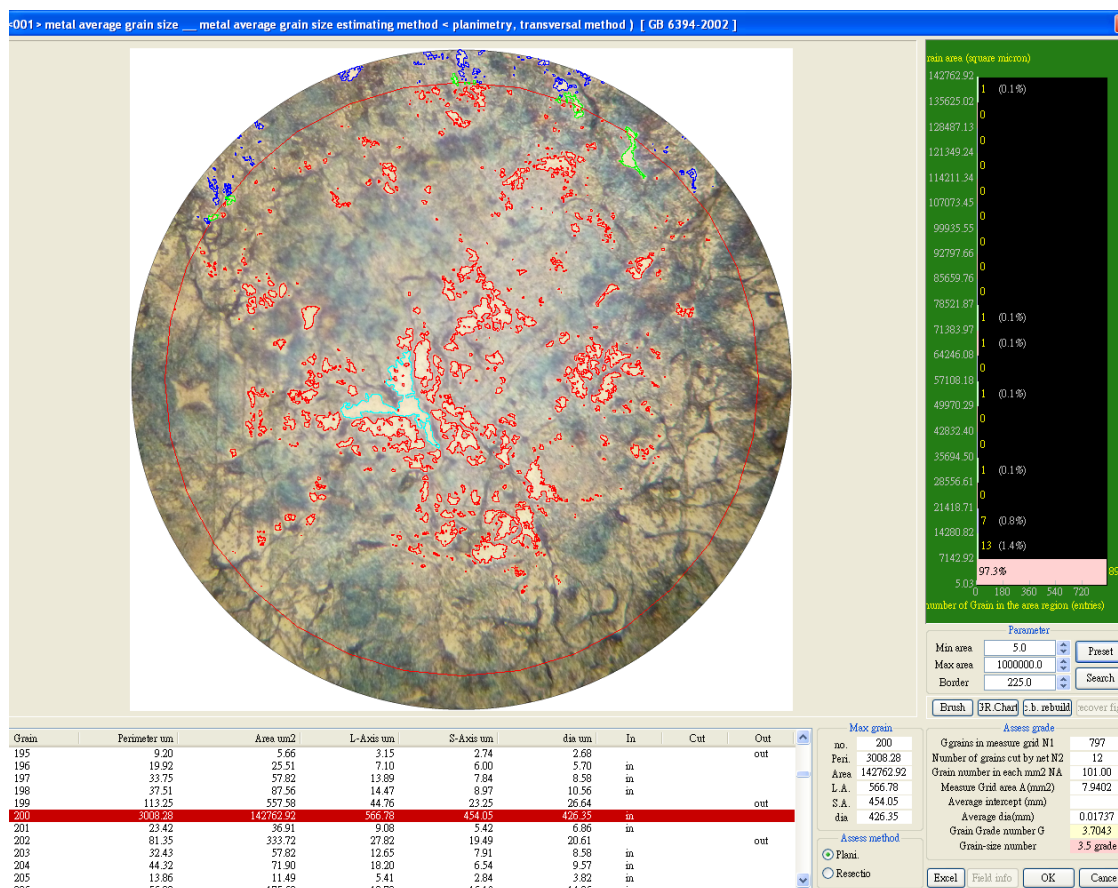


Fig. N° 4.10 Imagen capturada con un aumento de 50X con el microscopio.

Procedemos a utilizar el software del microscopio DX70A, para determinar el tamaño de grano en la imagen capturada.



Grain-size number: 3.5 grade

Fig. N° 4.11 Obtención del tamaño de grano.

4.3.2. Prueba de tensión

Los resultados de la resistencia a la tracción se obtuvieron con el software de la maquina empleada para el ensayo, estos figuran en la Tabla N° 4.6.

Tabla N° 4.6 Resultados del ensayo de tracción, después del recocido de baja temperatura

Item	Probeta	Ø Inicial	Esfuerzo de traccion		Maxima Deform
		mm	Mpa	Psi	mm
1	R1	12.7	132.00	19145	7.151
2	R2	12.7	144.00	20886	5.349
3	R3	12.7	102.00	14794	8.514
4	R4	12.7	141.00	20450	4.793
Promedio			130	18819	

A continuación se muestran los gráficos de Carga – Deformación de todas las probetas ensayadas.

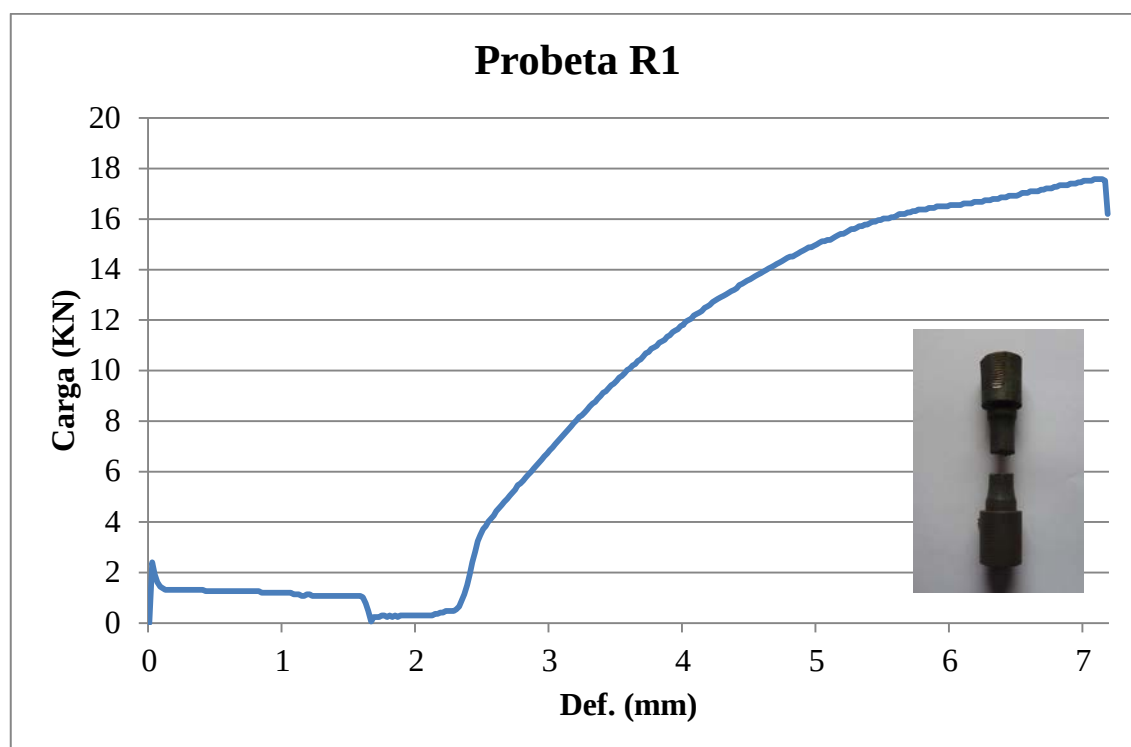


Fig. N° 4.12 Probeta R1.

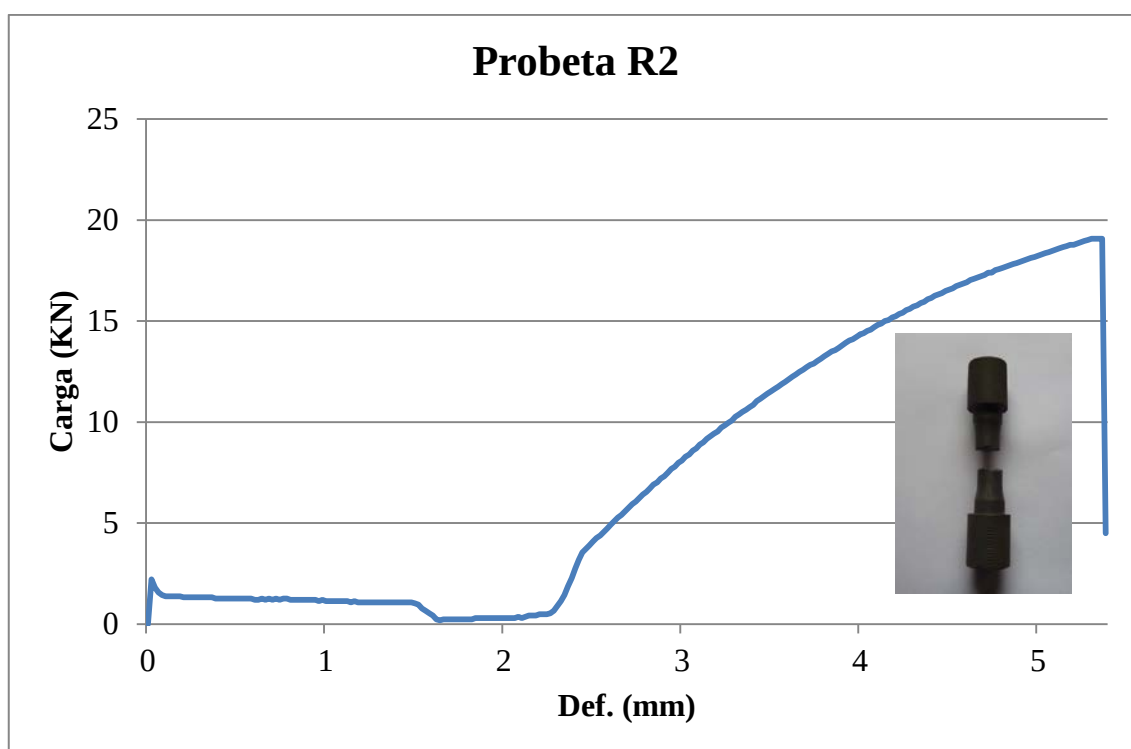


Fig. N° 4.13 Probeta R2.

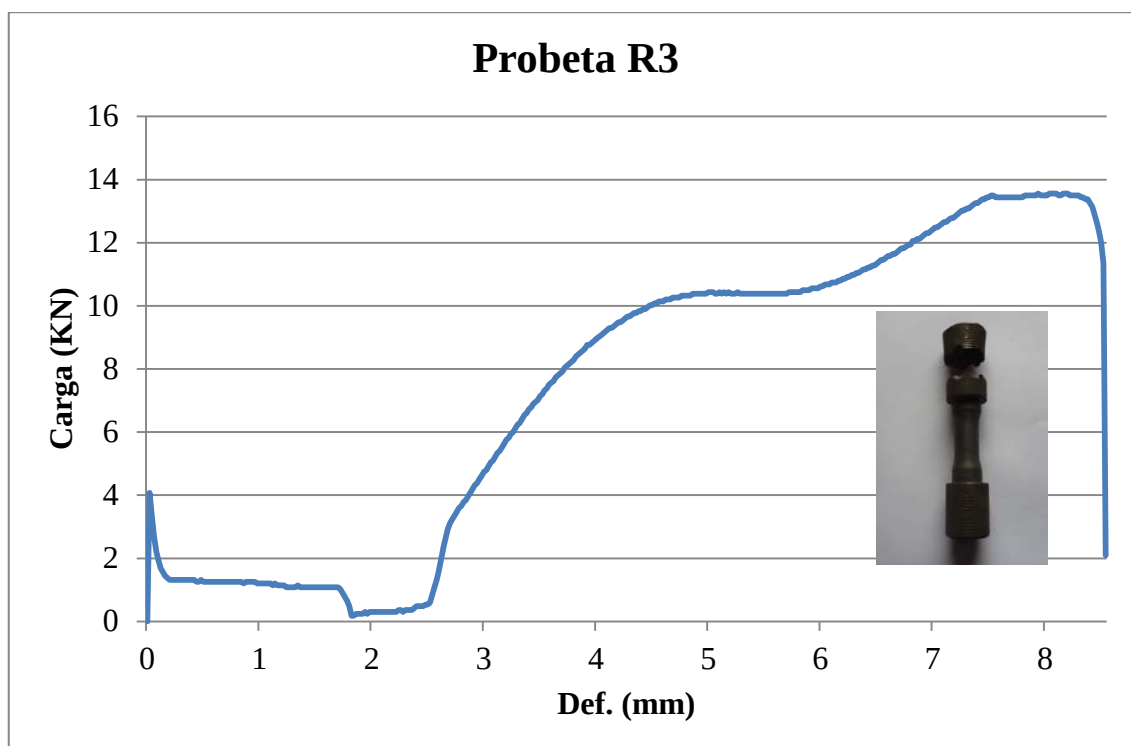


Fig. N° 4.14 Probeta R3.

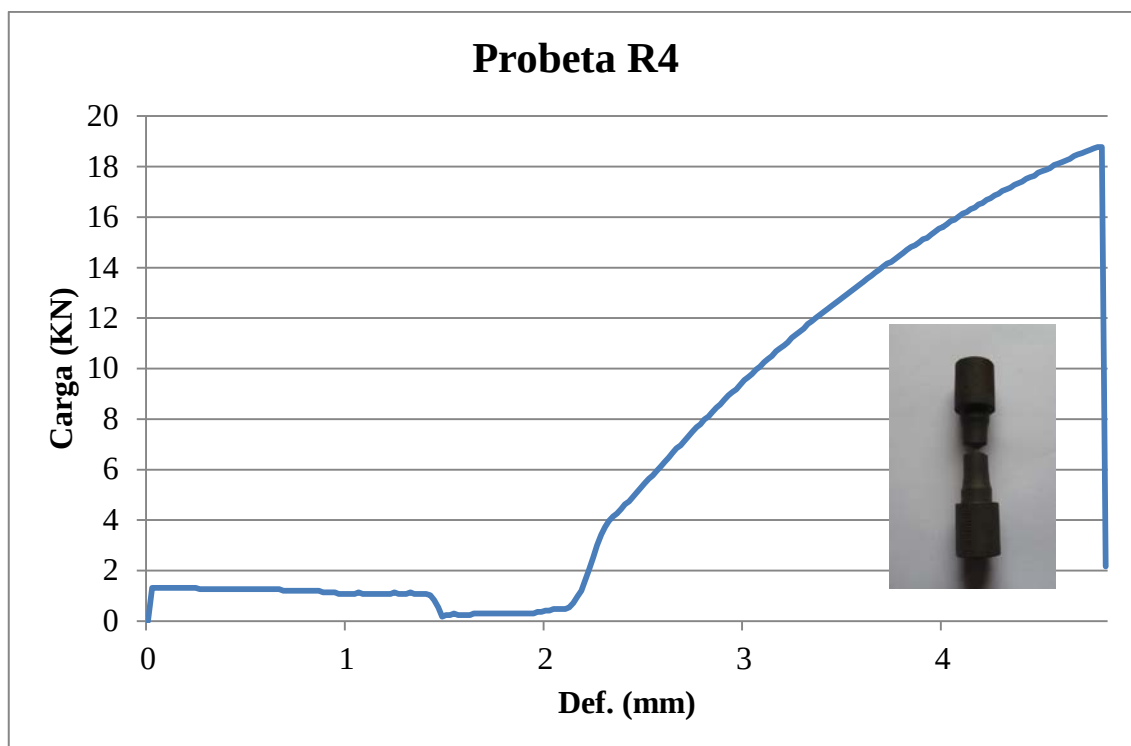


Fig. N° 4.15 Probeta R4.

4.3.3. Ensayo de dureza

Vemos los resultados de este ensayo en la Tabla N° 4.7:

Tabla N° 4.7 Resultados del ensayo de dureza, después del recocido de baja temperatura.

Item	Dureza	
	HRC	HBN
1	30.90	293
2	31.50	297
3	33.20	310
4	36.60	338
5	27.90	272
6	32.40	304
7	33.90	316
8	31.60	298
Promedio		304

4.3.4. Ensayo de resiliencia

Los resultados del ensayo de resiliencia, se obtuvieron con el software de la maquina empleada para el ensayo, estos se muestran en la Tabla 4.8.

Tabla N° 4.8 Resultados del ensayo de resiliencia, después del recocido de baja temperatura.

Item	Probeta	Resiliencia	Tenacidad
		J	J/cm2
1	CR1	4.90	4.90
2	CR2	4.40	4.40
3	CR3	4.40	4.40
4	CR4	5.00	5.00
Promedio		4.68	

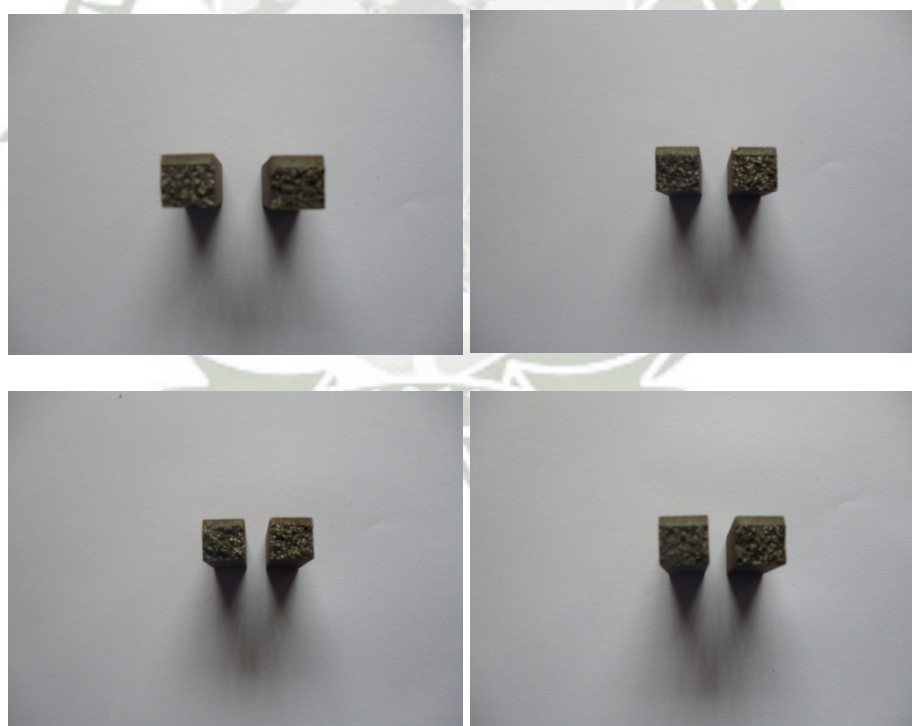


Fig. N° 4.16 Probetas de ensayo de resiliencia (izquierda a derecha): CR1, CR2, CR3 Y CR4.

4.4 DESPUÉS DEL NORMALIZADO

4.4.1. Análisis metalográfico

Se muestran las imágenes obtenidas de la probeta utilizada para el ensayo, en este caso se ve una fase perlita abundante en comparación con la fase ferrita que se muestra en menor cantidad; esto se debe a que este tratamiento busca la retención de perlita.

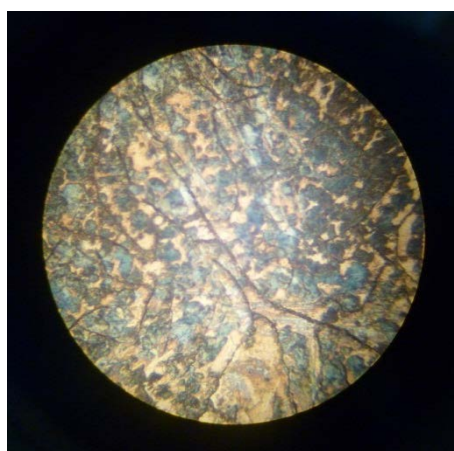


Fig. N° 4.17 Imagen capturada con un aumento de 50X con la cámara digital.

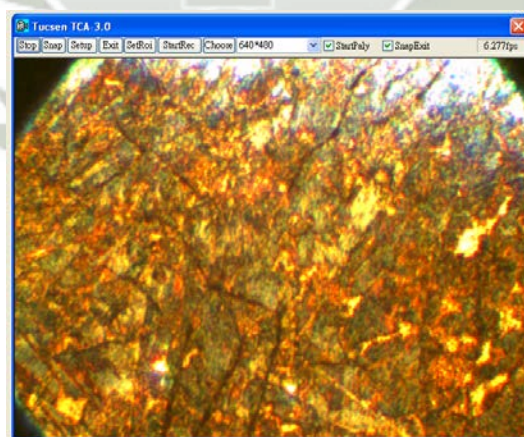
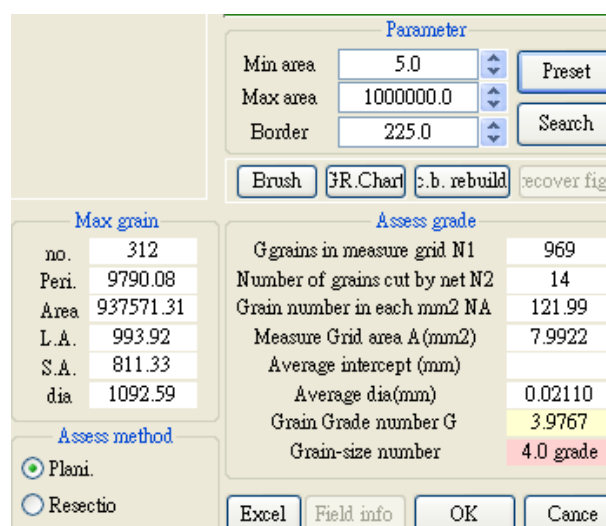
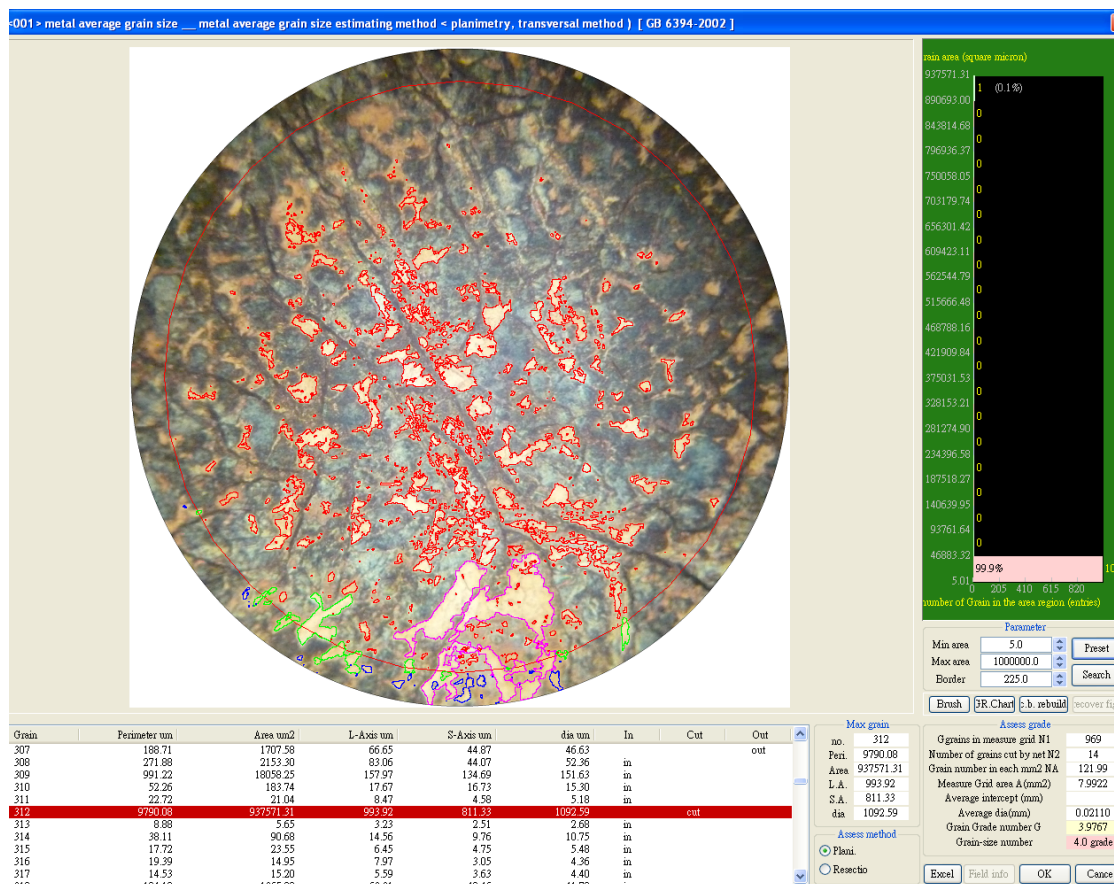


Fig. N° 4.18 Imagen capturada con un aumento de 50X con el microscopio.

Procedemos a utilizar el software del microscopio DX70A, para determinar el tamaño de grano en la imagen capturada.



Grain-size number: 4.0 grade

Fig. N° 4.19 Obtención del tamaño de grano.

4.4.2. Prueba de tensión

Los resultados de la resistencia a la tracción se obtuvieron con el software de la maquina empleada para el ensayo, estos figuran en la Tabla N° 4.9.

Tabla N° 4.9 Resultados del ensayo de tracción, después del normalizado.

Item	Probeta	Ø Inicial	Esfuerzo de traccion		Maxima Deform
		mm	Mpa	Psi	mm
1	N1	12.7	163.00	23641	4.387
2	N2	12.7	135.00	19580	7.130
3	N3	12.7	146.00	21176	5.149
4	N4	12.7	157.00	22771	5.326
Promedio			150	21792	

A continuación se muestran los gráficos de Carga – Deformación de todas las probetas ensayadas.

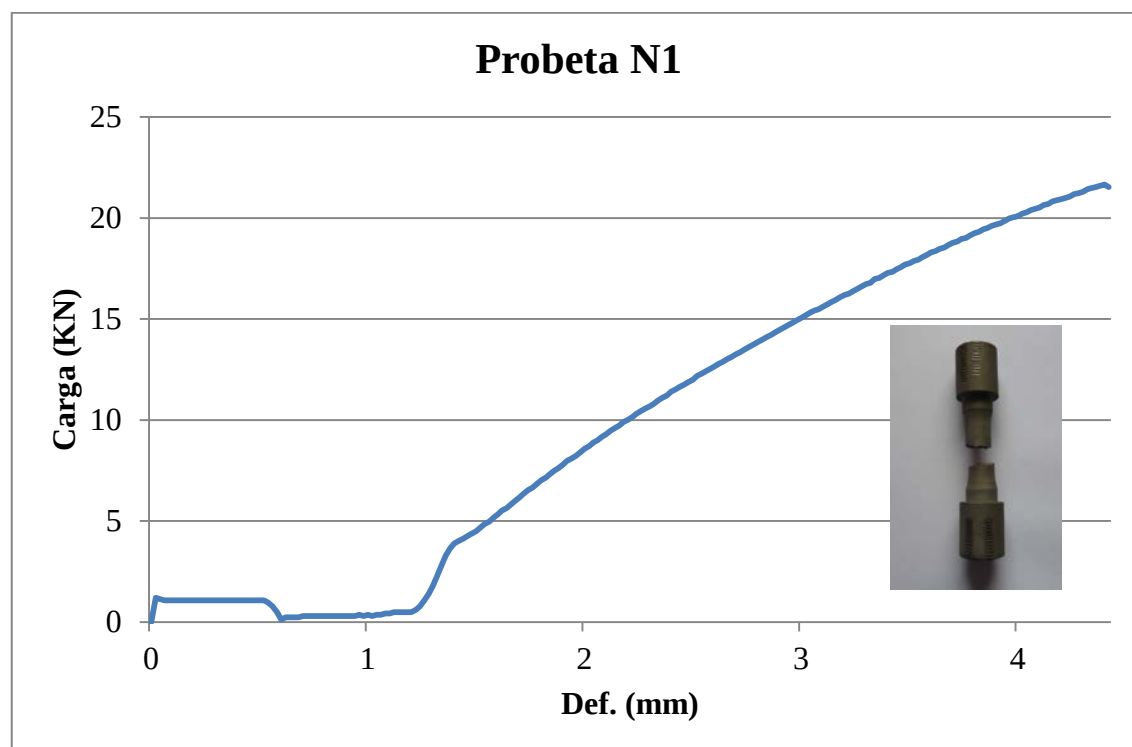


Fig. N° 4.20 Probeta N1.

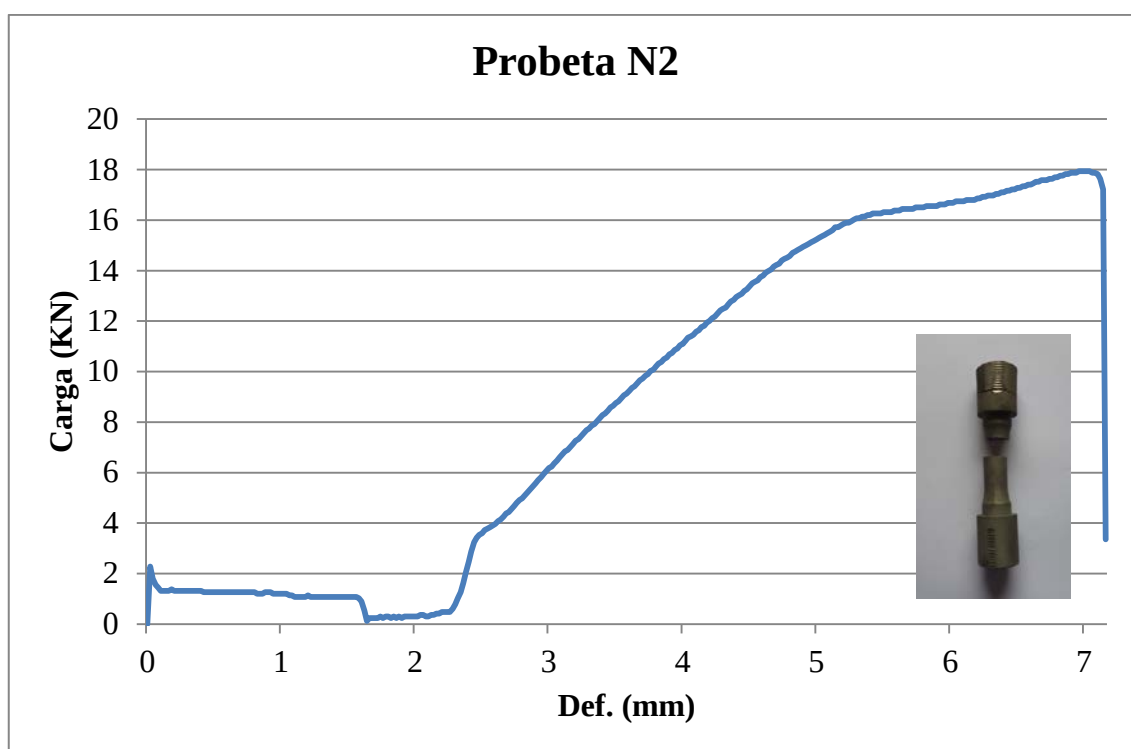


Fig. N° 4.21 Probeta N2.

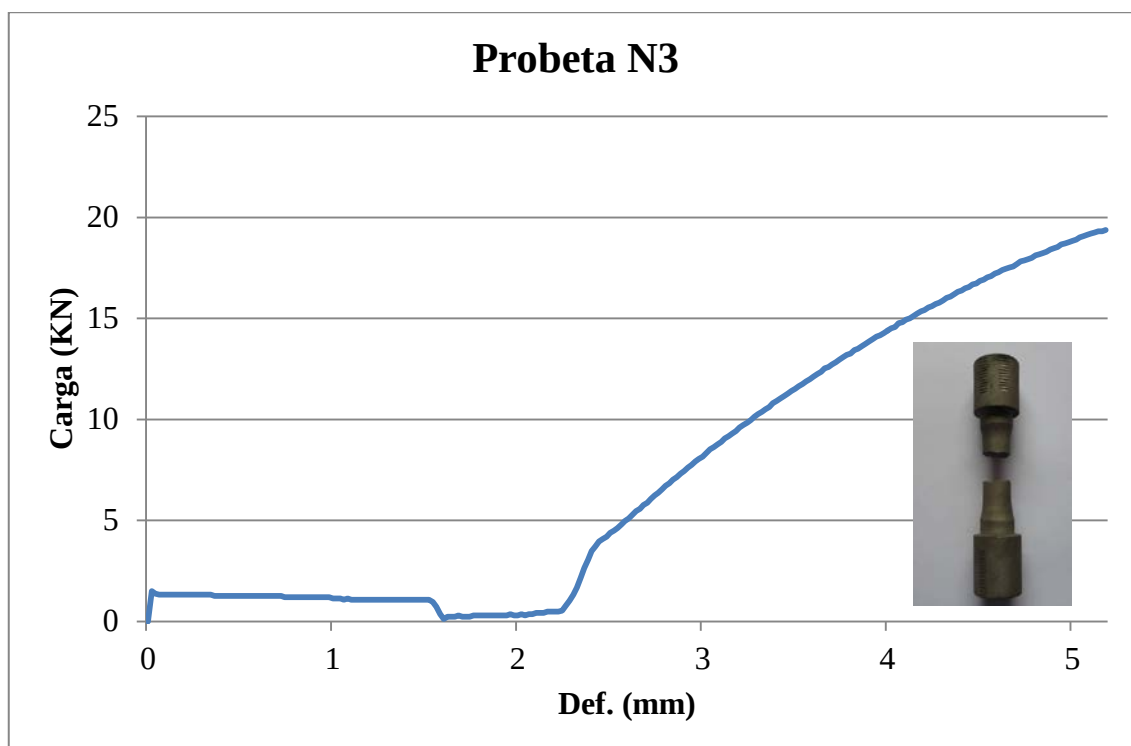


Fig. N° 4.22 Probeta N3.

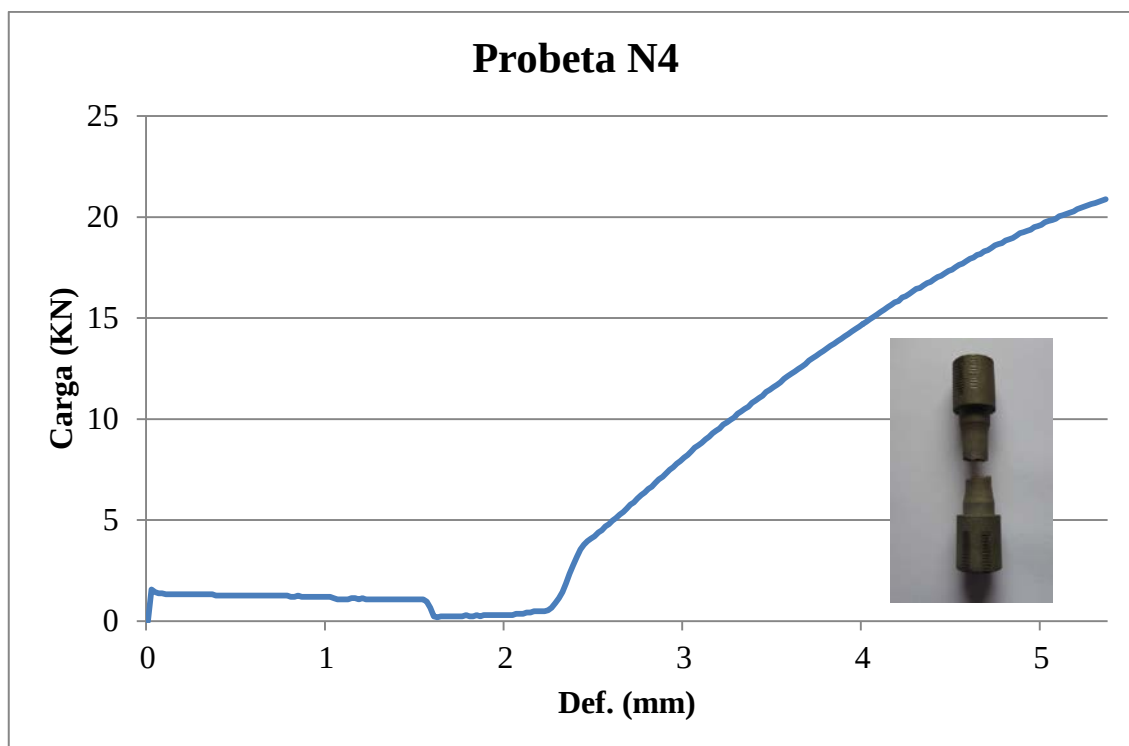


Fig. N° 4.23 Probeta N4.

4.4.3. Ensayo de dureza

Vemos los resultados de este ensayo en la Tabla N° 4.10:

Tabla N° 4.10 Resultados del ensayo de dureza, después del normalizado.

Item	Dureza	
	HRC	HBN
1	38.80	358
2	39.50	365
3	43.80	409
4	45.80	432
5	42.00	390
6	43.60	407
7	45.40	427
8	41.40	383
Promedio		396

4.4.4. Ensayo de resiliencia

Los resultados del ensayo de resiliencia, se obtuvieron con el software de la maquina empleada para el ensayo, estos se muestran en la Tabla N° 4.11.

Tabla N° 4.11 Resultados del ensayo de resiliencia, después del normalizado.

Item	Probeta	Resiliencia	Tenacidad
		J	J/cm2
1	CN1	5.70	5.70
2	CN2	5.70	7.20
3	CN3	5.00	6.30
4	CN4	5.20	6.50
Promedio		5.40	

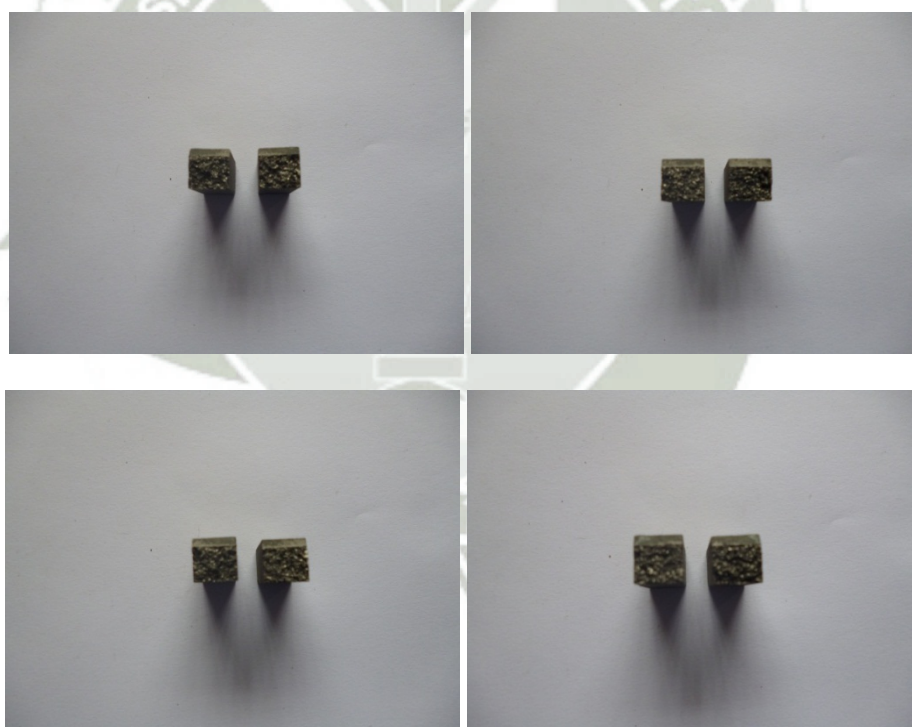


Fig. N° 4.24 Probetas de ensayo de resiliencia (izquierda a derecha): CN1, CN2, CN3 Y CN4.

CAPITULO V

ANÁLISIS DE RESULTADOS

5.1 FUNDICIÓN EN BRUTO ANTES DEL TRATAMIENTO

5.1.1. Características y Microestructura

- 1) En una fundición gris normal, los porcentajes de carbono están entre los 2.5% y 4.0%. En nuestro caso la fundición tiene un porcentaje promedio de 3.13% C aproximadamente; esto nos indica que estamos dentro del rango que se considera normal para este tipo de material.

Como se puede ver el porcentaje de carbono está cercano al límite inferior y esto influye en la formación del grafito y en menor cantidad la formación de cementita.

- 2) No se tiene información sobre los contenidos de Silicio, Azufre y Fosforo, estos aleantes nos ayudarían para interpretar la formación de las diferentes fases

presentes en la probeta; en el caso del silicio la fundición debería estar entre el 1 al 3.8%, lo cual nos ayuda para evitar la presencia de cementita, en el caso del azufre debería encontrarse entre 0.01 a 0.12 % de no ser el caso podría generarse la formación del sulfuro de hierro lo cual sería perjudicial para las propiedades mecánicas de la fundición.

5.1.2. Análisis Metalográfico

- 1) Del análisis metalográfico de la probeta que no fue tratada térmicamente, se pudo observar la presencia del grafito tipo A (ver Fig. 5.1); que se presenta cuando el enfriamiento es lento, siendo además el tipo de grafito que siempre está presente en las fundiciones grises.

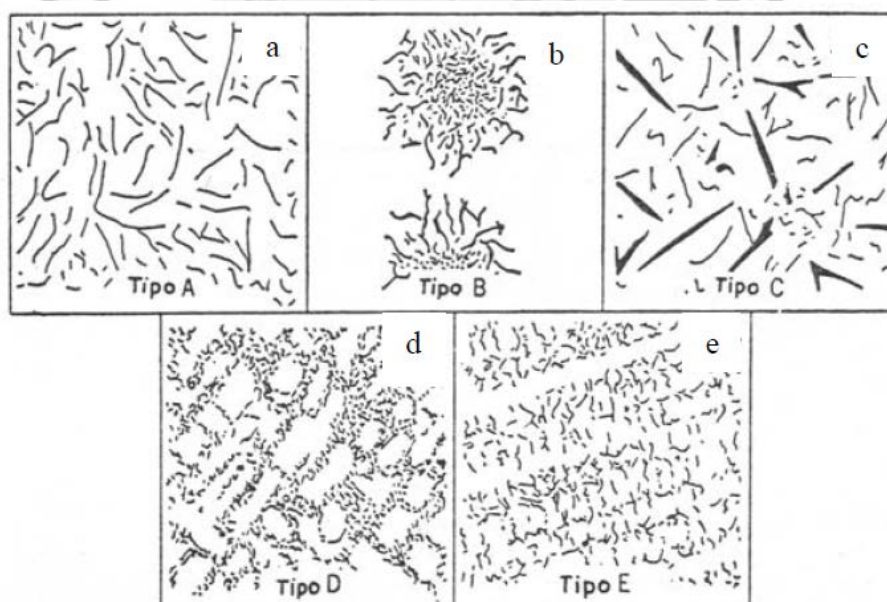


Fig. N° 5.1 Tipos de grafito que suelen aparecer en las fundiciones: a) Tipo A, b) Tipo B, c) Tipo C, d) Tipo D y e) Tipo E.

Fuente: José Apraiz Barreiro, Fundiciones, 6ta Edición, 1998, p.68

5.1.3. Ensayos Mecánicos

- 1) El ensayo de tracción efectuado a las probetas bajo la norma ASTM A48 nos arrojó como resultados fundiciones de la clase 20, este tipo concuerda con nuestra fundición ferrito-perlitica. Estas fundiciones están por debajo de las consideradas de buena calidad (clase 30). El valor promedio del esfuerzo de tracción está cercano a los 17 Ksi que según la especificación este debería ser mayor a los 20 Ksi.
- 2) Gran protagonismo en estos resultados lo tiene la cantidad, forma, tamaño y distribución del grafito; las porosidades e impurezas que presento el material. Estos factores disminuyen las propiedades mecánicas de las fundiciones. Durante el ensayo se observó que las probetas en su mayoría, contaban con irregularidades y porosidades.
- 3) Los valores de dureza obtenidos en la probeta son en exceso mayores a los esperados; el promedio de dureza es de 335 HBN, no se encuentran dentro del rango de durezas para estas fundiciones ferrito-perliticas, que van desde los 130 hasta los 180 HB; Existe una dispersión entre los valores tomados y esto podría deberse a la presencia de porosidades y e impurezas que afectan de la misma forma a la resistencia a la tracción.
- 4) La resiliencia en promedio fue de 4 J, y la tenacidad de un valor aproximado de 4.9 J/cm^2 , estos valores son considerados como bajos en comparación a otros materiales. Después del ensayo de tenacidad puede verse en todas las probetas una fractura frágil, de aspecto brillante y granular. Siendo esta una de las principales características de las fundiciones grises laminares.

5.2 FUNDICIÓN DESPUÉS DEL RECOCIDO DE BAJA TEMPERATURA

5.2.1. Análisis Metalográfico y Proceso del Tratamiento

- 1) Esta probeta fue trabajada con una temperatura de recocido de 700° C, tomamos el valor mínimo recomendado para este tratamiento debido a que la dimensión de la probeta es menor que la ideal para el tratamiento. El enfriamiento se realizó dentro el horno a unos 50° C por hora, obteniendo el enfriamiento total de la probeta pasadas las 12 horas.
- 2) Se observó también la modificación del tamaño de grano en comparación con la probeta que no fue sometida a un tratamiento térmico. El tamaño de grano se incrementó prácticamente en 2 grados. El grano con mayor tamaño en la imagen es el numero 200 (ver Fig. 4.9) con un área aproximada de 142762.92 micrones cuadrados.
- 3) Se concluye que existe una formación de ferrita a partir de la perlita siendo esta una fundición no aleada, al tener esta nueva composición se obtiene como propiedad una máxima maquinabilidad en la probeta. Es por esta razón que a este tipo de recocido también se le conoce como ferritizado.

5.2.2. Ensayos Mecánicos

- 1) En cuanto a las 4 probetas ensayadas para determinar el esfuerzo a la tracción se obtuvo como promedio 19 Ksi (ver figura 5.2), valor que está por debajo de la resistencia que tiene una fundición de grado 20 de baja calidad (20 Ksi).

Este valor puede verse alterado debido a que durante el ensayo realizado a la probeta R3 la fractura no se dio en la zona esperada, sino más bien en la base inferior de la probeta la cual era sujeta por la mordaza de la máquina universal de tracción; este valor de esfuerzo fue de 102 MPa el cual es muy bajo y ayudó a disminuir considerablemente el promedio de esfuerzo de las otras 03 probetas.

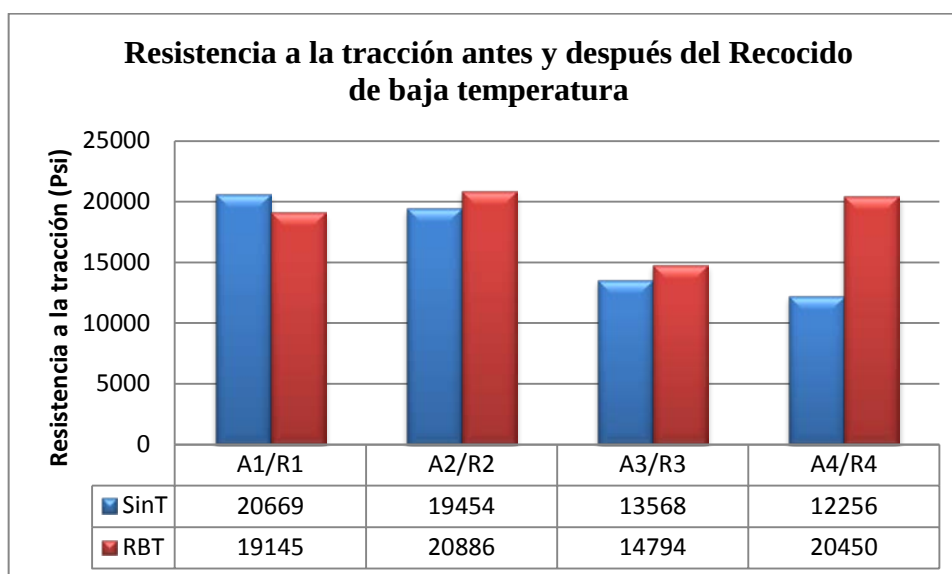


Fig. N° 5.2 Comparación gráfica de la resistencia a la tracción antes y después del recocido de baja temperatura.

- 2) La dureza de la probeta ha disminuido en comparación con la dureza obtenida antes de tratar térmicamente la fundición gris (ver figura N° 5.3), más aun este valor no es el esperado para la fundición ya que sigue siendo mayor a los establecidos para este tipo de fundición. Esta disminución de la dureza se debe a que el material ha ido adquiriendo mayor fase ferrita la cual es más blanda.

El valor promedio se redujo hasta los 304 HBN, sin embargo el esperado debe ser cercano a los 143 HB para una probeta con recocido, se debe tener en cuenta

que los valores tomados cerca de los bordes de la probeta fueron mayores que los tomados en la parte central de esta.

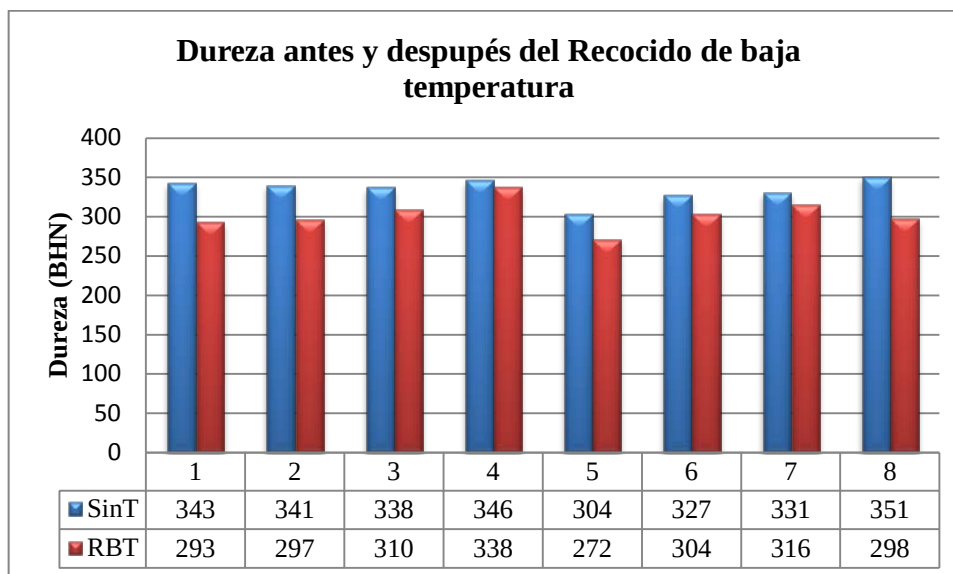


Fig. N° 5.3 Comparación grafica de la dureza antes y después del recocido de baja temperatura.

- 3) La resiliencia en promedio de las 4 probetas analizadas es de 4.68 J, mostrando un ligero incremento en comparación con el resultado obtenido de las probetas que no sufrieron un tratamiento térmico. El incremento de ferrita en la matriz; no es determinante para esta propiedad ya que no afecta la ductilidad de una fundición y solo se ven cambios muy tenues. Por otro lado se sabe también que en las fundiciones grises no existe una correspondencia entre dureza y tenacidad como en los aceros y otros materiales, además factores que influyen mucho en estos valores son la cantidad de grafito, tipo de grafito y la porosidad que presenta la fundición.

En la figura N° 5.4 se muestran estas pequeñas variaciones de la resiliencia en forma gráfica.

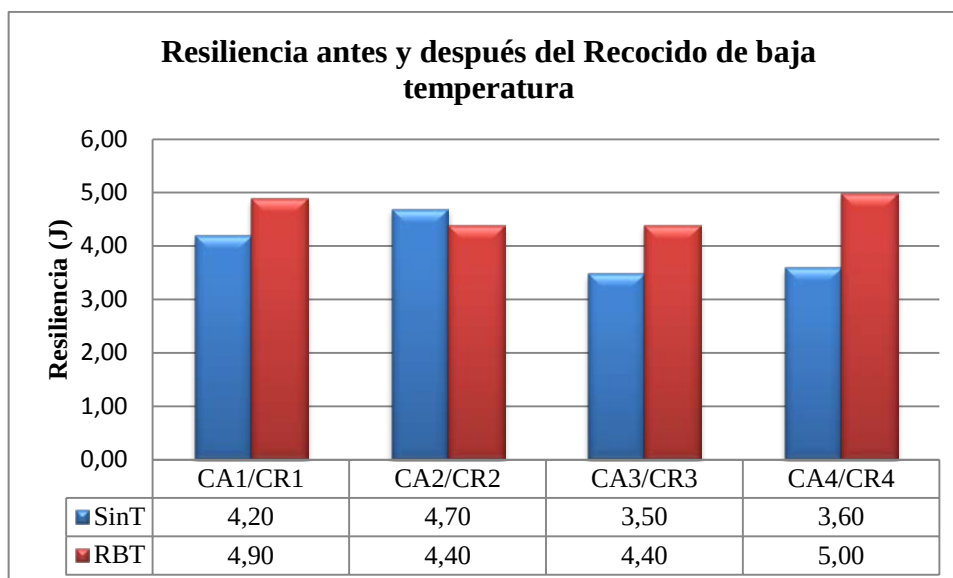


Fig. N° 5.4 Comparación grafica de la resiliencia antes y después del recocido de baja temperatura.

5.3 FUNDICIÓN DESPUÉS DEL NORMALIZADO

5.2.1. Análisis Metalográfico y Proceso del Tratamiento

- 1) Para el normalizado se consideró elevar la temperatura de la probeta a 870° C y se trabajó con un enfriamiento rápido al aire calmo, este proceso de enfriamiento culmino en los 80 minutos posteriores de ser retirada la probeta del horno.
- 2) El tamaño de grano volvió a incrementarse; esta vez hasta un grado de 4. El grano con mayor tamaño fue el 312 (ver Fig. 4.16) el cual tenía un área de 937571.31 micrones cuadrados.
- 3) Se puede concluir que después de este tratamiento se da una eliminación de los carburos en su mayor cantidad y se retiene la perlita, la cantidad de perlita que se obtenga depende de la cantidad de austenita que se obtenga durante el calentamiento.

5.2.2. Ensayos Mecánicos

- 1) El ensayo de tracción para estas probetas tiene como promedio 22 Ksi aproximadamente, asegurándose así el grado 20 para esta fundición según la norma ASTM A48. Se debe considerar que la probeta N2 presento una pequeña fractura en la base superior que es sujeta por las mordazas de la maquina universal de tracción, este valor no consiguió una modificación considerable en el promedio de la resistencia, pero si se ve una variación en el gráfico de carga – deformación ocasionando así una curva no característica de las fundiciones (ver figura N° 5.5).

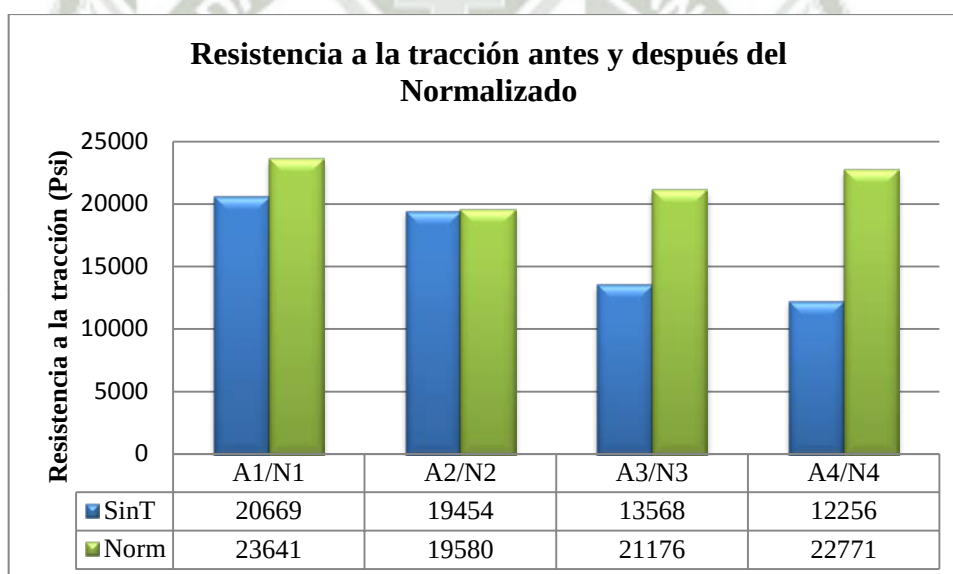


Fig. N° 5.5 Comparación grafica de la resistencia a la tracción antes y después del normalizado.

- 2) En el ensayo de dureza si se obtuvo un incremento substancial en la dureza (ver figura N° 5.6) comparado con las otras dos probetas, esto se debe a la presencia de perlita en la nueva composición de la fundición; mas no es el valor de dureza

característico de las fundiciones grises, ya que si bien se incrementó este valor sigue siendo mayor al esperado.

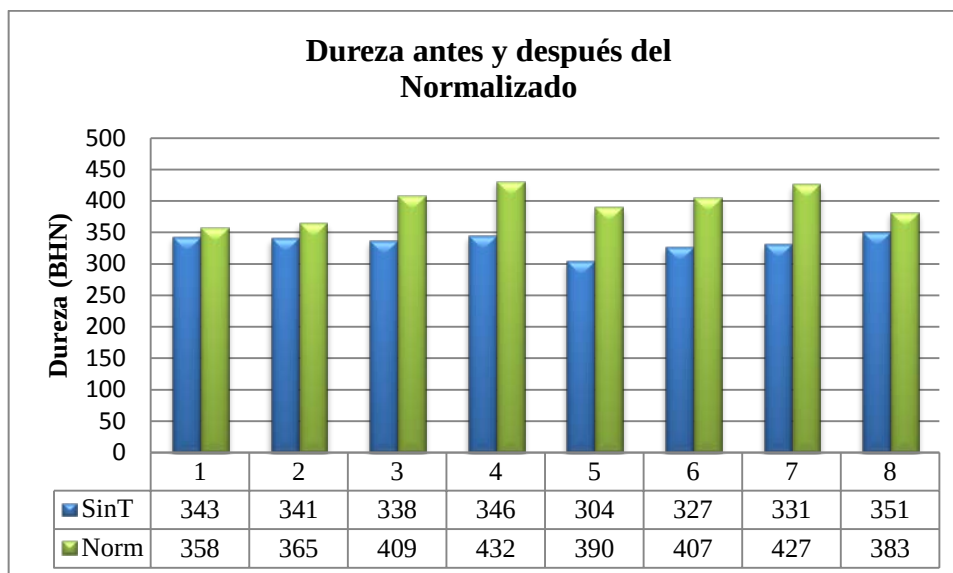


Fig. N° 5.6 Comparación grafica de la dureza antes y después del normalizado.

- 3) El valor promedio de resiliencia para las probetas ensayadas es de 5.4 J y el valor de tenacidad es aproximadamente de 6.43 J/cm². Se observa un incremento en comparación con las pruebas anteriores, pero se muestra un mayor incremento en la tenacidad del material.

Como ya se había mencionado anteriormente, los valores de la tenacidad están sujetos a la cantidad de grafito, tipo de grafito y la porosidad que presenta la fundición. Además en situaciones donde se requiera un material tenaz, el uso de una fundición gris laminar, no será posible debido a sus bajos valores en tenacidad.

En la figura N° 5.7 se muestra la variación de la tenacidad de las probetas que fueron sometidas al normalizado y las que no sufrieron ningún tratamiento térmico.

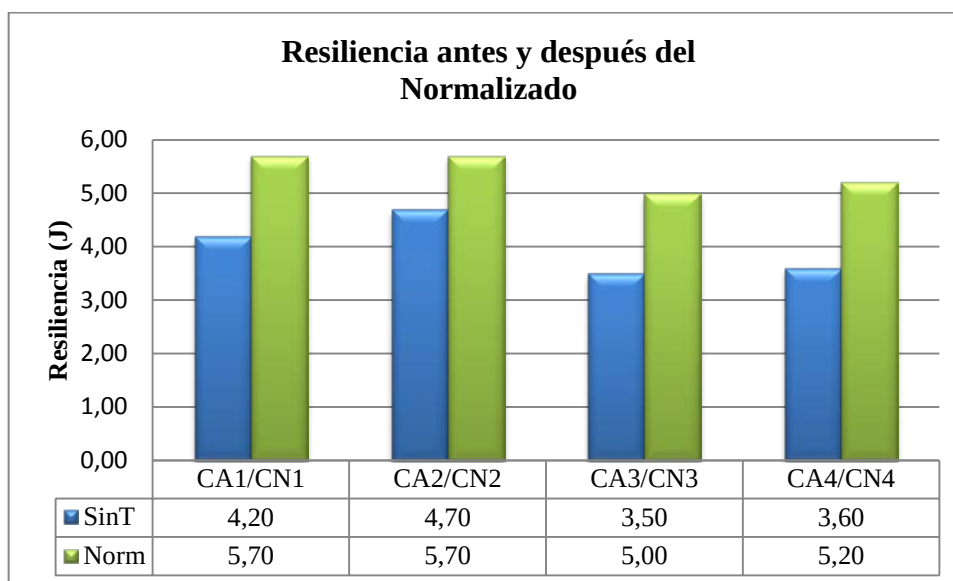


Fig. N° 5.7 Comparación grafica de la resiliencia antes y después del normalizado.

- 4) En conclusión se ve un incremento considerable en las propiedades mecánicas del material, logrando resistencias y durezas intermedias, esto se debe a la presencia de perlita la cual es una matriz más resistente.

CONCLUSIONES

- 1) A través de los ensayos mecánicos y los análisis metalográficos se logró determinar el comportamiento de la fundición gris al ser sometida a diferentes tratamientos térmicos, en nuestro caso tratamientos con un proceso de ferritizado y otro de perlitzado.
- 2) El horno de mufla utilizado para realizar los dos tratamientos térmicos (Recocido de baja temperatura y Normalizado), nos permitió controlar los tiempos adecuados de permanencia y los grados de temperaturas correctos para conseguir la óptima transformación de las fases en la fundición (ferrita y perlita respectivamente).
- 3) En el tratamiento térmico de recocido de baja temperatura, se ha demostrado que la temperatura de 700 °C es crítica para la formación de ferrita en fundiciones no aleadas como las de nuestro caso.
- 4) De las pruebas efectuadas en el laboratorio, se ha comprobado que con el tratamiento de recocido de baja temperatura se consigue una menor dureza, se ablanda la matriz y se liberan tensiones en la fundición, dándole así una mayor maquinabilidad a la fundición.
- 5) En el tratamiento térmico de normalizado se debe asegurar principalmente la completa transformación de ferrita a austenita (y lo que sea posible de perlita),

en nuestro caso esto se consiguió con la permanencia de la pieza a 870° C por un lapso de 1 hora seguido de un enfriamiento al aire. Obteniendo de esta manera un incremento de la fase perlita en la fundición.

- 6) De los resultados obtenidos se verifica que con el tratamiento de normalizado se mejora las propiedades mecánicas de la fundición, debido al incremento de la fase perlita. Si bien es cierto, el incremento de perlita no es elevado, representa un incremento apreciable de la resistencia y/o dureza del material.
- 7) En el análisis metalográfico realizado a las probetas, se determinó la presencia del grafito tipo A, el cual es característico para las fundiciones grises de baja aleación.
- 8) La fundición que se ha analizado no tienen una composición química estandarizada. Además, no fue posible determinar el grado de aleación de la fundición evaluada.

RECOMENDACIONES

- 1) Se recomienda realizar un nuevo ensayo de dureza a todas las probetas, ya que los valores obtenidos están fuera de los rangos esperados. Esto puede deberse a que siendo la fundición gris un material blando es recomendable un ensayo de dureza en el cual la medida resulte del cociente entre la carga aplicada y el área de la huella dejada por el indentador y que no sea solo una variable dependiente de la profundidad de la indentación (caso dureza Rockwell).
- 2) En el ensayo de metalografía se debe utilizar lentes que permitan generar un mayor aumento y un software que permita la captura de imágenes con una mayor fidelidad, para asegurar la correcta evaluación e interpretación de la muestra.
- 3) Se debe tener en cuenta que en el ensayo de tracción hubo unas probetas que sufrieron la fractura en la base de sujeción de las mordazas de la máquina de tracción, consecuentemente los valores de resistencia a la tracción se vieron afectados haciendo disminuir considerablemente el grado de la fundición. Se recomienda realizar este ensayo con más probetas para asegurar el respaldo experimental y obtener la mayor información posible.
- 4) Se deberá tener especial cuidado en los intervalos de temperatura y los tiempos de permanencia en estas para los diferentes tratamientos térmicos, ya que éste es

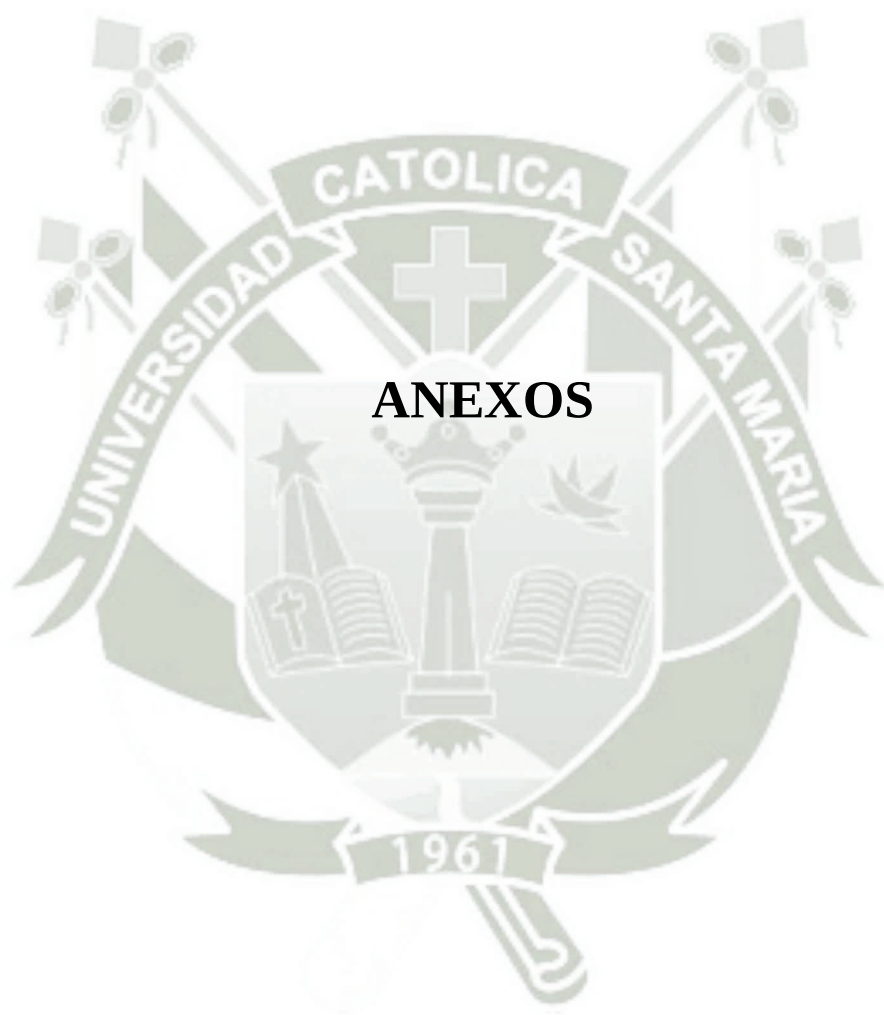
un punto crítico en la transformación de la estructura cristalina, y es lo que determina las propiedades físicas y mecánicas de la fundición.

- 5) Se recomienda realizar un análisis químico completo de la muestra de fundición utilizada, para determinar la composición exacta del carbono y sus aleantes, caso de silicio, fosforo y azufre que son elementos determinantes para las propiedades de las fundiciones grises.



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- 16) <http://iesvillalbahervastecnologia.files.wordpress.com/2009/09/tratamientos-termicos.pdf>.
- 17) <http://www.slideshare.net/xMorfe0x/tratamientos-termicos-no-2>.
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ANEXOS

**Anexo 1. Standard Test Method for
Evaluating the Microstructure of Graphite in Iron
Castings (A 247 – 67)**



Standard Test Method for Evaluating the Microstructure of Graphite in Iron Castings¹

This standard is issued under the fixed designation A 247; 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.

1. Scope

1.1 This test method covers the classification of graphite in cast irons in terms of type, distribution, and size. This test method is intended to be applicable for all iron-carbon alloys containing graphite particles, and may be applied to gray irons, malleable irons, and the ductile (nodular) irons.

1.2 The reference standards included in this test method are in no way to be construed as specifications. In an appropriate specification for a specific material where graphite microstructure is an important consideration this test method may be used as a reference to define concisely the graphite microstructure required.

1.3 These standards are offered primarily to permit accurate reporting of microstructures of cast irons and to facilitate the comparison of reports by different laboratories or investigators.

1.4 *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 consult and 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 Specimens²

3. Summary of Test Method

3.1 The reference diagrams included in this standard form the basis for classification. Characteristic features of graphite particles are designated by numerals and letters. Type, distribution, and size of observed graphite are compared with the idealized microstructures in the standard charts and rated accordingly as closely as possible to the equal or similar microstructures in the charts.

4. Significance and Use

4.1 The comparison of observed graphite particles with the structures shown in the charts give only purely descriptive information on the type, distribution, and size of the graphite in the sample being evaluated. It does not indicate except in a

very broad way the origin of the graphite, or the suitability of the iron-carbon alloy for a particular service.

5. Test Specimens or Samples

5.1 The preferred sample is a section cut from an actual casting that is being evaluated. When this is impractical, a test lug or projection often can be cast attached to the casting and sawed or broken off to be used as the sample. If neither of these methods is convenient, microscopical test coupons, such as that recommended by the Ductile Iron Research Committee (12K) of the American Foundrymen's Society³ should be cast from metal representative of the castings poured.

6. Polishing

6.1 Grinding and polishing may follow the usual accepted metallographic procedures as covered in Methods E 3, except that care must be taken that the graphite is retained at the polished surface and not torn or dragged out. Use of diamond powder polishing compound in one of the final stages of polishing is very effective in retaining the graphite at the polished surface.

7. Classification of Graphite Form with Chart

7.1 The graphite form type chart (Plate I)⁴ is used as a reference standard by scanning the polished specimen under the microscope and noting the graphite forms in the microstructure that more nearly correspond to type designations on the chart.

7.2 Type I is the normal and usually desirable graphite form in ductile iron, although the presence of Type II graphite forms has little or no adverse effect on properties. Graphite forms represented by Types IV through VI often occur in ductile iron in conjunction with Types I and II. The percentages of each graphite type are estimated by observation, or better, by counting the particles of each type. Types present in a sample are to be reported in percentages to total 100. Any convenient magnification that clearly reveals the graphite form may be used.

7.3 Type III is the graphite form most often seen in malleable iron castings after annealing. Some malleable irons may contain Types I or II graphite particles also.

¹ This test method is under the jurisdiction of ASTM Committee A-4 on Iron Castings and is the direct responsibility of Subcommittee A04.21 on Testing.

Current edition effective Aug. 25, 1967. Originally issued 1941. Replaces A 247 – 47.

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

³ *Transactions*, American Foundrymen's Society, 1960, p. 655.

⁴ Plates I, II, and III may be obtained from ASTM Headquarters. Order ADJ0247.

7.4 Type VII is the flake graphite form usually seen in gray iron.

8. Classification of Graphite Distribution with Chart

8.1 The graphite distribution chart (Plate II)⁴ is useful principally in rating flake graphite, Type VII, distributions in gray cast iron. Occasionally, however, graphite in malleable or ductile iron may occur in a nonrandom distribution pattern which the distributions B to E may be used to describe.

9. Classification of Graphite Size by Chart

9.1 Two series of size charts, one for flake graphite, and one for nodules, are shown in Plate III⁴ to facilitate comparisons. At exactly 100 diameters magnification the *maximum* dimension of the graphite particles for the various size classes are shown in Table 1.

9.2 For direct comparison with the size classes in Plate III, the specimen to be evaluated should be projected on the ground glass screen, or photographed, at a magnification of exactly 100 diameters. Usually visual comparison with the chart is adequate to define the size class. If carefully calibrated, ocular

scales may be used to measure the serpentine length dimension of flakes or the diameter of nodules. Where a mixture of one or more sizes occurs in the same sample, the sizes may be reported as percentages of the total graphite area represented by the sizes involved. It is a common practice in malleable iron to use nodule count per unit area instead of a comparison chart as given here. Nodule count, with known free carbon content, is a measure of calculated average nodule area.

10. Report of Graphite Microstructure

10.1 To report the microstructure of graphite in cast iron the headings to be used are as follows: Sample identification; graphite form type or types; graphite distribution; graphite size class.

10.2 Graphite type, or types, is designated by a Roman numeral I through VII. Graphite distribution is designated by a capital letter A through E. Graphite size is designated by an Arabic numeral 1 through 8.

10.3 Graphite distribution is always designated for flake graphite irons, but may be omitted for malleable and ductile iron.

10.3.1 For example, a typical gray iron of normal graphite structure might be designated VII A4. If eutectiform graphite is present, the rating might be VII D7. Mixtures of these two may be described by giving both ratings with appropriate percentages, 70 % VII A4, 30 % VII D7.

10.3.2 A high-quality ductile iron could be designated I6. A slightly inferior ductile iron, with somewhat insufficient nodulizing alloy, might be 70 % I6, 30 % IV5.

10.3.3 Graphite in malleable irons may be similarly designated as Types III, II, or I and the size from the nodular size chart.

TABLE 1 Graphite Size

Size Class	Maximum Dimension at $\times 100$, mm ^A
1	128
2	64
3	32
4	16
5	8
6	4
7	2
8	1

^AThe gradation of sizes shown in each size class from the maximum dimension were computer calculated at the National Bureau of Standards using data obtained from actual micrographs (Wyman, L. L., and Moore, G. A., "Quantitative Metallographic Evaluations of Graphite Microstructures," Modern Castings, Vol 43, No. 1, Jan. 1963, p. 7).

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**Anexo 2. Standard Specification for
Gray Iron Castings (A 48/A 48M – 00)**



Designation: A 48/A 48M – 00

Standard Specification for Gray Iron Castings¹

This standard is issued under the fixed designation A 48/A 48M; 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. This specification replaces Federal Specification QQ-J-652.

1. Scope

1.1 This specification covers gray iron castings intended for general engineering use where tensile strength is a major consideration. Castings are classified on the basis of the tensile strength of the iron in separately cast test bars.

1.1.1 This specification subordinates chemical composition to tensile strength.

1.2 Castings produced to this specification are graded on the basis of minimum tensile strength obtained in special test coupons designed to standardize cooling rate. The tensile strength developed in certain casting sections may vary from test coupon values (see X1.2).

1.3 The values stated in either inch-pound units or SI units are to be regarded separately as standard. Within the text, the SI units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in nonconformance with the specification.

2. Referenced Documents

2.1 ASTM Standards:

A 644 Terminology Relating to Iron Castings²

E 8 Test Methods for Tension Testing of Metallic Materials³

2.2 Military Standard:

MIL-STD-129 Marking for Shipment and Storage⁴

2.3 Federal Standard:

Federal Standard No. 123 Marking for Shipment (Civil Agencies)⁴

3. Terminology

3.1 Definitions:

¹ This specification is under the jurisdiction of ASTM Committee A04 on Iron Castings and is the direct responsibility of Subcommittee A04.01 on Gray Iron Castings.

Current edition approved May 10, 2000. Published June 2000. Originally published as A 48 – 05. Last previous edition A 48 – 94a.

² Annual Book of ASTM Standards, Vol 01.02.

³ Annual Book of ASTM Standards, Vol 03.01.

⁴ Available from Standardization Documents Order Desk, Bldg. 4 Section D, 700 Robbins Ave., Philadelphia, PA 19111-5094, Attn: NPODS.

3.1.1 Definitions for many terms common to gray iron castings are found in Terminology A 644.

4. Classification

4.1 Castings ordered and produced in accordance with this specification are classified into a number of grades based on the properties of separately cast test bars (Table 1). Each class is designated by a number followed by a letter. The number indicates the minimum tensile strength of the separately cast test bar, and the letter indicates the size of the test bar. Examples of proper designations are as follows:

Gray Iron Castings, ASTM Specification A 48, Class 30B.

Gray Iron Castings, ASTM Specification A 48, Class 40C.

5. Ordering Information

5.1 Orders for material to this specification shall include the following information:

5.1.1 ASTM designation number and year of issue,

5.1.2 Class of iron required (see 4.1 and Table 1),

5.1.3 The size of the separately cast test bar (letter classification—A, B, C, or S) that best represents the thickness of the controlling section of the casting (see Table 2),

5.1.4 The tension test specimen (B or C) to be machined from test bar C (see 13.3, Table 3, and Fig. 1),

5.1.5 The tension test specimen to be machined from test bar S (see 13.4, Table 3, and Fig. 1),

5.1.6 Lot size (see Section 10),

5.1.7 Special requirements (see Section 6),

5.1.8 Saving tested specimens or unbroken test bars (see 15.1), and

5.1.9 Special preparation for delivery (see Section 19).

6. Special Requirements

6.1 When agreed upon in writing between the manufacturer and the purchaser, it may be necessary for the castings to meet special requirements as to hardness, chemical composition, microstructure, pressure tightness, radiographic soundness, dimensions, surface finish, etc.

TABLE 1 Requirements for Tensile Strength of Gray Cast Irons in Separately Cast Test Bars

Class	Tensile Strength, min, ksi [MPa]	Nominal Test Bar Diameter, in. [mm]
No. 20 A	20 (138)	0.88 (22.4)
No. 20 B		1.2 (30.5)
No. 20 C		2.0 (50.8)
No. 20 S		Bars S ^A
No. 25 A	25 (172)	0.88 (22.4)
No. 25 B		1.2 (30.5)
No. 25 C		2.0 (50.8)
No. 25 S		Bars S ^A
No. 30 A	30 (207)	0.88 (22.4)
No. 30 B		1.2 (30.5)
No. 30 C		2.0 (50.8)
No. 30 S		Bars S ^A
No. 35 A	35 (241)	0.88 (22.4)
No. 35 B		1.2 (30.5)
No. 35 C		2.0 (50.8)
No. 35 S		Bars S ^A
No. 40 A	40 (275)	0.88 (22.4)
No. 40 B		1.2 (30.5)
No. 40 C		2.0 (50.8)
No. 40 S		Bars S ^A
No. 45 A	45 (310)	0.88 (22.4)
No. 45 B		1.2 (30.5)
No. 45 C		2.0 (50.8)
No. 45 S		Bars S ^A
No. 50 A	50 (345)	0.88 (22.4)
No. 50 B		1.2 (30.5)
No. 50 C		2.0 (50.8)
No. 50 S		Bars S ^A
No. 55 A	55 (379)	0.88 (22.4)
No. 55 B		1.2 (30.5)
No. 55 C		2.0 (50.8)
No. 55 S		Bars S ^A
No. 60 A	60 (414)	0.88 (22.4)
No. 60 B		1.2 (30.5)
No. 60 C		2.0 (50.8)
No. 60 S		Bars S ^A

^AAll dimensions of test bar S shall be as agreed upon between the manufacturer and the purchaser.

TABLE 2 Separately Cast Test Bars for Use When a Specific Correlation Has Not Been Established Between the Test Bar and the Casting

Thickness of the Wall of the Controlling Section of the Casting, in. [mm]	Test Bar
Under 0.25 [under 6]	S
0.25 to 0.50 [6 to 13]	A
0.51 to 1.00 [13 to 25]	B
1.01 to 2 [26 to 51]	C
Over 2 [over 51]	S

7. Tensile Requirements

7.1 Test bars representing castings conforming to this specification shall meet the requirements for tensile strength as described in Table 1.

8. Dimensional Requirements

8.1 The castings shall conform to the dimensions or drawings furnished by the purchaser, or, if there are no drawings, to

the dimensions predicted by the pattern equipment supplied by the purchaser.

9. Workmanship and Finish

9.1 The surface of the casting shall be free of adhering sand, scale, cracks, and hot tears, as determined by visual examination.

9.2 No repairing by plugging or welding of any kind shall be permitted unless written permission is granted by the purchaser.

10. Sampling

10.1 A lot shall consist of one of the following:

10.1.1 All the metal poured from a single heating in a batch type melting furnace.

10.1.2 All the metal from two or more batch type melting furnaces poured into a single ladle or a single casting.

10.1.3 All the metal poured from a continuous melting furnace for a given period of time between changes in charge, processing conditions, or aim-for chemistry or 4 h, whichever is the shorter period.

10.1.3.1 The purchaser may agree to extend the 4-h time period to 8 h if the manufacturer can demonstrate sufficient process control to warrant such an extension.

11. Cast Test Bars

11.1 Test bars shall be separate castings poured from the same lot as the castings they represent and shall have dimensions as shown in Table 3. Allowance may be made for reasonable pattern draft within the tolerances shown in Table 3. Test bars A, B, and C are all standard test bars in the form of simple cylinders. Test bar S is special and is intended for use where the standard bars are not satisfactory.

11.2 The test bars shall be cast in dried, baked, or chemically bonded molds made mainly of an aggregate of siliceous sand with appropriate binders. The average grain size of the sand shall approximate that of the sand in which the castings are poured. Molds for the test bars shall be approximately at room temperature when poured. More than one test bar may be cast in a single mold, but each bar in the mold shall be surrounded by a thickness of sand which is not less than the diameter of the bar. A suitable design for a mold is shown in Fig. 2.

NOTE 1—The intent of these provisions is as follows: to prohibit the casting of test bars in molds of metal, graphite, zircon, light-weight aggregates, or other materials which would significantly affect the tensile strength of the iron; to prohibit control of tensile strength of the test bars by manipulation of the grain size of the sand; and to prohibit the casting of test bars in molds preheated substantially above room temperature.

11.3 Test bars that are intended to represent castings that are cooled in the mold to less than 900°F [480°C], before shakeout, shall be cooled in their molds to a temperature less than 900°F [480°C]. They then may be cooled in still air to room temperature.

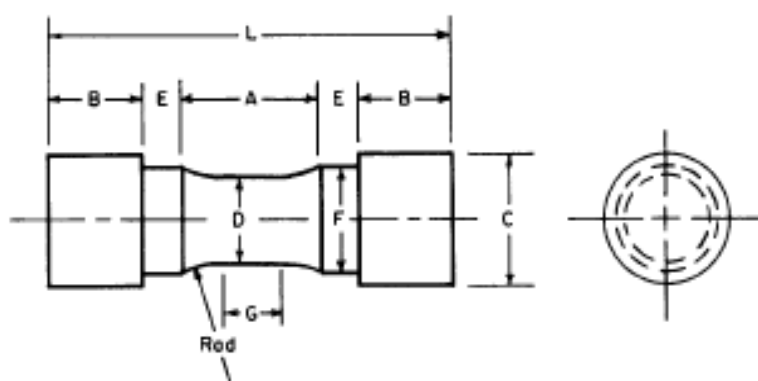
11.4 Test bars that are intended to represent castings that are hotter than 900°F [480°C], when shaken out of their molds, shall be cooled as described in 11.3 or (by agreement between the manufacturer and the purchaser) may be shaken out of their molds at approximately the same temperature as the castings they represent.

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TABLE 3 Diameters and Lengths of Cast Test Bars

Test Bar	As-Cast Diameter, in. [mm]			Length, in. [mm]	
	Nominal (Mid-Length)	Minimum (Bottom)	Maximum (Top)	Minimum (Specified)	Maximum (Recommended)
A	0.88 [22.5]	0.85 [21.5]	0.96 [24.5]	5.0 [125]	6.0 [150]
B	1.20 [30.5]	1.14 [29.0]	1.32 [33.5]	6.0 [150]	9.0 [230]
C	2.00 [50.8]	1.90 [48.3]	2.10 [53.3]	7.0 [175]	10.0 [255]
S ^A	...	...	...	...	...

^AAll dimensions of test bar S shall be as agreed upon by the manufacturer and the purchaser.



Dimensions, in. [mm]	Tension Test Specimen A	Tension Test Specimen B	Tension Test Specimen C
G—Length of parallel, min	0.50 [13]	0.75 [19]	1.25 [32]
D—Diameter	0.500 ± 0.010 [12.7 ± 0.25]	0.750 ± 0.015 [19.0 ± 0.38]	1.25 ± 0.025 [30 ± 0.65]
R—Radius of fillet, min	1 [25]	1 [25]	2 [50]
A—Length of reduced section, min	1½ [32]	1½ [38]	2½ [57]
L—Overall length, min	3¾ [95]	4 [100]	6¾ [160]
C—Diameter of end section, approx	¾ [22]	1½ [32]	1½ [48]
E—Length of shoulder, min	¼ [6]	¼ [6]	¾ [8]
F—Diameter of shoulder	¾ ± 1/16 [16 ± 0.4]	1½ ± 1/16 [25 ± 0.4]	1½ ± 1/16 [36 ± 0.4]
B—Length of end section	A	A	A

^AOptional to fit holders on testing machine. If threaded, root diameter shall not be less than dimension F.

FIG. 1 Tension-Test Specimens

11.5 When castings are stress-relieved, annealed, or otherwise heat-treated, test bars shall receive the same thermal treatment and shall be treated adjacent to the castings they represent.

12. Number of Tests and Retests

12.1 The tension test shall be conducted in accordance with Test Method E 8.

12.2 One tension test shall be performed on each lot and shall conform to the tensile requirements specified.

12.3 If the results of a valid test fail to conform to the requirements of this specification, two retests shall be made. If either retest fails to meet the specification requirements, the castings represented by these test specimens shall be rejected. A valid test is one wherein the specimen has been properly prepared and appears to be sound and on which the approved test procedure has been followed.

12.4 If sufficient separately cast test pieces are not available, the manufacturer shall have the option of removing a test specimen from a location of representative casting, as agreed upon between the manufacturer and purchaser.

12.5 If the first test results indicate that a heat treatment is needed to meet the test requirements, the entire lot of castings and the representative test specimens shall be heat treated together. Testing shall proceed in accordance with 12.1-12.3.

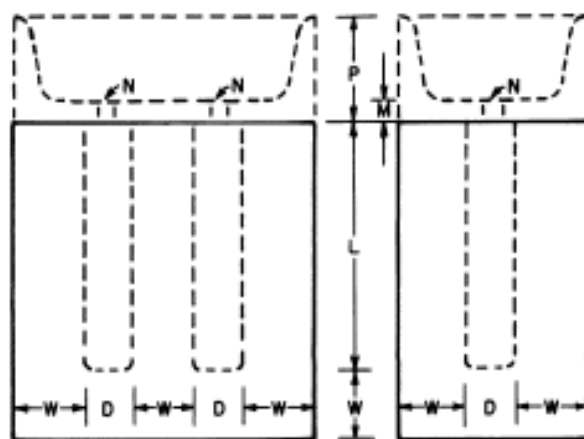
12.6 If, after testing, a test specimen shows evidence of a defect, the results of the test may be invalidated and another made on a specimen from the same lot.

13. Tension Test Specimens

13.1 For test Bar A, the tension-test specimen A, as shown in Fig. 1, shall be machined concentric with the axis of the test bar.

13.2 For test Bar B, the tension test specimen B, as shown in Fig. 1, shall be machined concentric with the axis of the test bar.

13.3 For test Bar C, tension test specimens B or C, as shown in Fig. 1, shall be machined concentric with the axis of the test bar. Unless the size of the tension test specimen to be machined from test bar C is specified in writing by the purchaser, the decision whether to use tension test specimen B or C shall be made by the manufacturer of the castings.

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**Required Features:**

1. Material—Aggregate of dry siliceous sand.
2. Position—Bars vertical.
3. L—See Table 3.
4. D—See Table 3.
5. W—Not less than diameter D.

Optional Features:

1. Number of test bars in a single mold—Two suggested.
2. Design of pouring cup.
3. P—2 in. [50 mm], suggested.
4. N— $\frac{1}{8}$ in. [8 mm] in diameter, suggested.
5. M—1.5 N, suggested.

FIG. 2 Suitable Design and Dimensions for Mold for Separately Cast Cylindrical Test Bars for Gray Iron

13.4 For test bar S, the nature and dimensions of the tension test specimen shall be determined by agreement between the manufacturer and purchaser.

14. Tension Test

14.1 Tension test specimens shall fit the holders of the testing machine in such a way that the load shall be axial.

14.2 The elapsed time from the beginning of loading in the tension test to the instant of fracture shall be not less than 15 s for test specimen A and not less than 20 s for specimens B and C.

15. Inspection

15.1 Unless otherwise specified in the contract or purchase order, the manufacturer shall be responsible for carrying out all the tests and inspections required by this specification, using his own or other reliable facilities, and he shall maintain complete records of all such tests and inspections. Such records shall be available for review by the purchaser.

15.1.1 When agreed upon between the manufacturer and purchaser, tested specimens or unbroken test bars from the same lot shall be saved for a period of three months after the date of the test report.

15.2 The purchaser reserves the right to perform any of the inspections set forth in the specification where such inspections are deemed necessary to ensure that supplies and services conform to the prescribed requirements.

16. Rejection and Resubmission

16.1 Any castings or lot of castings failing to comply with the requirements of this specification may, where possible, be reprocessed, retested, and reinspected. If the tests and inspections on the reprocessed casting(s) show compliance with this specification, the castings shall be acceptable; if they do not, they shall be rejected.

16.2 If the purchaser should find that a casting or lot of castings fails to comply with this specification subsequent to receipt at his facility, he shall so notify the manufacturer promptly and in no case later than six weeks after receipt of the shipment, stating clearly the basis for rejection.

17. Certification

17.1 When specified by the purchaser's order or contract, a manufacturer's certification or compliance statement that the casting or lot of castings was made, sampled, tested, and inspected in accordance with this specification, including a report of test results shall be furnished at the time of shipment, and such certification or compliance statement shall be the basis for acceptance of the casting or lot of castings.

17.2 A signature is not required on the certification or test report. However, the document shall clearly identify the organization submitting the certification and the authorized agent of the manufacturer who certified the test results. Notwithstanding the absence of a signature, the organization submitting the certification is responsible for its content.

18. Product Marking

18.1 When the size of the casting permits, each casting shall bear the identifying mark of the manufacturer and the part or pattern number at a location shown on the covering drawing or, if not shown on the drawing, at a location at the discretion of the producer.

19. Preparation for Delivery

19.1 Unless otherwise stated in the contract or order, the cleaning, preservation and packing of castings for shipment shall be in accordance with the manufacturer's commercial practice. Packaging and marking shall also be adequate to identify the contents and to ensure acceptance and safe delivery by the carrier for the mode of transportation employed.

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19.2 *U.S. Government Procurement*—When specified in the contract or purchase order, marking for shipment shall be in accordance with the requirements of Fed. Std. No. 123 for civil agencies and MIL-STD-129 for military activities.

20. Keywords

20.1 gray iron castings

APPENDIX

(Nonmandatory Information)

XI. MECHANICAL PROPERTIES OF CASTINGS

X1.1 The mechanical properties of iron castings are influenced by the cooling rate during and after solidification, by chemical composition (particularly carbon equivalent), by the design of the casting, by the design and nature of the mold, by the location and effectiveness of gates and risers, and by certain other factors.

X1.2 The cooling rate in the mold and, hence, the properties developed in any particular section are influenced by the presence of cores; chills and chaplets; changes in section thickness; and the existence of bosses, projections, and inter-sections, such as junctions of ribs and bosses. Because of the complexity of the interactions of these factors, no precise quantitative relationship can be stated between the properties of the iron in various locations of the same casting or between the properties of a casting and those of a test specimen cast from the same iron. When such a relationship is important and must be known for a specification application, it may be determined by appropriate experimentation.

X1.3 Gray iron castings in Classes 20, 25, 30 and 35 are

characterized by excellent machinability, high damping capacity, low modulus of elasticity, and comparative ease of manufacture.

X1.3.1 Castings in Classes 40, 45, 50, 55 and 60 are usually more difficult to machine, have lower damping capacity and a higher modulus of elasticity, and are more difficult to manufacture.

X1.4 When reliable information is unavailable on the relationship between properties in a casting and those in a separately cast test specimen, and where experimentation would be unfeasible, the size of the test casting should be so selected as to approximate the thickness of the main or controlling section of the casting.

X1.5 If iron castings are welded (see 9.2), the microstructure of the iron is usually altered, particularly in the vicinity of the weldment. Therefore, the properties of the casting may be adversely affected by welding. Where practical, appropriate post weld heat treatment may reduce this effect of welding.

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**Anexo 3. Standard Test Methods for Notched Bar
Impact Testing of Metallic Materials
(E 23 – 01)**

Standard Test Methods for Notched Bar Impact Testing of Metallic Materials¹

This standard is issued under the fixed designation E 23; 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.

1. Scope

1.1 These test methods describe notched-bar impact testing of metallic materials by the Charpy (simple-beam) test and the Izod (cantilever-beam) test. They give the requirements for: test specimens, test procedures, test reports, test machines (see Annex A1) verifying Charpy impact machines (see Annex A2), optional test specimen configurations (see Annex A3), pre-cracking Charpy V-notch specimens (see Annex A4), designation of test specimen orientation (see Annex A5), and determining the percent of shear fracture on the surface of broken impact specimens (see Annex A6). In addition, information is provided on the significance of notched-bar impact testing (see Appendix X1), methods of measuring the center of strike (see Appendix X2), and the availability of Charpy V-notch verification specimens (see Appendix X3).

1.2 These test methods do not address the problems associated with impact testing at temperatures below -196°C (-320°F , 77°K).

1.3 The values stated in SI units are to be regarded as the standard. Inch-pound units are provided for information only.

1.4 *This standard does not purport to address all of the safety concerns, if any, 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.* Specific precautionary statements are given in Section 5.

2. Referenced Documents

2.1 ASTM Standards:

E 177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods²

E 399 Test Method for Plane-Strain Fracture Toughness of Metallic Materials³

E 604 Test Method for Dynamic Tear Energy of Metallic Materials³

E 691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method²

¹ These test methods are under the jurisdiction of ASTM Committee E28 on Mechanical Testing and are the direct responsibility of Subcommittee E2807 on Impact Testing.

Current edition approved April 10, 2001. Published June 2001. Originally published as E 23 – 33 T. Last previous edition E 23 – 00.

² Annual Book of ASTM Standards, Vol 14.02.

³ Annual Book of ASTM Standards, Vol 03.01.

E 1271 Practice for Qualifying Charpy Verification Specimens of Heat-treated Steel³

E 1313 Guide for Recommended Formats for Data Records Used in Computerization of Mechanical Test Data for Metals⁴

3. Summary of Test Method

3.1 The essential features of an impact test are: a suitable specimen (specimens of several different types are recognized), an anvil or support on which the test specimen is placed to receive the blow of the moving mass, a moving mass that has sufficient energy to break the specimen placed in its path, and a device for measuring the energy absorbed by the broken specimen.

4. Significance and Use

4.1 These test methods of impact testing relate specifically to the behavior of metal when subjected to a single application of a force resulting in multi-axial stresses associated with a notch, coupled with high rates of loading and in some cases with high or low temperatures. For some materials and temperatures the results of impact tests on notched specimens, when correlated with service experience, have been found to predict the likelihood of brittle fracture accurately. Further information on significance appears in Appendix X1.

5. Precautions in Operation of Machine

5.1 Safety precautions should be taken to protect personnel from the swinging pendulum, flying broken specimens, and hazards associated with specimen warming and cooling media.

6. Apparatus

6.1 General Requirements:

6.1.1 The testing machine shall be a pendulum type of rigid construction.

6.1.2 The testing machine shall be designed and built to conform with the requirements given in Annex A1.

6.2 Inspection and Verification

6.2.1 Inspection procedures to verify impact machines directly are provided in A2.2 and A2.3. The items listed in A2.2 must be inspected annually.

6.2.2 The procedures to verify Charpy V-notch machines

⁴ Annual Book of ASTM Standards, Vol 14.01.

indirectly, using verification specimens, are given in A2.4. Charpy impact machines must be verified annually.

7. Test Specimens

7.1 Configuration and Orientation:

7.1.1 Specimens shall be taken from the material as specified by the applicable specification. Specimen orientation should be designated according to the terminology given in Annex A5.

7.1.2 The type of specimen chosen depends largely upon the characteristics of the material to be tested. A given specimen may not be equally satisfactory for soft nonferrous metals and hardened steels; therefore, many types of specimens are recognized. In general, sharper and deeper notches are required to distinguish differences in very ductile materials or when using low testing velocities.

7.1.3 The specimens shown in Figs. 1 and 2 are those most widely used and most generally satisfactory. They are particularly suitable for ferrous metals, excepting cast iron.⁵

7.1.4 The specimen commonly found suitable for die-cast alloys is shown in Fig. 3.

7.1.5 The specimens commonly found suitable for powdered metals (P/M) are shown in Figs. 4 and 5. The specimen

⁵ Report of Subcommittee XV on Impact Testing of Committee A-3 on Cast Iron, Proceedings, ASTM, Vol 33 Part 1, 1933.

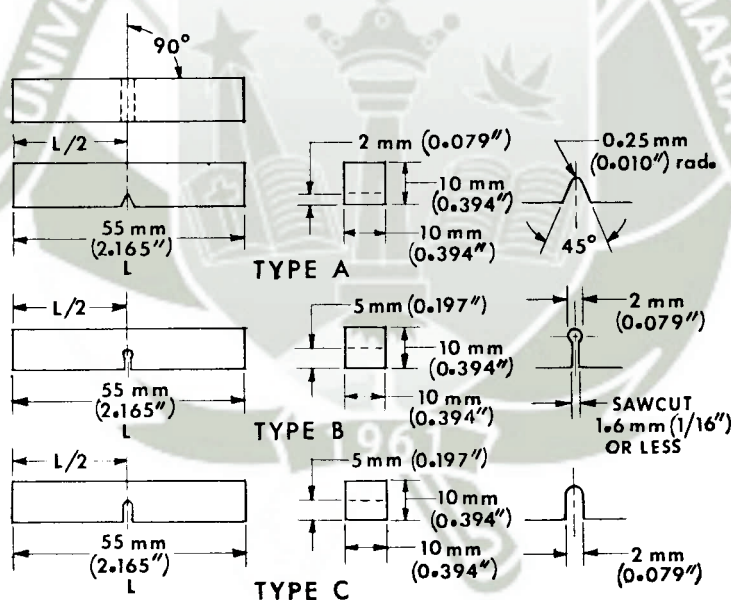
surface may be in the as-produced condition or smoothly machined, but polishing has proven generally unnecessary. Unnotched specimens are used with P/M materials. In P/M materials, the impact test results are affected by specimen orientation. Therefore, unless otherwise specified, the position of the specimen in the machine shall be such that the pendulum will strike a surface that is parallel to the compacting direction.

7.1.6 Sub-size and supplementary specimen recommendations are given in Annex A3.

7.2 Specimen Machining:

7.2.1 When heat-treated materials are being evaluated, the specimen shall be finish machined, including notching, after the final heat treatment, unless it can be demonstrated that the impact properties of specimens machined before heat treatment are identical to those machined after heat treatment.

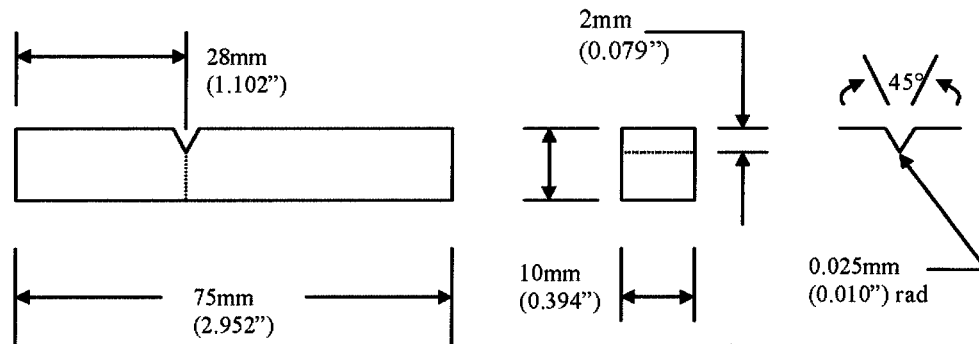
7.2.2 Notches shall be smoothly machined but polishing has proven generally unnecessary. However, since variations in notch dimensions will seriously affect the results of the tests, adhering to the tolerances given in Fig. 1 is necessary (Appendix X1.2 illustrates the effects from varying notch dimensions on Type A specimens). In keyhole specimens, the round hole shall be carefully drilled with a slow feed rate. The slot may be cut by any feasible method, but care must be exercised in cutting the slot to ensure that the surface of the drilled hole opposite the slot is not damaged.



NOTE 1—Permissible variations shall be as follows:

Notch length to edge	90 ±2°
Adjacent sides shall be at	90° ±10 min
Cross-section dimensions	±0.075 mm (±0.003 in.)
Length of specimen (<i>L</i>)	+0, -2.5 mm (+0, -0.100 in.)
Centering of notch (<i>L</i> /2)	±1 mm (±0.039 in.)
Angle of notch	±1°
Radius of notch	±0.025 mm (±0.001 in.)
Notch depth:	
Type A specimen	±0.025 mm (±0.001 in.)
Types B and C specimen	±0.075 mm (±0.003 in.)
Finish requirements	2 μm (63 μin.) on notched surface and opposite face; 4 μm (125 μin.) on other two surfaces

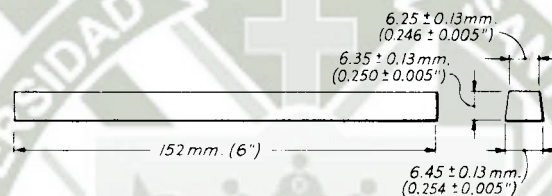
FIG. 1 Charpy (Simple-Beam) Impact Test Specimens, Types A, B, and C



NOTE 1—Permissible variations shall be as follows:

Notch length to edge	$90 \pm 2^\circ$
Cross-section dimensions	$\pm 0.025 \text{ mm } (\pm 0.001 \text{ in.})$
Length of specimen	$+0, -2.5 \text{ mm } (\pm 0, -0.100 \text{ in.})$
Angle of notch	$\pm 1^\circ$
Radius of notch	$\pm 0.025 \text{ mm } (\pm 0.001 \text{ in.})$
Notch depth	$\pm 0.025 \text{ mm } (\pm 0.001 \text{ in.})$
Adjacent sides shall be at	$90^\circ \pm 10 \text{ min}$
Finish requirements	$2 \mu\text{m } (63 \mu\text{in.})$ on notched surface and opposite face; $4 \mu\text{m } (125 \mu\text{in.})$ on other two surfaces

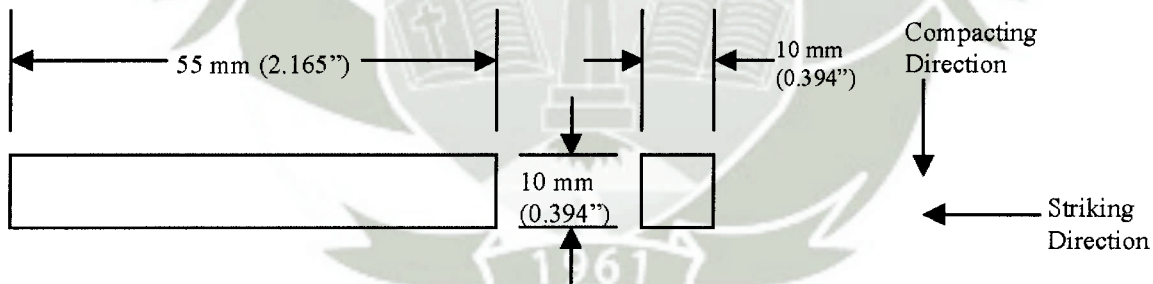
FIG. 2 Izod (Cantilever-Beam) Impact Test Specimen, Type D



NOTE 1—Two Izod specimens may be cut from this bar.

NOTE 2—Blow shall be struck on narrowest face.

FIG. 3 Izod Impact Test Bar for Die Castings Alloys



NOTE 1—Permissible variations shall be as follows:

Adjacent sides shall be at	$90^\circ \pm 10 \text{ min}$
Cross section dimensions	$\pm 0.125 \text{ mm } (0.005 \text{ in.})$
Length of specimen	$+0, -2.5 \text{ mm } (+0, -0.100 \text{ in.})$

FIG. 4 Charpy (Simple Beam) Impact Test Specimens for Metal Powder Structural Parts

7.2.3 Identification marks shall only be placed in the following locations on specimens: either of the 10-mm square ends; the side of the specimen that faces up when the specimen is positioned in the anvils (see Note 1); or the side of the specimen opposite the notch. No markings, on any side of the specimen, shall be within 15 mm of the center line of the notch. An electrostatic pencil may be used for identification purposes, but caution must be taken to avoid excessive heat.

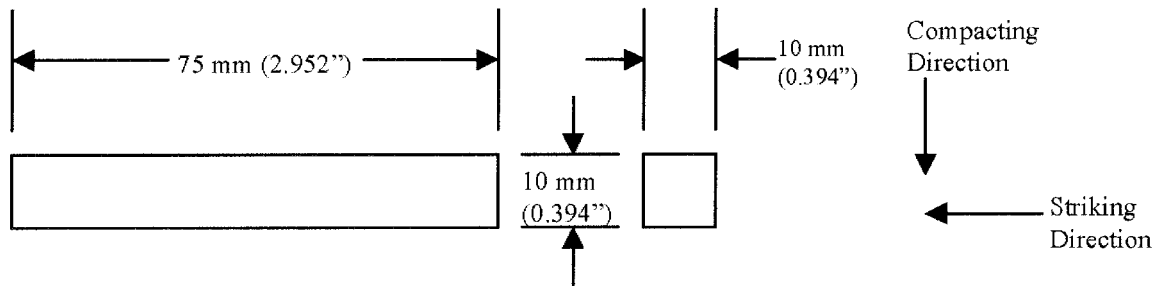
NOTE 1—Careful consideration should be given before placing identification marks on the side of the specimen to be placed up when positioned

in the anvils. If the test operator is not careful, the specimen may be placed in the machine with the identification marking resting on the specimen supports. Under these circumstances, the absorbed energy value obtained may be unreliable.

8. Procedure

8.1 Preparation of the Apparatus:

8.1.1 Perform a routine procedure for checking impact machines at the beginning of each day, each shift, or just prior to testing on a machine used intermittently. It is recommended that the results of these routine checks be kept in a log book for



NOTE 1—Permissible variations shall be as follows:

Adjacent sides shall be at	$90^\circ \pm 10 \text{ min.}$
Cross section dimensions	$\pm 0.125 \text{ mm (0.005 in.)}$
Length of specimens	$+0, -2.5 \text{ mm (+0, -0.100 in.)}$

FIG. 5 Izod (Cantilever-Beam) Impact Test Specimen for Metal Powder Structural Parts

the machine. After the testing machine has been ascertained to comply with Annex A1 and Annex A2, carry out the routine check as follows:

8.1.1.1 Visually examine the striker and anvils for obvious damage and wear.

8.1.1.2 Check the zero position of the machine by using the following procedure: raise the pendulum to the latched position, move the pointer to near the maximum capacity of the range being used, release the pendulum, and read the indicated value. The pointer should indicate zero on machines reading directly in energy. On machines reading in degrees, the reading should correspond to zero on the conversion chart furnished by the machine manufacturer.

NOTE 2—On machines that do not compensate for windage and friction losses, the pointer will not indicate zero. In this case, the indicated values, when converted to energy, shall be corrected for frictional losses that are assumed to be proportional to the arc of swing.

8.1.1.3 To ensure that friction and windage losses are within allowable tolerances, the following procedure is recommended: raise the pendulum to the latched position, move the pointer to the negative side of zero, release the pendulum and allow it to cycle five times (a forward and a backward swing together count as one swing), prior to the sixth forward swing, set the pointer to between 5 and 10 % of the scale capacity of the dial, after the sixth forward swing (eleven half swings), record the value indicated by the pointer, convert the reading to energy (if necessary), divide it by 11 (half swings), then divide by the maximum scale value being used and multiply it by 100 to get the percent friction. The result, friction and windage loss, shall not exceed 0.4 % of scale range capacity being tested and should not change by more than 5 % of friction measurements previously made on the machine. If the friction and windage loss value does exceed 0.4 % or is significantly different from previous measurements, check the indicating mechanism, the latch height, and the bearings for wear and damage. However, if the machine has not been used recently, let the pendulum swing for 50 to 100 cycles, and repeat the friction test before undertaking repairs to the machine.

8.2 Test Temperature Considerations:

8.2.1 The temperature of testing affects the impact properties of most materials. For materials with a body centered cubic structure, a transition in fracture mode occurs over a tempera-

ture range that depends on the chemical composition and microstructure of the material. Test temperatures may be chosen to characterize material behavior at fixed values, or over a range of temperatures to characterize the transition region, lower shelf, or upper shelf behavior, or all of these. The choice of test temperature is the responsibility of the user of this test method and will depend on the specific application.

8.2.2 The temperature of a specimen can change significantly during the interval it is removed from the temperature conditioning environment, transferred to the impact machine, and the fracture event is completed (see Note 5). When using a heating or cooling medium near its boiling point, use data from the references in Note 5 or calibration data with thermocouples to confirm that the specimen is within the stated temperature tolerances when the striker contacts the specimen. If excessive adiabatic heating is expected, monitor the specimen temperature near the notch during fracture.

8.2.3 Verify temperature-measuring equipment at least every six months. If liquid-in-glass thermometers are used, an initial verification shall be sufficient, however, the device shall be inspected for problems, such as the separation of liquid, at least twice annually.

8.2.4 Hold the specimen at the desired temperature within $\pm 1^\circ \text{C}$ ($\pm 2^\circ \text{F}$) in the temperature conditioning environment (see 8.2.4.1 and 8.2.4.2). Any method of heating or cooling or transferring the specimen to the anvil(s) may be used provided the temperature of the specimen immediately prior to fracture is essentially the same as the holding temperature (see Note 5). The maximum change in the temperature of the specimen allowed for the interval between the temperature conditioning treatment and impact is not specified here, because it is dependent on the material being tested and the application. The user of nontraditional or lesser used temperature conditioning and transfer methods (or sample sizes) shall show that the temperature change for the specimen prior to impact is comparable to or less than the temperature change for a standard size specimen of the same material that has been thermally conditioned in a commonly used medium (oil, air, nitrogen, acetone, methanol), and transferred for impact within 5 seconds (see Note 5). Three temperature conditioning and transfer methods used in the past are: liquid bath thermal

conditioning and transfer to the specimen supports with centering tongs; furnace thermal conditioning and robotic transfer to the specimen supports; placement of the specimen on the supports followed by in situ heating and cooling.

8.2.4.1 For liquid bath cooling or heating use a suitable container, which has a grid or another type of specimen positioning fixture. Cover the specimens, when immersed, with at least 25 mm (1 in.) of the liquid, and position so that the notch area is not closer than 25 mm (1 in.) to the sides or bottom of the container, and no part of the specimen is in contact with the container. Place the device used to measure the temperature of the bath in the center of a group of the specimens. Agitate the bath and hold at the desired temperature within $\pm 1^\circ\text{C}$ ($\pm 2^\circ\text{F}$). Thermally condition the specimens for at least 5 min before testing, unless a shorter thermal conditioning time can be shown to be valid by measurements with thermocouples. Leave the mechanism (tongs, for example) used to handle the specimens in the bath for at least 5 min before testing, and return the mechanism to the bath between tests.

8.2.4.2 When using a gas medium, position the specimens so that the gas circulates around them and hold the gas at the desired temperature within $\pm 1^\circ\text{C}$ ($\pm 2^\circ\text{F}$) for at least 30 min. Leave the mechanism used to remove the specimen from the medium in the medium except when handling the specimens.

NOTE 3—Temperatures up to $+260^\circ\text{C}$ ($+500^\circ\text{F}$) may be obtained with

certain oils, but “flash-point” temperatures must be carefully observed.

NOTE 4—For testing at temperatures down to -196°C (-320°F , 77°K), standard testing procedures have been found to be adequate for most metals.

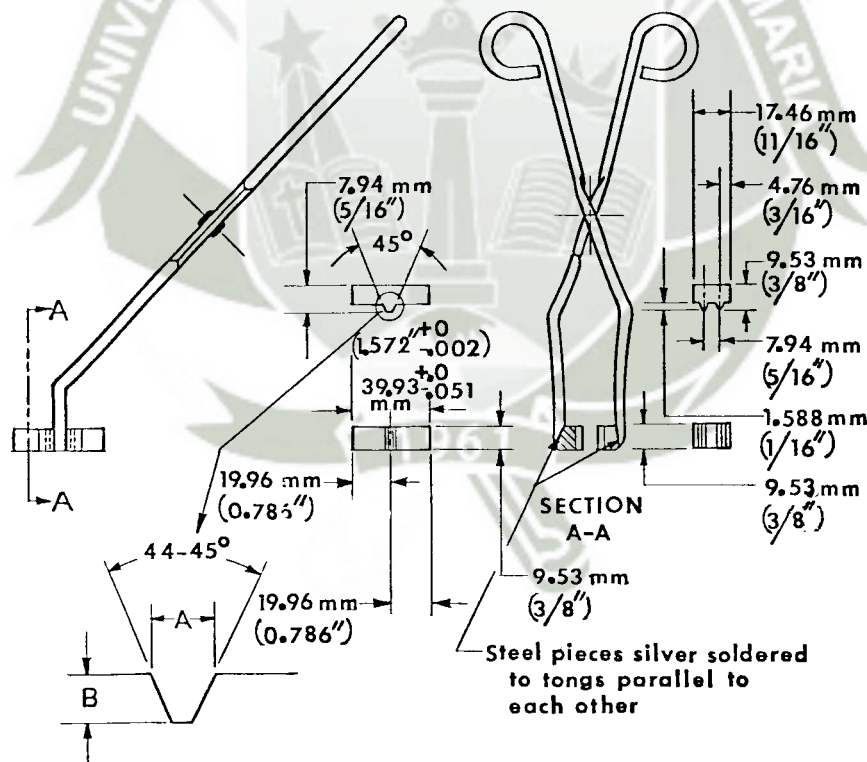
NOTE 5—A study has shown that a specimen heated to 100°C in water can cool 10°C in the 5 s allowed for transfer to the machine supports (1)⁶. Other studies, using cooling media that are above their boiling points at room temperature have also shown large changes in specimen temperature during the transfer of specimens to the machine anvils. In addition, some materials change temperature dramatically during impact testing at cryogenic temperatures due to adiabatic heating (2).

8.3 Charpy Test Procedure:

8.3.1 The Charpy test procedure may be summarized as follows: the test specimen is thermally conditioned and positioned on the specimen supports against the anvils; the pendulum is released without vibration, and the specimen is impacted by the striker. Information is obtained from the machine and from the broken specimen.

8.3.2 To position a test specimen in the machine, it is recommended that self-centering tongs similar to those shown in Fig. 6 be used (see A1.10.1). The tongs illustrated in Fig. 6 are for centering V-notch specimens. If keyhole specimens are used, modification of the tong design may be necessary. If an end-centering device is used, caution must be taken to ensure

⁶ The boldface numbers given in parentheses refer to a list of references at the end of the text.



NOTE 1—Unless otherwise shown, permissible variation shall be ± 1 mm (0.04 in.).

Specimen Depth, mm (in.)	Base Width (A), mm (in.)	Height (B), mm (in.)
10 (0.394)	1.60 to 1.70 (0.063 to 0.067)	1.52 to 1.65 (0.060 to 0.065)
5 (0.197)	0.74 to 0.80 (0.029 to 0.033)	0.69 to 0.81 (0.027 to 0.032)
3 (0.118)	0.45 to 0.51 (0.016 to 0.020)	0.36 to 0.48 (0.014 to 0.019)

FIG. 6 Centering Tongs for V-Notch Charpy Specimens

that low-energy high-strength specimens will not rebound off this device into the pendulum and cause erroneously high recorded values. Many such devices are permanent fixtures of machines, and if the clearance between the end of a specimen in test position and the centering device is not approximately 13 mm (0.5 in.), the broken specimens may rebound into the pendulum.

8.3.3 To conduct the test, prepare the machine by raising the pendulum to the latched position, set the energy indicator at the maximum scale reading, or initialize the digital display, or both, position the specimen on the anvils, and release the pendulum. If a liquid bath or gas medium is being used for thermal conditioning, perform the following sequence in less than 5 s (for standard $10 \times 10 \times 55$ mm specimens, see 8.2.4). Remove the test specimen from its cooling (or heating) medium with centering tongs that have been temperature conditioned with the test specimen, place the specimen in the test position, and, release the pendulum smoothly. If a test specimen has been removed from the temperature conditioning bath and it is questionable that the test can be conducted within the 5 s time frame, return the specimen to the bath for the time required in 8.2 before testing.

8.3.3.1 If a fractured impact specimen does not separate into two pieces, report it as unbroken. Unbroken specimens with absorbed energies of less than 80 % of the machine capacity may be averaged with values from broken specimens. If the individual values are not listed, report the percent of unbroken specimens with the average. If the absorbed energy exceeds 80 % of the machine capacity and the specimen passes completely between the anvils, report the value as approximate (see 10.1) and not averaged with the others. If an unbroken specimen does not pass between the machine anvils, the result will be reported as exceeding the machine capacity. A specimen shall never be struck more than once.

8.3.3.2 If a specimen jams in the machine, disregard the results and check the machine thoroughly for damage or maladjustment, which would affect its calibration.

8.3.3.3 To prevent recording an erroneous value, caused by jarring the indicator when locking the pendulum in its upright ("ready") position, read the value for each test from the indicator prior to locking the pendulum for the next test.

8.4 Izod Test Procedure:

8.4.1 The Izod test procedure may be summarized as follows: the test specimen is positioned in the specimen-holding fixture and the pendulum is released without vibration. Information is obtained from the machine and from the broken specimen. The details are described as follows:

8.4.2 Testing at temperatures other than room temperature is difficult because the specimen-holding fixture for Izod specimens is often part of the base of the machine and cannot be readily cooled (or heated). Consequently, Izod testing is not recommended at other than room temperature.

8.4.3 Clamp the specimen firmly in the support vise so that the centerline of the notch is in the plane of the top of the vise within 0.125 mm (0.005 in.). Set the energy indicator at the maximum scale reading, and release the pendulum smoothly. Sections 8.3.3.1-8.3.3.3 inclusively, also apply when testing Izod specimens.

9. Information Obtainable from Impact Tests

9.1 *The absorbed energy* shall be taken as the difference between the energy in the striking member at the instant of impact with the specimen and the energy remaining after breaking the specimen. This value is determined by the machine's scale reading which has been corrected for windage and friction losses.

NOTE 6—Alternative means for energy measurement are acceptable provided the accuracy of such methods can be demonstrated. Methods used in the past include optical encoders and strain gaged strikers.

9.2 *Lateral expansion measurement* methods must take into account the fact that the fracture path seldom bisects the point of maximum expansion on both sides of a specimen. One half of a broken specimen may include the maximum expansion for both sides, one side only, or neither. Therefore, the expansion on each side of each specimen half must be measured relative to the plane defined by the undeformed portion on the side of the specimen, as shown in Fig. 7. For example, if A_1 is greater than A_2 , and A_3 is less than A_4 , then the lateral expansion is the sum of $A_1 + A_4$.

9.2.1 Before making any expansion measurements, it is essential that the two specimen halves are visually examined for burrs that may have formed during impact testing; if the burrs will influence the lateral expansion measurements, they must be removed (by rubbing on emery cloth or any other suitable method), making sure that the protrusions to be measured are not rubbed during the removal of the burr. Then, examine each fracture surface to ascertain that the protrusions have not been damaged by contacting an anvil, a machine mounting surface, ect. Lateral expansion shall not be measured on a specimen with this type of damage.

9.2.2 Lateral expansion shall not be reported for specimens that did not separate into two halves during the impact test, with one exception. The lateral expansion of an unbroken specimen can be reported if the following two conditions are met: the specimen can be separated by pushing the hinged halves together once and then pulling them apart without further fatiguing the specimen, and the lateral expansion measured for the unbroken specimen (prior to bending) is equal to or greater than that measured for the separated halves.

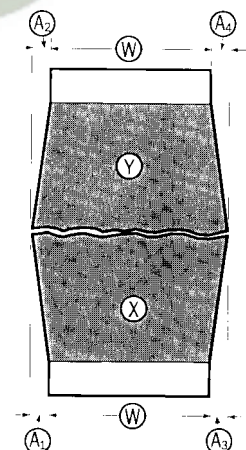


FIG. 7 Halves of Broken Charpy V-Notch Impact Specimen Illustrating the Measurement of Lateral Expansion, Dimensions A_1 , A_2 , A_3 , A_4 and Original Width, Dimension W

9.2.3 Lateral expansion may be measured easily by using a gage like the one shown in Fig. 8 (assembly and details shown in Fig. 9). Using this type of gage the measurement is made with the following procedure: orient the specimen halves so that the compression sides are facing each other, take one half of the fractured specimen and press it against the anvil and dial gage plunger and record the reading, make a similar measurement on the other half (same side) of the fractured specimen and disregard the lower of the two values, do the same for the other side of the fractured specimen, report the sum of the maximum expansions for the 2 sides as the lateral expansion for the specimen.

9.3 *The percentage of shear fracture* on the fracture surfaces of impact specimens may be determined using a variety of methods. The acceptable methods are defined in Annex A6. For each method, the user must distinguish between regions formed by ductile stable crack growth mechanisms, and regions formed by brittle fast crack propagation (unstable crack growth mechanisms). The typical zones of fracture appearance are shown in Fig. 10, where the “flat fracture” region is the region in which unstable crack growth occurs on a microsecond time scale.

The percent shear area on the fracture surface of a Charpy impact specimen is typically calculated as the difference between the total fractured area and the area of flat fracture. The measurement methods described here provide estimates for the area of the macroscopically flat fracture region (directly or indirectly), but do not consider details of the fracture mode for this “flat” region of unstable fracture. The flat fracture region could be 100 percent cleavage, a mixture of cleavage and ductile-dimple fracture morphologies, or other combinations of ductile-brittle fracture morphologies. Estimates of ductility within the unstable crack growth region are beyond the scope of these methods.

10. Report

10.1 *Absorbed energy values above 80 %* of the scale range are inaccurate and shall be reported as approximate. Ideally an impact test would be conducted at a constant impact velocity. In a pendulum-type test, the velocity decreases as the fracture progresses. For specimens that have impact energies approaching 80 % of the capacity of the pendulum, the velocity of the pendulum decreases (to about 45 % of the initial velocity) during fracture to the point that accurate impact energies are no longer obtained.

10.2 *For commercial acceptance testing*, report the following information (for each specimen tested):

10.2.1 Specimen type (and size if not the full-size specimen),

10.2.2 Test temperature,

10.2.3 Absorbed energy, and

10.2.4 Any other contractual requirements.

10.3 *For other than commercial acceptance testing* the following information is often reported in addition to the information in 10.2:

10.3.1 Lateral expansion,

10.3.2 Unbroken specimens,

10.3.3 Fracture appearance (% shear, See Note A6.1),

10.3.4 Specimen orientation, and

10.3.5 Specimen location.

NOTE 7—A recommended format for computerization of notched bar impact test data is available in Practice E 1313.

11. Precision and Bias

11.1 *An Interlaboratory study* used CVN specimens of low energy and of high energy to find sources of variation in the CVN absorbed energy. Data from 29 laboratories were included with each laboratory testing one set of five specimens of

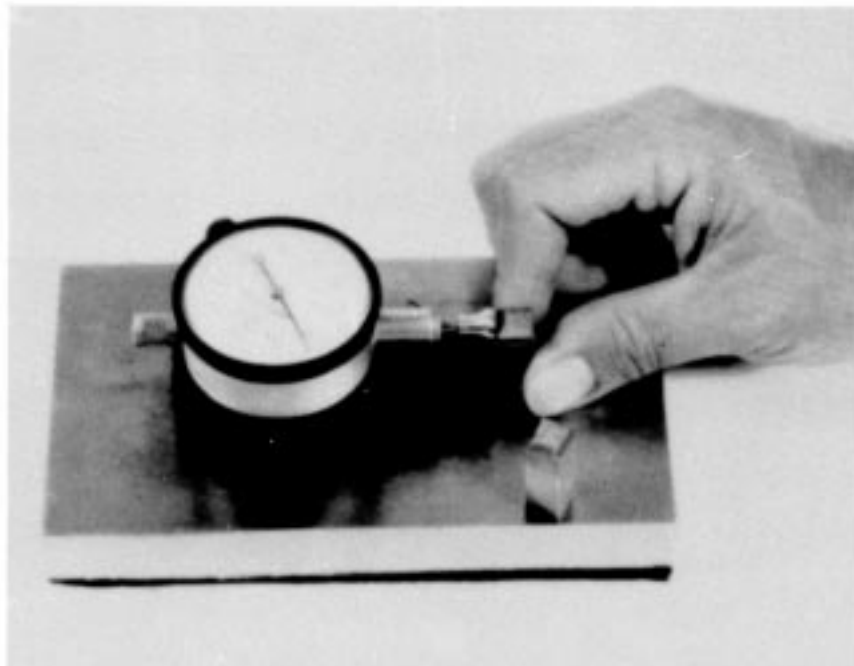


FIG. 8 Lateral Expansion Gage for Charpy Impact Specimens

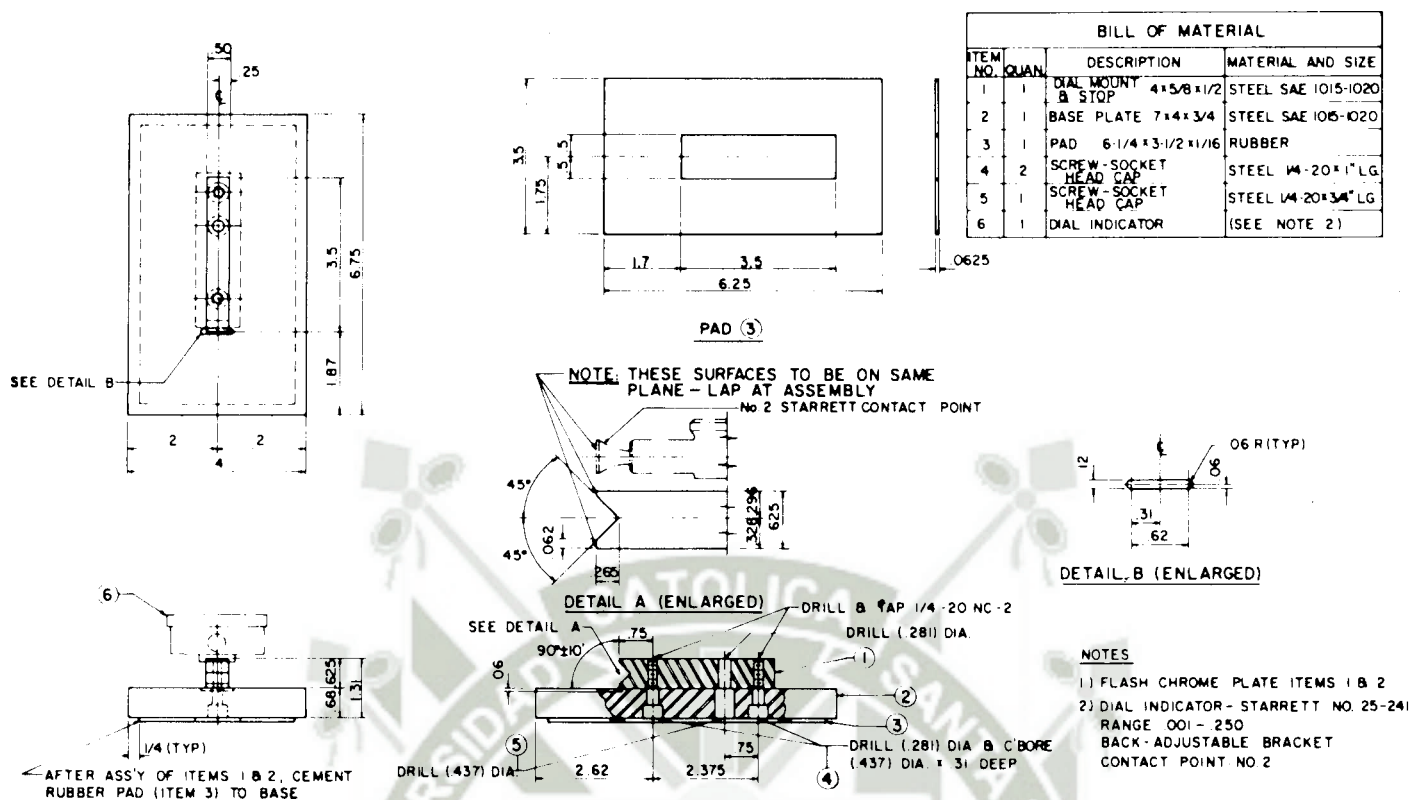
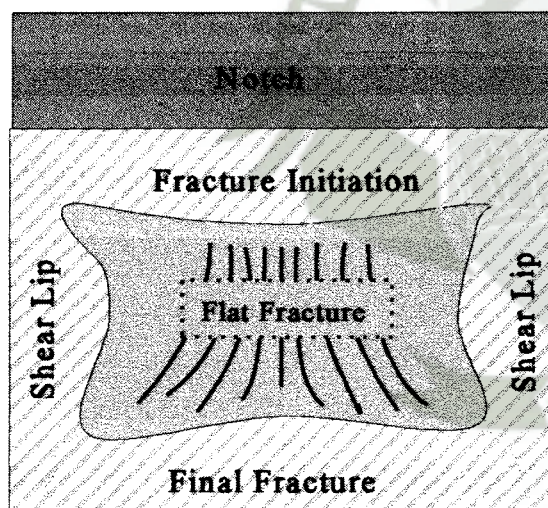


FIG. 9 Assembly and Details for Lateral Expansion Gage



NOTE 1—The shear of ductile fracture regions on the fracture surface include the fracture initiation region, the two shear lips, and the region of final fracture. The flat or radial fracture region is a region of less ductile unstable crack growth.

FIG. 10 Determination of Percent Shear Fracture

each energy level. Except being limited to only two energy levels (by availability of reference specimens), Practice E 691 was followed for the design and analysis of the data, the details

are given in ASTM Research Report NO. RR:E28-1014.⁷

11.2 *Precision*—The *Precision* information given below (in units of J and ft-lbf) is for the average CVN absorbed energy of five test determinations at each laboratory for each material.

Material	Low Energy		High Energy	
	J	ft-lbf	J	ft-lbf
Absorbed Energy	15.9	11.7	96.2	71.0
95 % Repeatability Limit	2.4	1.7	8.3	6.1
95 % Reproducibility Limits	2.7	2.0	9.2	6.8

The terms repeatability and reproducibility limit are used as defined in Practice E 177. The respective standard deviations among test results may be obtained by dividing the above limits by 2.8.

11.3 *Bias*— *Bias cannot be defined* for CVN absorbed energy. The physical simplicity of the pendulum design is complicated by complex energy loss mechanisms within the machine and the specimen. Therefore, there is no absolute standard to which the measured values can be compared.

12. Keywords

12.1 charpy test; fracture appearance; Izod test; impact test; notched specimens; pendulum machine

⁷ Supporting data have been filed at ASTM Headquarters and may be obtained by requesting Research Report E28-1014.

ANNEXES

(Mandatory Information)

A1. GENERAL REQUIREMENTS FOR IMPACT MACHINES

A1.1 *The machine frame* shall be equipped with a bubble level or a machined surface suitable for establishing levelness of the axis of pendulum bearings or, alternatively, the levelness of the axis of rotation of the pendulum may be measured directly. The machine shall be level to within 3:1000 and securely bolted to a concrete floor not less than 150 mm (6 in.) thick or, when this is not practical, the machine shall be bolted to a foundation having a mass not less than 40 times that of the pendulum. The bolts shall be tightened as specified by the machine manufacturer.

A1.2 *A scale or digital display*, graduated in degrees or energy, on which readings can be estimated in increments of 0.25 % of the energy range or less shall be furnished for the machine.

A1.2.1 The scales and digital displays may be compensated for windage and pendulum friction. The error in the scale reading at any point shall not exceed 0.2 % of the range or 0.4 % of the reading, whichever is larger. (See A2.3.8.)

A1.3 *The total friction and windage losses* of the machine during the swing in the striking direction shall not exceed 0.75 % of the scale range capacity, and pendulum energy loss from friction in the indicating mechanism shall not exceed 0.25 % of scale range capacity. See A2.3.8 for friction and windage loss calculations.

A1.4 *The position of the pendulum*, when hanging freely, shall be such that the striker is within 2.5 mm (0.10 in.) from the test specimen. When the indicator has been positioned to read zero energy in a free swing, it shall read within 0.2 % of scale range when the striker of the pendulum is held against the test specimen. The plane of swing of the pendulum shall be perpendicular to the transverse axis of the Charpy specimen anvils or Izod vise within 3:1000.

A1.5 *Transverse play of the pendulum* at the striker shall not exceed 0.75 mm (0.030 in.) under a transverse force of 4 % of the effective weight of the pendulum applied at the center of strike. Radial play of the pendulum bearings shall not exceed 0.075 mm (0.003 in.).

A1.6 *The impact velocity* (tangential velocity) of the pendulum at the center of the strike shall not be less than 3 nor more than 6 m/s (not less than 10 nor more than 20 ft/s).

A1.7 *The height of the center of strike* in the latched position, above its free hanging position, shall be within 0.4 % of the range capacity divided by the supporting force, mea-

sured as described in A2.3.5.1 If windage and friction are compensated for by increasing the height of drop, the height of drop may be increased by not more than 1 %.

A1.8 *The mechanism for releasing the pendulum* from its initial position shall operate freely and permit release of the pendulum without initial impulse, retardation, or side vibration. If the same lever used to release the pendulum is also used to engage the brake, means shall be provided for preventing the brake from being accidentally engaged.

A1.9 *Specimen clearance* is needed to ensure satisfactory results when testing materials of different strengths and compositions. The test specimen shall exit the machine with a minimum of interference. Pendulums used on Charpy machines are of three basic designs, as shown in Fig. A1.1.

A1.9.1 When using a C-type pendulum or a compound pendulum, the broken specimen will not rebound into the pendulum and slow it down if the clearance at the end of the specimen is at least 13 mm (0.5 in.) or if the specimen is deflected out of the machine by some arrangement such as that shown in Fig. A1.1.

A1.9.2 When using the U-type pendulum, means shall be provided to prevent the broken specimen from rebounding against the pendulum (see Fig. A1.1). In most U-type pendulum machines, steel shrouds should be designed and installed to the following requirements: (a) have a thickness of approximately 1.5 mm (0.06 in.), (b) have a minimum hardness of 45 HRC, (c) have a radius of less than 1.5 mm (0.06 in.) at the underside corners, and (d) be so positioned that the clearance between them and the pendulum overhang (both top and sides) does not exceed 1.5 mm (0.06 in.).

NOTE A1.1—In machines where the opening within the pendulum permits clearance between the ends of a specimen (resting on the anvil supports) and the shrouds, and this clearance is at least 13 mm (0.5 in.), the requirements (a) and (d) need not apply.

A1.10 *Charpy Apparatus:*

A1.10.1 Means shall be provided (see Fig. A1.2) to locate and support the test specimen against two anvil blocks in such a position that the center of the notch can be located within 0.25 mm (0.010 in.) of the midpoint between the anvils (see 8.3.2).

A1.10.2 The supports and striker shall be of the forms and dimensions shown in Fig. A1.2. Other dimensions of the pendulum and supports should be such as to minimize interference between the pendulum and broken specimens.

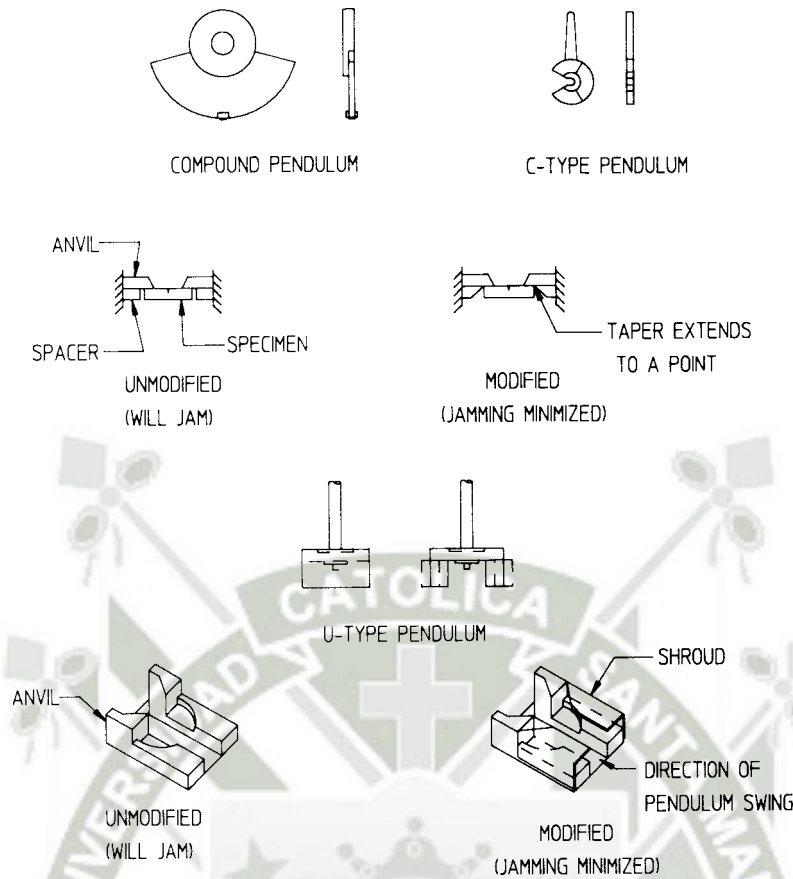


FIG. A1.1 Typical Pendulums and Anvils for Charpy Machines, Shown with Modifications to Minimize Jamming

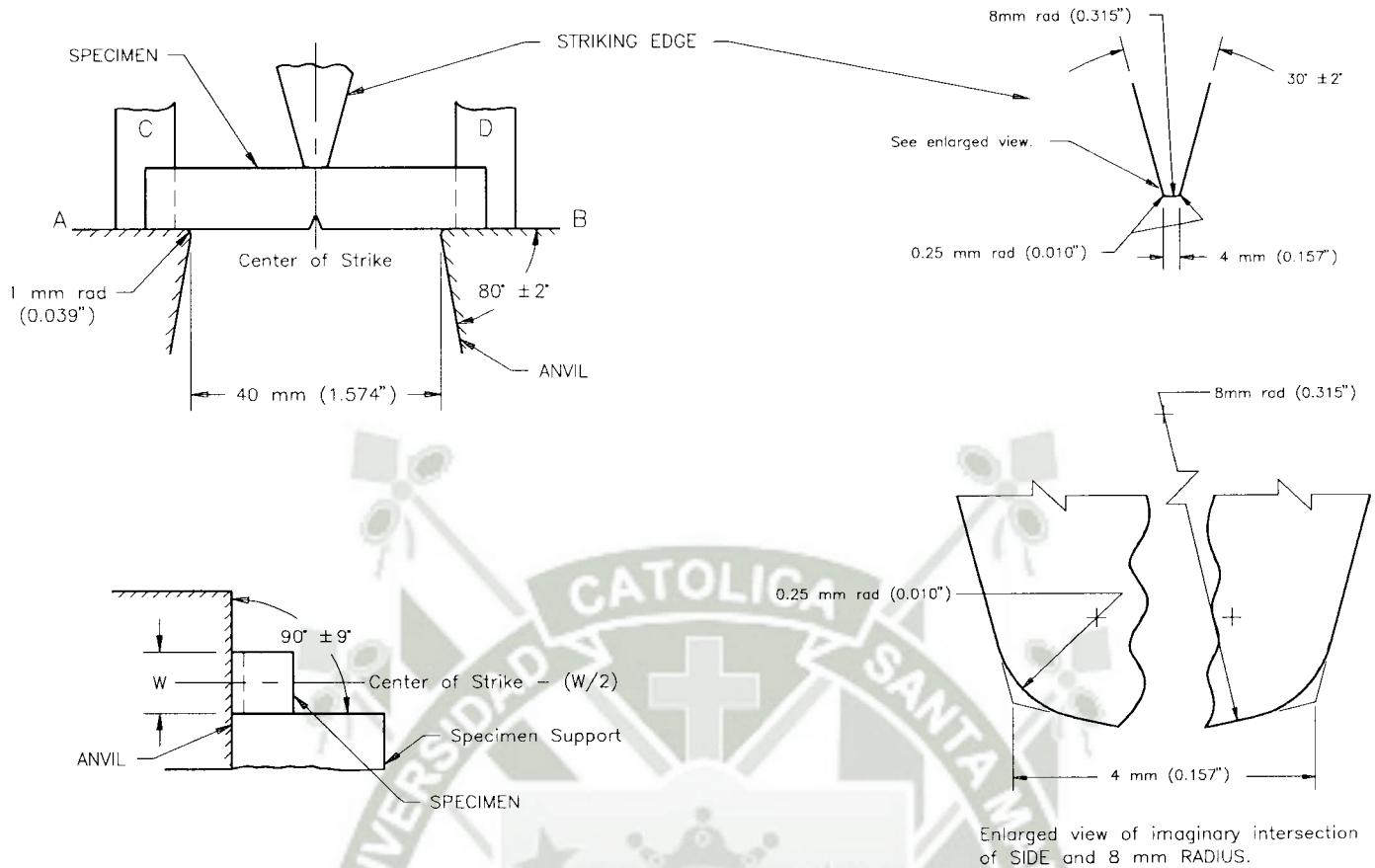
A1.10.3 The center line of the striker shall advance in the plane that is within 0.40 mm (0.016 in.) of the midpoint between the supporting edges of the specimen anvils. The striker shall be perpendicular to the longitudinal axis of the specimen within 5:1000. The striker shall be parallel within 1:1000 to the face of a perfectly square test specimen held against the anvil.

A1.11 Izod Apparatus:

A1.11.1 Means shall be provided (see Fig. A1.3) for clamping the specimen in such a position that the face of the specimen is parallel to the striker within 1:1000. The edges of the clamping surfaces shall be sharp angles of $90 \pm 1^\circ$ with

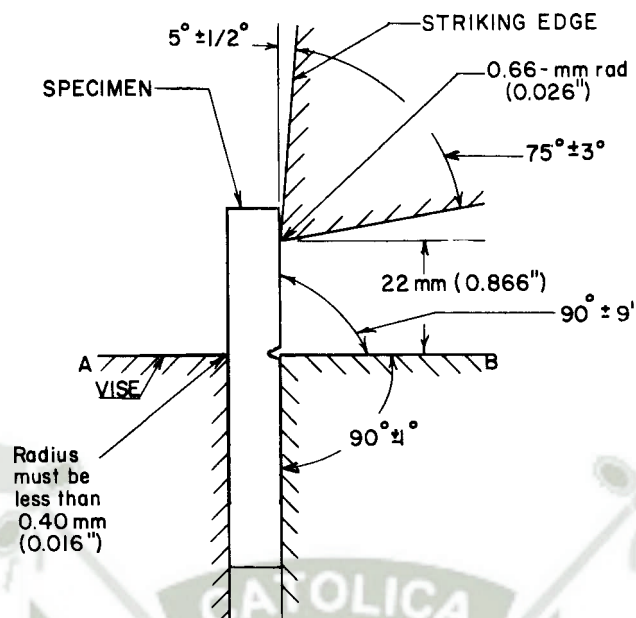
radii less than 0.40 mm (0.016 in.). The clamping surfaces shall be smooth with a 2- μ m (63- μ in.) finish or better, and shall clamp the specimen firmly at the notch with the clamping force applied in the direction of impact. For rectangular specimens, the clamping surfaces shall be flat and parallel within 0.025 mm (0.001 in.). For cylindrical specimens, the clamping surfaces shall be contoured to match the specimen and each surface shall contact a minimum of $\pi/2$ rad (90°) of the specimen circumference.

A1.11.2 The dimensions of the striker and its position relative to the specimen clamps shall be as shown in Fig. A1.3.



All dimensional tolerances shall be ± 0.05 mm (0.002 in.) unless otherwise specified.

FIG. A1.2 Charpy Striking Tup



All dimensional tolerances shall be ± 0.05 mm (0.002 in.) unless otherwise specified.

NOTE 1—The clamping surfaces of A and B shall be flat and parallel within 0.025 mm (0.001 in.).

NOTE 2—Finish on unmarked parts shall be 2 μ m (63 μ in.).

NOTE 3—Striker width must be greater than that of the specimen being tested.

FIG. A1.3 Izod (Cantilever-Beam) Impact Test

A2. VERIFICATION OF PENDULUM IMPACT MACHINES

A2.1 The verification of impact machines has two parts: direct verification, which consists of inspecting the machine to ensure that the requirements of this annex and Annex A1 are met, and indirect verification, which entails the testing of verification specimens.

A2.1.1 Izod machines are verified by direct verification only.

A2.1.2 Charpy machines shall be verified annually. Data is valid only when produced within 365 days following the date of the most recent successful verification test. Charpy machines shall also be verified immediately after replacing parts that may affect the measured energy, after making repairs or adjustments, after they have been moved, or whenever there is reason to doubt the accuracy of the results, without regard to the time interval. These restrictions include cases where parts, which may affect the measured energy, are removed from the machine and then reinstalled without modification (for example, when the striker or anvils are removed to permit use of a different striker or set of anvils and then are reinstalled). It is not intended that parts not subjected to wear (such as pendulum and scale linearity) are to be directly verified each year unless a problem is evident. Only the items cited in A2.2 are required to be inspected annually. Other parts of the machine shall be directly verified at least once, when the machine is new, or when parts are replaced.

A2.2 Direct Verification of Parts Requiring Annual Inspection:

A2.2.1 Inspect the specimen supports, anvils, and striker and replace any of these parts that show signs of wear. A straight edge or radius gage can be used to discern differences between the used and unused portions of these parts to help identify a worn condition (see Note A2.1).

NOTE A2.1—To measure the anvil or striker radii, the recommended procedure is to make a replica (casting) of the region of interest and measure cross sections of the replica. This can be done with the anvils and striker in place on the machine or removed from the machine. Make a dam with cardboard and tape surrounding the region of interest, then pour a low-shrinkage casting compound into the dam (silicon rubber casting compounds work well). Allow the casting to cure, remove the dam, and slice cross sections through the region of interest with a razor. Use these cross sections to make radii measurements on optical comparators or other instruments.

A2.2.2 Ensure the bolts that attach the anvils and striker to the machine are tightened to the manufacturer's specifications.

A2.2.3 Verify that the shrouds, if applicable, are properly installed (see A1.9.2).

A2.2.4 The pendulum release mechanism, which releases the pendulum from its initial position, shall comply with A1.8.

A2.2.5 Check the level of the machine in both directions (see A1.1).

A2.2.6 Check that the foundation bolts are tightened to the manufacturer's specifications.

NOTE A2.2—Expansion bolts or fasteners with driven in inserts shall not be used for foundations. These fasteners will work loose and/or tighten up against the bottom of the machine indicating a false high torque value when the bolts are tightened.

A2.2.7 Check the indicator zero and the friction loss of the machine as described in 8.1.

A2.3 *Direct Verification of Parts to be Verified at Least Once:*

A2.3.1 Specimen anvils and supports or Izod vises shall conform to the dimensions shown in Fig. A1.2 or Fig. A1.3.

NOTE A2.3—The impact machine will be inaccurate to the extent that some energy is used in deformation or movement of its component parts or of the machine as a whole; this energy will be registered as used in fracturing the specimen.

A2.3.2 The striker shall conform to the dimensions shown in Fig. A1.2 or Fig. A1.3. The mounting surfaces must be clean and free of defects that would prevent a good fit. Check that the striker complies with A1.10.3 (for Charpy tests) or A1.11.1 (for Izod tests).

A2.3.3 The pendulum alignment shall comply with A1.4 and A1.5. If the side play in the pendulum or the radial play in the bearings exceeds the specified limits, adjust or replace the bearings.

A2.3.4 *Determine the Center of Strike*—For Charpy machines the center of strike of the pendulum is determined using a half-width specimen (10 by 5 mm) in the test position. With the striker in contact with the specimen, a line marked along the top edge of the specimen on the striker will indicate the center of strike. For Izod machines, the center of strike may be considered to be the contact line when the pendulum is brought into contact with a specimen in the normal testing position.

A2.3.5 *Determine the Potential Energy*—The following procedure shall be used when the center of strike of the pendulum is coincident with the radial line from the centerline of the pendulum bearings (herein called the axis of rotation) to the center of gravity (see Appendix X2). If the center of strike is more than 1.0 mm (0.04 in.) from this line, suitable corrections in elevation of the center of strike must be made in A2.3.8.1 and A2.3.9, so that elevations set or measured correspond to what they would be if the center of strike were on this line. The potential energy of the system is equal to the height from which the pendulum falls, as determined in A2.3.5.2, times the supporting force, as determined in A2.3.5.1

A2.3.5.1 To measure the supporting force, support the pendulum horizontally to within 15:1000 with two supports, one at the bearings (or center of rotation) and the other at the center of strike on the striker (see Fig. A2.1). Then arrange the support at the striker to react upon some suitable weighing device such as a platform scale or balance, and determine the weight to within 0.4 %. Take care to minimize friction at either point of support. Make contact with the striker through a round rod crossing the edge at a 90° angle. The supporting force is the scale reading minus the weights of the supporting rod and any shims that may be used to maintain the pendulum in a horizontal position.

A2.3.5.2 Determine the height of pendulum drop for compliance with the requirement of A1.7. On Charpy machines determine the height from the top edge of a half-width (or

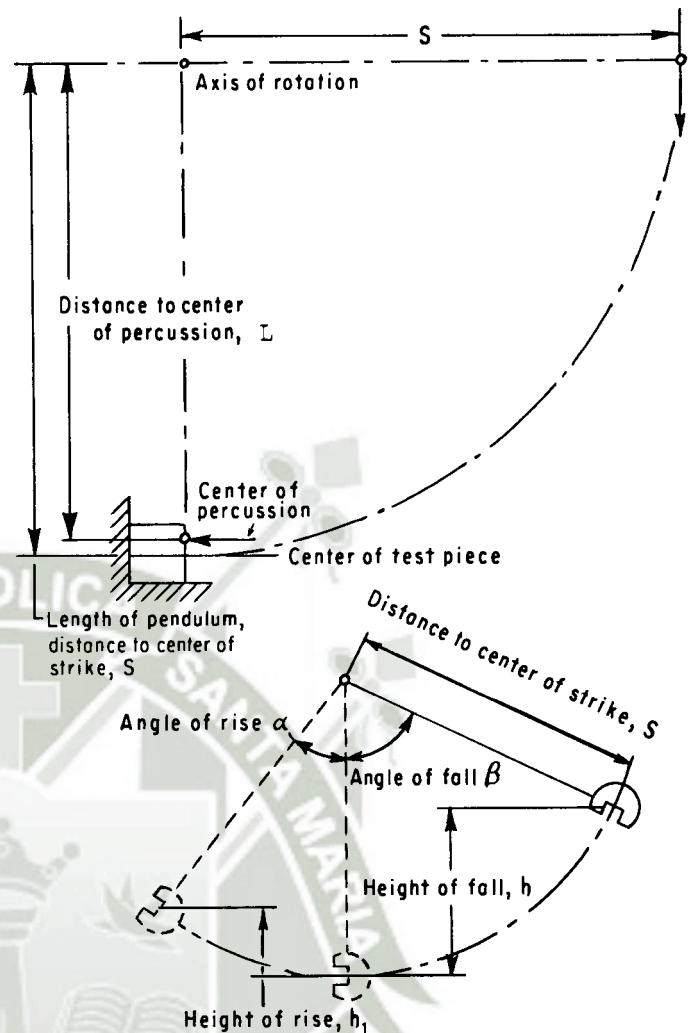


FIG. A2.1 Dimensions for Calculations

center of a full-width) specimen to the elevated position of the center of strike to 0.1 %. On Izod machines determine the height from a distance 22.66 mm (0.892 in.) above the vise to the release position of the center of strike to 0.1 %. The height may be determined by direct measurement of the elevation of the center of strike or by calculation from the change in angle of the pendulum using the following formulas (see Fig. A2.1):

$$h = S(1 - \cos(\beta)) \quad (A2.1)$$

$$h_1 = S(1 - \cos(\alpha)) \quad (A2.2)$$

where

h = initial elevation of the striker, m (ft),

S = length of the pendulum distance to the center of strike, m (ft),

β = angle of fall,

h_1 = height of rise, m (ft), and

α = angle of rise.

A2.3.6 Determine the impact velocity, $[v]$, of the machine, neglecting friction, by means of the following equation:

$$v = \sqrt{2gh} \quad (A2.3)$$

where:

v = velocity, m/s (ft/s),

g = acceleration of gravity, 9.81 m/s² (32.2 ft/s²), and

h = initial elevation of the striker, m (ft).

A2.3.7 The center of percussion shall be at a point within 1 % of the distance from the axis of rotation to the center of strike in the specimen, to ensure that minimum force is transmitted to the point of rotation. Determine the location of the center of percussion as follows:

A2.3.7.1 Using a stop watch or some other suitable time-measuring device, capable of measuring time to within 0.2 s, swing the pendulum through a total angle not greater than 15° and record the time for 100 complete cycles (to and fro). The period of the pendulum then, is the time for 100 cycles divided by 100.

A2.3.7.2 Determine the center of percussion by means of the following equation:

$$L = \frac{gp^2}{4\pi^2} \quad (\text{A2.4})$$

where:

L = distance from the axis to the center of percussion, m (ft),

g = local gravitational acceleration (accuracy of one part in one thousand), m/s² (ft/s²),

π = 3.1416, and

p = period of a complete swing (to and fro), s.

A2.3.8 *Determination of the Friction Losses*—The energy loss from friction and windage of the pendulum and friction in the recording mechanism, if not corrected, will be included in the energy loss attributed to breaking the specimen and can result in erroneously high measurements of absorbed energy. For machines recording in degrees, frictional losses are usually not compensated for by the machine manufacturer, whereas in machines recording directly in energy, they are usually compensated for by increasing the starting height of the pendulum. Determine energy losses from friction as follows:

A2.3.8.1 Without a specimen in the machine, and with the indicator at the maximum energy reading, release the pendulum from its starting position and record the energy value indicated. This value should indicate zero energy if frictional losses have been corrected by the manufacturer. Now raise the pendulum slowly until it just contacts the indicator at the value obtained in the free swing. Secure the pendulum at this height and determine the vertical distance from the center of strike to the top of a half-width specimen positioned on the specimen rest supports within 0.1 % (see A2.3.5). Determine the supporting force as in A2.3.5.1 and multiply by this vertical distance. The difference in this value and the initial potential energy is the total energy loss in the pendulum and indicator combined. Without resetting the pointer, repeatedly release the pendulum from its initial position until the pointer shows no further movement. The energy loss determined by the final position of the pointer is that due to the pendulum alone. The frictional loss in the indicator alone is then the difference between the combined indicator and pendulum losses and those due to the pendulum alone.

A2.3.9 The indicating mechanism accuracy shall be

checked to ensure that it is recording accurately over the entire range (see A1.2.1). Check it at graduation marks corresponding to approximately 0, 10, 20, 30, 50, and 70 % of each range. With the striker marked to indicate the center of strike, lift the pendulum and set it in a position where the indicator reads, for example, 13 J (10 ft·lbf). Secure the pendulum at this height and determine the vertical distance from the center of strike to the top of a half-width specimen positioned on the specimen supports within 0.1 % (see A2.3.5). Determine the residual energy by multiplying the height of the center of strike by the supporting force, as described in A2.3.5.1. Increase this value by the total frictional and windage losses for a free swing (see A2.3.8.1) multiplied by the ratio of the angle of swing of the pendulum from the latch to the energy value being evaluated to the angle of swing of the pendulum from the latch to the zero energy reading. Subtract the sum of the residual energy and proportional frictional and windage loss from the potential energy at the latched position (see A2.3.5). The indicator shall agree with the energy calculated within the limits of A1.2.1. Make similar calculations at other points of the scale. The indicating mechanism shall not overshoot or drop back with the pendulum. Make test swings from various heights to check visually the operation of the pointer over several portions of the scale.

NOTE A2.4—Indicators that indicate in degrees shall be checked using the above procedure. Degree readings from the scale shall be converted to energy readings using the conversion formula or table normally used in testing. In this way the formula or table can also be checked for windage and friction corrections.

A2.4 Indirect Verification:

A2.4.1 Indirect verification requires the testing of specimens with certified values to verify the accuracy of Charpy impact machines.

A2.4.1.1 Verification specimens with certified values are produced at low (12 to 20 J), high (88 to 115 J), and super-high (210 to 230 J) energy levels. To meet the verification requirements, the average value determined for a set of verification specimens at each energy level tested shall correspond to the certified values of the verification specimens within 1.4 J (1.0 ft·lbf) or 5.0 %, whichever is greater.

A2.4.1.2 Verification specimens are available from the National Institute of Standards and Technology (NIST) through the Standard Reference Materials Program (see Annex A3). Other sources of verification specimens may be used provided they conform to Practice E 1271 and their reference value has been established on the three reference machines owned, maintained, and operated by NIST in Boulder, CO.

NOTE A2.5—Verification specimens are available for Charpy machines only. Detailed information pertaining to the availability of verification specimens is given in Appendix X3.

A2.4.2 The verified range of a Charpy impact machine is described with reference to the lowest and highest energy specimens tested on the machine. These values are determined from tests on sets of verification specimens at two or more levels of absorbed energy, except in the case where a Charpy machine has a maximum capacity that is too low for two energy levels to be tested. In this case, one level of absorbed energy can be used for indirect verification.

A2.4.3 Determine the usable range of the impact testing machine prior to testing verification specimens. The usable range of an impact machine is dependent upon the resolution of the scale or readout device at the low end and the capacity of the machine at the high end.

A2.4.3.1 The resolution of the scale or readout device establishes the lower limit of the usable range for the machine. The lower limit is equal to 25 times the resolution of the scale or readout device at 15J (11 ft-lbf).

NOTE A2.6—On analog scales, the resolution is the smallest change in energy that can be discerned on the scale. This is usually $\frac{1}{4}$ to $\frac{1}{5}$ of the difference between 2 adjacent marks on the scale at the 15J (11 ft-lbf) energy level.

NOTE A2.7—Digital scales usually incorporate devices, such as digital encoders, with a fixed discrete angular resolution. The resolution of these types of readout devices is the smallest change in energy that can be consistently measured at 15J. The resolution of these types of devices is usually not a change in the last digit shown on the display because resolution is a function of the angular position of the pendulum and changes throughout the swing. For devices which incorporate a verification mode in which a live readout of absorbed energy is available, the pendulum may be moved slowly in the area of 15 J to observe the smallest change in the readout device (the resolution).

A2.4.3.2 The upper limit of the usable range of the machine is equal to 80 % of the capacity of the machine.

A2.4.4 Only verification specimens that are within the usable range of the impact machine shall be tested. To verify the machine over its full usable range, test the lowest and highest energy levels of verification specimens commercially available that are within the machines' usable range. If the ratio of the highest and lowest certified values tested is greater than four, testing of a third set of intermediate energy specimens is required (if the specimens are commercially available).

NOTE A2.8—Use the upper bound of the energy range given for the low, high, and super-high verification specimens (20, 115, and 230 J respectively to determine the highest energy level verification specimens

that can be tested. Alternately, use the lower bound of the energy range given for the verification specimens to determine the minimum energy level for testing.

A2.4.4.1 If the low energy verification specimens were not tested (tested only high and super-high), the lower limit of the verified range shall be one half the energy of the lowest energy verification set tested.

NOTE A2.9—For example, if the certified value of the high energy specimens tested was 100J, the lower limit would be 50J.

A2.4.4.2 If the highest energy verification specimens available for a given Charpy machine capacity have not been tested, the upper value of the verified range shall be 1.5 times the certified value of the highest energy specimens tested.

NOTE A2.10—For example, if the machine being tested has a maximum capacity of 325 J (240 ft-lbf) and only low and high energy verification specimens were tested, the upper bound of the verified range would be 150 J ($100 \text{ J} * 1.5 = 150 \text{ J}$), assuming that the high energy samples tested had a certified value of 100J. To verify this machine over its full range, low, high, and super-high verification specimens would have to be tested, because super-high verification specimens can be tested on a machine with a 325J capacity (80 % of 325J is 260J, and the certified value of super-high specimens never exceed 230J). See Table A2.1.

TABLE A2.1 Verified Ranges for Various Machine Capacities and Verification Specimens Tested^A

Machine Capacity J	Resolution J	Usable Range J	Verification Specimens Tested			Verified Range J
			Low	High	Super-high	
80	0.10	2.5 to 64	X	...	...	2.5 to 64
160	0.20	5.0 to 128	X	X	...	5.0 to 128
325	0.25	6.25 to 260	X	X	X	6.25 to 260
400	0.30	7.5 to 320	...	X	X	50 to 320
400	0.15	3.75 to 320	X	X	...	3.75 to 150
400	0.15	3.75 to 320	X	X	X	3.75 to 320

^AIn these examples, the high energy verification specimens are assumed to have a certified value of 100J.

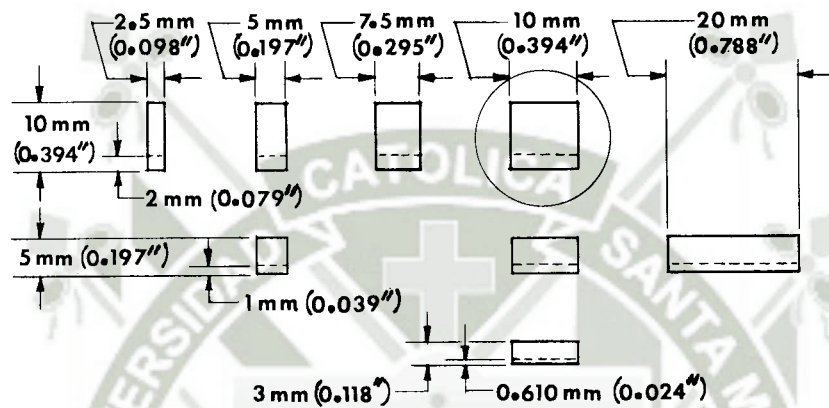
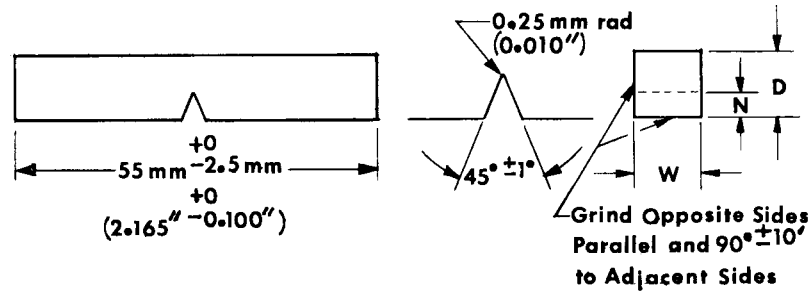
A3. ADDITIONAL IMPACT TEST SPECIMEN CONFIGURATIONS

A3.1 *Sub-Size Specimen*—When the amount of material available does not permit making the standard impact test specimens shown in Figs. 1 and 2, smaller specimens may be used, but the results obtained on different sizes of specimens cannot be compared directly (X1.3). When Charpy specimens other than the standard are necessary or specified, it is recommended that they be selected from Fig. A3.1.

A3.2 *Supplementary Specimens*—For economy in preparation of test specimens, special specimens of round or rectangular cross section are sometimes used for cantilever beam test.

These are shown as Specimens X, Y, and Z in Figs. A3.2 and A3.3. Specimen Z is sometimes called the Philpot specimen, after the name of the original designer. For hard materials, the machining of the flat surface struck by the pendulum is sometimes omitted. Types Y and Z require a different vise from that shown in Fig. A1.3, each half of the vise having a semi-cylindrical recess that closely fits the clamped portion of the specimen. As previously stated, the results cannot be reliably compared with those obtained using specimens of other sizes or shapes.

On subsize specimens the length, notch angle, and notch radius are constant (see Fig. 1); depth (D), notch depth (N), and width (W) vary as indicated below.

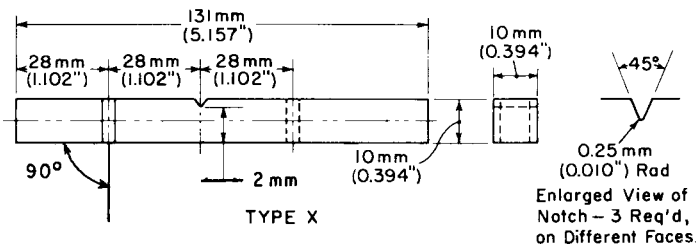


NOTE 1—Circled specimen is the standard specimen (see Fig. 1).

NOTE 2—Permissible variations shall be as follows:

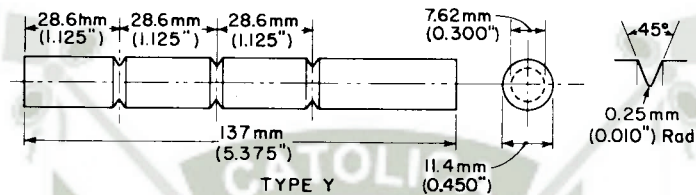
Cross-section dimensions	$\pm 1\%$ or ± 0.075 mm (0.003 in.), whichever is smaller
Radius of notch	± 0.025 mm (0.001 in.)
Depth of notch	± 0.025 mm (0.001 in.)
Finish requirements	2 μ m (63 μ in.) on notched surface and opposite face; 4 μ m (125 μ in.) on other two surfaces

FIG. A3.1 Charpy (Simple-Beam) Subsize (Type A) Impact Test Specimens



NOTE 1—Permissible variations for type X specimens shall be as follows:

Notch length to edge	$90 \pm 2^\circ$
Adjacent sides shall be at	$90^\circ \pm 10 \text{ min}$
Notch depth of Type X specimen	$\pm 0.025 \text{ mm } (\pm 0.001 \text{ in.})$

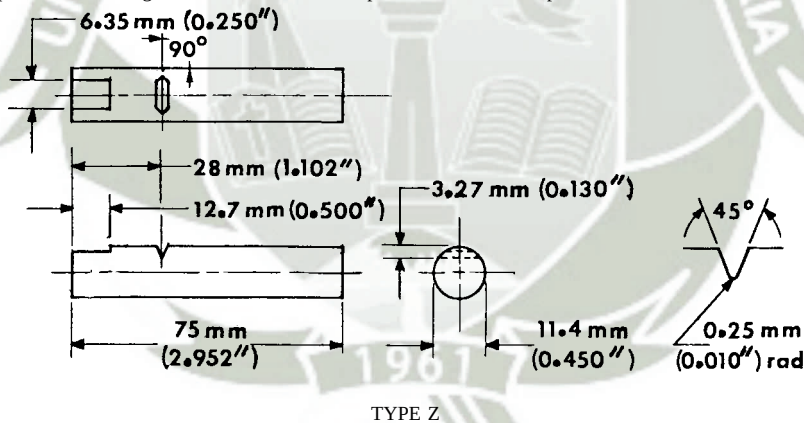


NOTE 2—Permissible variations for both specimens shall be as follows:

Cross-section dimensions	$\pm 0.025 \text{ mm } (\pm 0.001 \text{ in.})$
Lengthwise dimensions	$+0, -2.5 \text{ mm } (+0, -0.100 \text{ in.})$
Angle of notch	$\pm 1^\circ$
Radius of notch	$\pm 0.025 \text{ mm } (\pm 0.001 \text{ in.})$
Notch diameter of Type Y specimen	$\pm 0.025 \text{ mm } (\pm 0.001 \text{ in.})$

FIG. A3.2 Izod (Cantilever-Beam) Impact Test Specimens, Types X and Y

The flat shall be parallel to the longitudinal centerline of the specimen and shall be parallel to the bottom of the notch within 2:1000.



NOTE 1—Permissible variations shall be as follows:

Notch length to longitudinal centerline	$90 \pm 2^\circ$
Cross-section dimensions	$\pm 0.025 \text{ mm } (\pm 0.001 \text{ in.})$
Length of specimen	$+0, -2.5 \text{ mm } (+0 -0.100 \text{ in.})$
Angle of notch	$\pm 1^\circ$
Radius of notch	$\pm 0.025 \text{ mm } (\pm 0.001 \text{ in.})$
Notch depth	$\pm 0.025 \text{ mm } (.130 \pm 0.001 \text{ in.})$

FIG. A3.3 Izod (Cantilever-Beam) Impact Test Specimen (Philpot), Type Z

A4. PRECRACKING CHARPY V-NOTCH IMPACT SPECIMENS

A4.1 Scope

A4.1.1 This annex describes the procedure for the fatigue precracking of standard Charpy V-notch (CVN) impact speci-

mens. The annex provides information on applications of precracked Charpy impact testing and fatigue-precracking procedures.

A4.2 Significance and Use

A4.2.1 Section 4 also applies to precracked Charpy V-notch impact specimens.

A4.2.2 It has been found that fatigue-precracked CVN specimens generally result in better correlations with other impact toughness tests such as Test Method E 604 and with fracture toughness tests such as Test Method E 399 than the standard V-notch specimens (3,4,5,6,7,8). Also, the sharper notch yields more conservative estimations of the notched impact toughness and the transition temperature of the material (9,10).

A4.3 Apparatus

A4.3.1 The equipment for fatigue cracking shall be such that the stress distribution is symmetrical through the specimen thickness; otherwise, the crack will not grow uniformly. The stress distribution shall also be symmetrical about the plane of the prospective crack; otherwise the crack will deviate unduly from that plane and the test result will be significantly affected.

A4.3.2 The recommended fixture to be used is shown in Fig. A4.1. The nominal span between support rollers shall be $4D \pm 0.2D$, where D is the depth of the specimen. The diameter of the rollers shall be between $D/2$ and D . The radius of the ram shall be between $D/8$ and D . This fixture is designed to minimize frictional effects by allowing the support rollers to rotate and move apart slightly as the specimen is loaded, thus permitting rolling contact. The rollers are initially positioned

against stops that set the span length and are held in place by low-tension springs (such as rubber bands). Fixtures, rolls, and ram should be made of high hardness (greater than 40 HRC) steels.

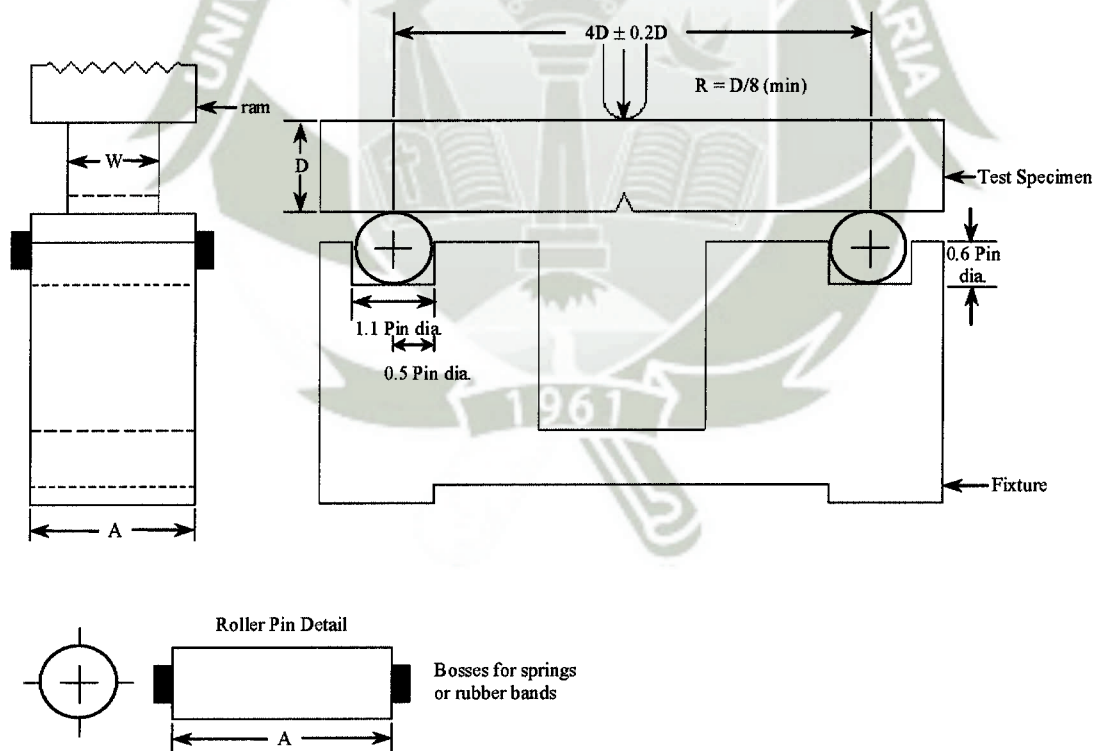
A4.4 Test Specimens

A4.4.1 The dimensions of the precracked Charpy specimen are essentially those of type-A shown in Fig. A4.2. The notch depth plus the fatigue crack extension length shall be designated as N . When the amount of material available does not permit making the standard impact test specimen, smaller specimens may be made by reducing the width; but the results obtained on different sizes of specimens cannot be compared directly (see X1.3).

A4.4.2 The fatigue precracking is to be done with the material in the same heat-treated condition as that in which it will be impact tested. No intermediate treatments between fatigue precracking and testing are allowed.

A4.4.3 Because of the relatively blunt machined V-notch in the Charpy impact specimen, fatigue crack initiation can be difficult. Early crack initiation can be promoted by pressing or milling a sharper radius into the V-notch. Care must be taken to ensure that excessive deformation at the crack tip is avoided.

A4.4.4 It is advisable to mark two pencil lines on each side of the specimen normal to the anticipated paths of the surface traces of the fatigue crack. The first line should indicate the point at which approximately two-thirds of the crack extension



L = length = 55 mm +0, -2.5 mm,
 D = depth = 10 mm $\pm$ 0.075 mm,
 W = variable width (see A3.1),
 N = notch depth = 2 mm $\pm$ 0.025 mm, included angle of notch = $45^\circ \pm 1^\circ$, and
radius of notch = 0.25 mm $\pm$ 0.025 m.

FIG. A4.1 Fatigue Precracking-Fixture Design

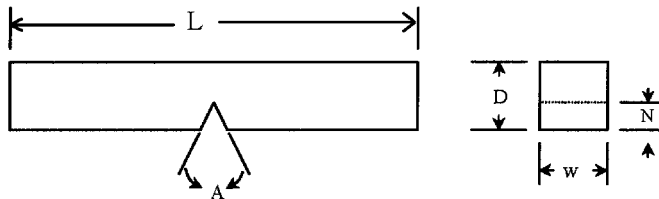


FIG. A4.2 Charpy (Simple-Beam, type A) Impact Test Specimen

has been accomplished. At this point, the stress intensity applied to the specimen should be reduced. The second line should indicate the point of maximum crack extension. At this point, fatigue precracking should be terminated.

A4.5 Fatigue Precracking Procedure

A4.5.1 Set up the test fixture so that the line of action of the applied load shall pass midway between the support roll center within 1 mm. Measure the span to within 1 % of the nominal length. Locate the specimen with the crack tip midway between the rolls within 1 mm of the span, and square to the roll axes within 2°.

A4.5.2 Select the initial loads used during precracking so that the remaining ligament remains undamaged by excessive plasticity. If the load cycle is maintained constant, the maximum K (stress intensity) and the K range will increase with crack length; care must be taken to ensure that the maximum K value is not exceeded to prevent excessive plastic deformation at the crack tip. This is done by continually shedding the load as the fatigue crack extends. The maximum load to be used at any instant can be calculated from Eq A4.1 and A4.2 while the minimum load should be kept at 10 % of the maximum. Eq A4.1 relates the maximum load to a stress intensity (K) value for the material that will ensure an acceptable plastic-zone size at the crack tip. It is also advisable to check this maximum load to ensure that it is below the limit load for the material using Eq A4.2. When the most advanced crack trace has almost reached the first scribed line corresponding to approximately two-thirds of the final crack length, reduce the maximum load so that $0.6 K_{\max}$ is not exceeded.

A4.5.3 Fatigue cycling is begun, usually with a sinusoidal waveform and near to the highest practical frequency. There is no known marked frequency effect on fatigue precrack formation up to at least 100 Hz in the absence of adverse environments; however, frequencies of 15 to 30 Hz are typically used. Carefully monitor the crack growth optically. A low-power magnifying glass is useful in this regard. If crack growth is not observed on one side when appreciable growth is observed on the first, stop fatigue cycling to determine the cause and remedy for the behavior. Simply turning the specimen around in relation to the fixture will often solve the problem. When the most advanced crack trace has reached the halfway mark, turn the specimen around in relation to the fixture and complete the fatigue cycling. Continue fatigue cycling until the surface traces on both sides of the specimen indicate that the desired overall length of notch plus crack is reached. The fatigue crack should extend at least 1 mm beyond the tip of the V-notch but no more than 3 mm. A fatigue crack extension of approximately 2 mm is recommended.

A4.5.4 When fatigue cracking is conducted at a temperature T_1 and testing will be conducted at a different temperature T_2 ,

and $T_1 > T_2$, the maximum stress intensity must not exceed 60 % of the $K_{\max}$ of the material at temperature T_1 multiplied by the ratio of the yield stresses of the material at the temperatures T_1 and T_2 , respectively. Control of the plastic-zone size during fatigue cracking is important when the fatigue cracking is done at room temperature and the test is conducted at lower temperatures. In this case, the maximum stress intensity at room temperature must be kept to low values so that the plastic-zone size corresponding to the maximum stress intensity at low temperatures is smaller.

A4.6 Calculation

A4.6.1 Specimens shall be precracked in fatigue at load values that will not exceed a maximum stress intensity, $K_{\max}$, or three-point bend specimens use:

$$P_{\max} = [K_{\max} * W * D^{3/2}] / [S * f(N/D)] \quad (A4.1)$$

where:

- $P_{\max}$ = maximum load to be applied during precracking,
- $K_{\max}$ = maximum stress intensity = $\sigma_{ys} * (2 * \pi * r_y)^{1/2}$, where r_y is the radius of the induced plastic zone size which should be less than or equal to 0.5 mm,
- D = specimen depth,
- W = specimen width,
- S = span, and
- $f(N/D)$ = geometrical factor (see Table A4.1).

A4.6.2 See the appropriate section of Test Method E 399 for the $f(N/D)$ calculation. Table A4.1 contains calculated values for $f(N/D)$ for CVN precracking. Eq A4.2 should be used to ensure that the loads used in fatigue cracking are well below the calculated limit load for the material.

TABLE A4.1 Calculations of $f(N/D)$

N (mm)	D (mm)	N/D	f(N/D)
2.00	10.00	0.20	1.17
2.10	10.00	0.21	1.21
2.20	10.00	0.22	1.24
2.30	10.00	0.23	1.27
2.40	10.00	0.24	1.31
2.50	10.00	0.25	1.34
2.60	10.00	0.26	1.37
2.70	10.00	0.27	1.41
2.80	10.00	0.28	1.45
2.90	10.00	0.29	1.48
3.00	10.00	0.30	1.52
3.10	10.00	0.31	1.56
3.20	10.00	0.32	1.60
3.30	10.00	0.33	1.64
3.40	10.00	0.34	1.69
3.50	10.00	0.35	1.73
3.60	10.00	0.36	1.78
3.70	10.00	0.37	1.83
3.80	10.00	0.38	1.88
3.90	10.00	0.39	1.93
4.00	10.00	0.40	1.98
4.10	10.00	0.41	2.04
4.20	10.00	0.42	2.10
4.30	10.00	0.43	2.16
4.40	10.00	0.44	2.22
4.50	10.00	0.45	2.29
4.60	10.00	0.46	2.35
4.70	10.00	0.47	2.43
4.80	10.00	0.48	2.50
4.90	10.00	0.49	2.58
5.00	10.00	0.50	2.66

$$P_L = (4/3) * [D * (D - N)^2 * \sigma_{ys}] / S \quad (A4.2)$$

where:

P_L = limit load for the material.

A4.7 Crack Length Measurement

A4.7.1 After fracture, measure the initial notch plus fatigue crack length, N , to the nearest 1 % at the following three positions: at the center of the crack front and midway between the center and the intersection of the crack front with the specimen surfaces. Use the average of these three measurements as the crack length.

A4.7.2 If the difference between any two of the crack length measurements exceeds 10 % of the average, or if part of the crack front is closer to the machine notch root than 5 % of the

average, the specimen should be discarded. Also, if the length of either surface trace of the crack is less than 80 % of the average crack length, the specimen should be discarded.

A4.8 Report

A4.8.1 Report the following information for each specimen tested: type of specimen used (and size if not the standard size), test temperatures, and energy absorption. Report the average precrack length in addition to these Test Method E 23 requirements.

A4.8.2 The following information may be provided as supplementary information: lateral expansion, fracture appearance, and also, it would probably be useful to report energy absorption normalized in some manner.

A5. SPECIMEN ORIENTATION

A5.1 Designation of Specimen Axis:

A5.1.1 The L-axis is coincident with the main direction of grain flow due to processing. This axis is usually referred to as the longitudinal direction (see Fig. A5.1, Fig. A5.2, and Fig. A5.3).

A5.1.2 The S-axis is coincident with the direction of the main working force. This axis is usually referred to as the short-transverse-direction.

A5.1.3 The T-axis is normal to the L- and S-axes. This axis is usually referred to as the transverse direction.

A5.1.4 Specimens parallel to the surface of wrought products, processed with the same degree of homogenous deformation along the L- and T axes may be called T specimens.

A5.1.5 Specimens normal to the uniform grain flow of wrought products (or grain growth in cast products), whose grain flow is exclusively in one direction, so that T- and S specimens are equivalent, may be called S specimens.

A5.2 Designation of Notch Orientation:

A5.2.1 The notch orientation is designated by the direction

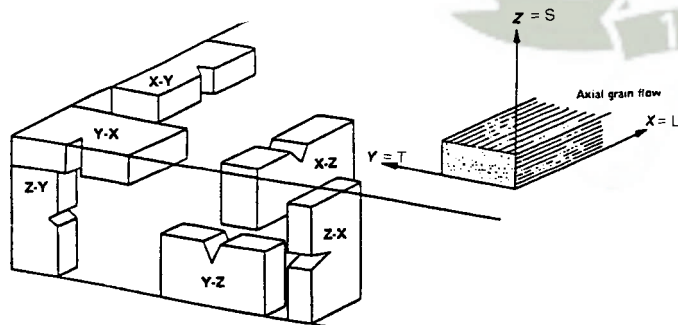


FIG. A5.1 Fracture Planes Along Principal Axes

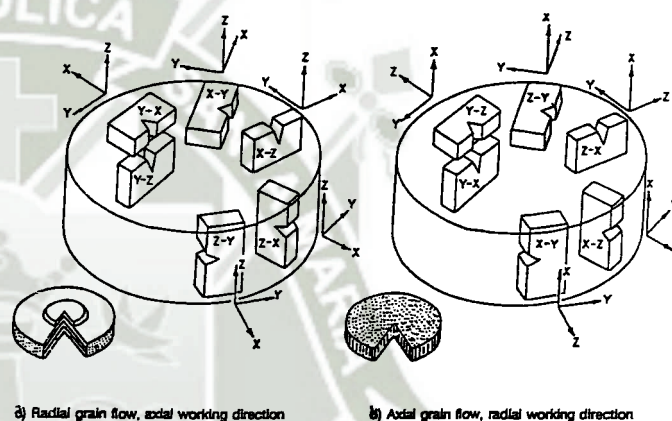


FIG. A5.2 Fracture Planes—Cylindrical Sections

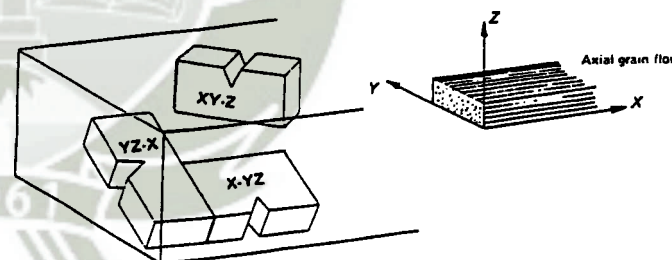


FIG. A5.3 Fracture Planes not Along Principal Axes

in which fracture propagates. This letter is separated from the specimen-axis designation by a hyphen. In unique cases (Fig. A5.3), when fracture propagates across two planes, two letters are required to designate notch orientation.

A6. DETERMINATION OF THE PROPORTION OF SHEAR FRACTURE SURFACE

A6.1 These fracture-appearance methods are based on the concept that 100% shear (ductile) fracture occurs above the transition-temperature range and cleavage (brittle) fracture occurs below the range. This concept appears to be appropriate, at least for body-centered-cubic iron-based alloys that undergo a distinct ductile to brittle transition, but interpretation is complicated in materials which exhibit mixed mode fracture during unstable crack growth. In the transition-temperature range, fracture is initiated at the root of the notch by fibrous tearing. A short distance from the notch, unstable crack growth occurs as the fracture mechanism changes to cleavage or mixed mode mechanism, which often results in distinct radial markings in the central portion of the specimen (indicative of fast, unstable fracture). After several microseconds the unstable crack growth arrests. Final fracture occurs at the remaining ligament and at the sides of the specimen in a ductile manner. As shear-lips are formed at the sides of the specimen, the plastic hinge at the remaining ligament ruptures. In the ideal case, a "picture frame" of fibrous (ductile) fracture surrounds a relatively flat area of cleavage (brittle) fracture.

The five methods used below may be used to determine the percentage of ductile fracture on the surface of impact specimens. It is recommended that the user qualitatively characterize the fracture mode of the flat fracture zone, and provide a description of how the shear measurements were made. The

accuracy of the methods are grouped in order of increasing precision.

NOTE A6.1—Round robin data (five U.S. companies, 1990) estimates of the percent shear for five quenched and tempered 8219 steels and four microalloyed 1040 steels indicated the following: (1) results using method A6.1.1 systematically underestimated the percent shear (compared with method A6.1.4), (2) the error using method A6.1.2 was random and, (3) The typical variation in independent measurements using method A6.1.4 was on the order of 5 to 10 % for microalloyed 1040 steels.

A6.1.1 Measure the length and width of the flat fracture region of the fracture surface, as shown in Fig. 10, and determine the percent shear from either Table A6.1 or Table A6.2 depending on the units of measurement.

A6.1.2 Compare the appearance of the fracture of the specimen with a fracture appearance chart such as that shown in Fig. A6.1.

A6.1.3 Magnify the fracture surface and compare it to a precalibrated overlay chart or measure the percent shear fracture by means of a planimeter.

A6.1.4 Photograph the fracture surface at a suitable magnification and measure the percent shear fracture by means of a planimeter.

A6.1.5 Capture a digital image of the fracture surface and measure the percent shear fracture using image analysis software.

TABLE A6.1 Percent Shear for Measurements Made in Millimetres

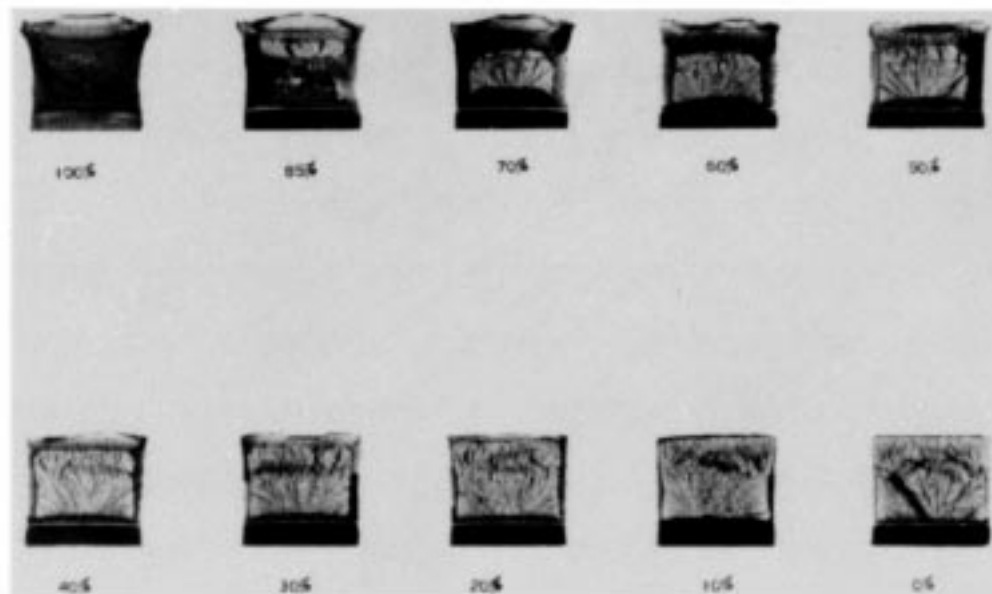
NOTE 1—100 % shear is to be reported when either A or B is zero.

Dimension B, mm	Dimension A, mm																			
	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10	
1.0	99	98	98	97	96	96	95	94	94	93	92	92	91	91	90	89	89	88	88	
1.5	98	97	96	95	94	93	92	92	91	90	89	88	87	86	85	84	83	82	81	
2.0	98	96	95	94	92	91	90	89	88	86	85	84	82	81	80	79	77	76	75	
2.5	97	95	94	92	91	89	88	86	84	83	81	80	78	77	75	73	72	70	69	
3.0	96	94	92	91	89	87	85	83	81	79	77	76	74	72	70	68	66	64	62	
3.5	96	93	91	89	87	85	82	80	78	76	74	72	69	67	65	63	61	58	56	
4.0	95	92	90	88	85	82	80	77	75	72	70	67	65	62	60	57	55	52	50	
4.5	94	92	89	86	83	80	77	75	72	69	66	63	61	58	55	52	49	46	44	
5.0	94	91	88	85	81	78	75	72	69	66	62	59	56	53	50	47	44	41	37	
5.5	93	90	86	83	79	76	72	69	66	62	59	55	52	48	45	42	38	35	31	
6.0	92	89	85	81	77	74	70	66	62	59	55	51	47	44	40	36	33	29	25	
6.5	92	88	84	80	76	72	67	63	59	55	51	47	43	39	35	31	27	23	19	
7.0	91	87	82	78	74	69	65	61	56	52	47	43	39	34	30	26	21	17	12	
7.5	91	86	81	77	72	67	62	58	53	48	44	39	34	30	25	20	16	11	6	
8.0	90	85	80	75	70	65	60	55	50	45	40	35	30	25	20	15	10	5	0	

TABLE A6.2 Percent Shear for Measurements Made in Inches

NOTE 1—100 % shear is to be reported when either A or B is zero.

Dimension B, in.	Dimension A, in.																
	0.05	0.10	0.12	0.14	0.16	0.18	0.20	0.22	0.24	0.26	0.28	0.30	0.32	0.34	0.36	0.38	0.40
0.05	98	96	95	94	94	93	92	91	90	90	89	88	87	86	85	85	84
0.10	96	92	90	89	87	85	84	82	81	79	77	76	74	73	71	69	68
0.12	95	90	88	86	85	83	81	79	77	75	73	71	69	67	65	63	61
0.14	94	89	86	84	82	80	77	75	73	71	68	66	64	62	59	57	55
0.16	94	87	85	82	79	77	74	72	69	67	64	61	59	56	53	51	48
0.18	93	85	83	80	77	74	72	68	65	62	59	56	54	51	48	45	42
0.20	92	84	81	77	74	72	68	65	61	58	55	52	48	45	42	39	36
0.22	91	82	79	75	72	68	65	61	57	54	50	47	43	40	36	33	29
0.24	90	81	77	73	69	65	61	57	54	50	46	42	38	34	30	27	23
0.26	90	79	75	71	67	62	58	54	50	46	41	37	33	29	25	20	16
0.28	89	77	73	68	64	59	55	50	46	41	37	32	28	23	18	14	10
0.30	88	76	71	66	61	56	52	47	42	37	32	27	23	18	13	9	3
0.31	88	75	70	65	60	55	50	45	40	35	30	25	20	18	10	5	0



(a) Fracture Appearance Charts and Percent Shear Fracture Comparator



(b) Guide for Estimating Fracture Appearance

FIG. A6.1 Fracture Appearance

APPENDIXES

(Nonmandatory Information)

X1. NOTES ON SIGNIFICANCE OF NOTCHED-BAR IMPACT TESTING

X1.1 Notch Behavior:

X1.1.1 The Charpy V-notch (CVN) impact test has been

used extensively in mechanical testing of steel products, in research, and in procurement specifications for over three

decades. Where correlations with fracture mechanics parameters are available, it is possible to specify CVN toughness values that would ensure elastic-plastic or plastic behavior for fracture of fatigue cracked specimens subjected to minimum operating temperatures and maximum in service rates of loading.

X1.1.2 The notch behavior of the face-centered cubic metals and alloys, a large group of nonferrous materials and the austenitic steels can be judged from their common tensile properties. If they are brittle in tension, they will be brittle when notched, while if they are ductile in tension they will be ductile when notched, except for unusually sharp or deep notches (much more severe than the standard Charpy or Izod specimens). Even low temperatures do not alter this characteristic of these materials. In contrast, the behavior of the ferritic steels under notch conditions cannot be predicted from their properties as revealed by the tension test. For the study of these materials the Charpy and Izod type tests are accordingly very useful. Some metals that display normal ductility in the tension test may nevertheless break in brittle fashion when tested or when used in the notched condition. Notched conditions include constraints to deformation in directions perpendicular to the major stress, or multi axial stresses, and stress concentrations. It is in this field that the Charpy and Izod tests prove useful for determining the susceptibility of a steel to notch-brittle behavior though they cannot be directly used to appraise the serviceability of a structure.

X1.2 Notch Effect:

X1.2.1 The notch results in a combination of multi axial stresses associated with restraints to deformation in directions perpendicular to the major stress, and a stress concentration at the base of the notch. A severely notched condition is generally not desirable, and it becomes of real concern in those cases in which it initiates a sudden and complete failure of the brittle type. Some metals can be deformed in a ductile manner even down to very low temperatures, while others may crack. This difference in behavior can be best understood by considering the cohesive strength of a material (or the property that holds it together) and its relation to the yield point. In cases of brittle fracture, the cohesive strength is exceeded before significant plastic deformation occurs and the fracture appears crystalline. In cases of the ductile or shear type of failure, considerable deformation precedes the final fracture and the broken surface appears fibrous instead of crystalline. In intermediate cases, the

fracture comes after a moderate amount of deformation and is part crystalline and part fibrous in appearance.

X1.2.2 When a notched bar is loaded, there is a normal stress across the base of the notch which tends to initiate fracture. The property that keeps it from cleaving, or holds it together, is the “cohesive strength”. The bar fractures when the normal stress exceeds the cohesive strength. When this occurs without the bar deforming it is the condition for brittle fracture.

X1.2.3 In testing, though not in service because of side effects, it happens more commonly that plastic deformation precedes fracture. In addition to the normal stress, the applied load also sets up shear stresses which are about 45° to the normal stress. The elastic behavior terminates as soon as the shear stress exceeds the shear strength of the material and deformation or plastic yielding sets in. This is the condition for ductile failure.

X1.2.4 This behavior, whether brittle or ductile, depends on whether the normal stress exceeds the cohesive strength before the shear stress exceeds the shear strength. Several important facts of notch behavior follow from this. If the notch is made sharper or more drastic, the normal stress at the root of the notch will be increased in relation to the shear stress and the bar will be more prone to brittle fracture (see Table X1.1). Also, as the speed of deformation increases, the shear strength increases and the likelihood of brittle fracture increases. On the other hand, by raising the temperature, leaving the notch and the speed of deformation the same, the shear strength is lowered and ductile behavior is promoted, leading to shear failure.

X1.2.5 Variations in notch dimensions will seriously affect the results of the tests. Tests on E 4340 steel specimens⁶ have shown the effect of dimensional variations on Charpy results (see Table X1.1).

X1.3 Size Effect:

X1.3.1 Increasing either the width or the depth of the specimen tends to increase the volume of metal subject to distortion, and by this factor tends to increase the energy absorption when breaking the specimen. However, any increase in size, particularly in width, also tends to increase the degree of constraint and by tending to induce brittle fracture, may decrease the amount of energy absorbed. Where a standard-size specimen is on the verge of brittle fracture, this is particularly true, and a double width specimen may actually require less energy for rupture than one of standard width.

TABLE X1.1 Effect of Varying Notch Dimensions on Standard Specimens

	High-Energy Specimens, J (ft.-lbf)	Medium-Energy Specimens, J (ft.-lbf)	Low-Energy Specimens, J (ft.-lbf)
Specimen with standard dimensions	103.0 ± 5.2 (76.0 ± 3.8)	60.3 ± 3.0 (44.5 ± 2.2)	16.9 ± 1.4 (12.5 ± 1.0)
Depth of notch, 2.13 mm (0.084 in.) ^A	97.9 (72.2)	56.0 (41.3)	15.5 (11.4)
Depth of notch, 2.04 mm (0.0805 in.) ^A	101.8 (75.1)	57.2 (42.2)	16.8 (12.4)
Depth of notch, 1.97 mm (0.0775 in.) ^A	104.1 (76.8)	61.4 (45.3)	17.2 (12.7)
Depth of notch, 1.88 mm (0.074 in.) ^A	107.9 (79.6)	62.4 (46.0)	17.4 (12.8)
Radius at base of notch 0.13 mm (0.005 in.) ^B	98.0 (72.3)	56.5 (41.7)	14.6 (10.8)
Radius at base of notch 0.38 mm (0.015 in.) ^B	108.5 (80.0)	64.3 (47.4)	21.4 (15.8)

^AStandard 2.0 ± 0.025 mm (0.079 ± 0.001 in.).

^BStandard 0.25 ± 0.025 mm (0.010 ± 0.001 in.).

X1.3.2 In studies of such effects where the size of the material precludes the use of the standard specimen, for example when the material is 6.35-mm (0.25-in.) plate, subsize specimens are used. Such specimens (Fig. A3.1) are based on the Type A specimen of Fig. 1.

X1.3.3 General correlation between the energy values obtained with specimens of different size or shape is not feasible, but limited correlations may be established for specification purposes on the basis of special studies of particular materials and particular specimens. On the other hand, in a study of the relative effect of process variations, evaluation by use of some arbitrarily selected specimen with some chosen notch will in most instances place the methods in their proper order.

X1.4 *Temperature Effect:*

X1.4.1 The testing conditions also affect the notch behavior. So pronounced is the effect of temperature on the behavior of steel when notched that comparisons are frequently made by examining specimen fractures and by plotting energy value and fracture appearance versus temperature from tests of notched bars at a series of temperatures. When the test temperature has been carried low enough to start cleavage fracture, there may be an extremely sharp drop in absorbed energy or there may be a relatively gradual falling off toward the lower temperatures. This drop in energy value starts when a specimen begins to exhibit some crystalline appearance in the fracture. The transition temperature at which this embrittling effect takes place varies considerably with the size of the part or test specimen and with the notch geometry.

X1.5 *Testing Machine:*

X1.5.1 The testing machine itself must be sufficiently rigid or tests on high-strength low-energy materials will result in excessive elastic energy losses either upward through the pendulum shaft or downward through the base of the machine. If the anvil supports, the striker, or the machine foundation bolts are not securely fastened, tests on ductile materials in the range from 108 J (80 ft·lbf) may actually indicate values in excess of 122 to 136 J (90 to 100 ft·lbf).

X1.5.2 A problem peculiar to Charpy-type tests occurs when high-strength, low-energy specimens are tested at low temperatures. These specimens may not leave the machine in the direction of the pendulum swing but rather in a sidewise direction. To ensure that the broken halves of the specimens do not rebound off some component of the machine and contact

the pendulum before it completes its swing, modifications may be necessary in older model machines. These modifications differ with machine design. Nevertheless the basic problem is the same in that provisions must be made to prevent rebounding of the fractured specimens into any part of the swinging pendulum. Where design permits, the broken specimens may be deflected out of the sides of the machine and yet in other designs it may be necessary to contain the broken specimens within a certain area until the pendulum passes through the anvils. Some low-energy high-strength steel specimens leave impact machines at speeds in excess of 15.2 m/s (50 ft/s) although they were struck by a pendulum traveling at speeds approximately 5.2 m/s (17 ft/s). If the force exerted on the pendulum by the broken specimens is sufficient, the pendulum will slow down and erroneously high energy values will be recorded. This problem accounts for many of the inconsistencies in Charpy results reported by various investigators within the 14 to 34-J (10 to 25 ft·lb) range. Figure A1.1 illustrates a modification found to be satisfactory in minimizing jamming.

X1.6 *Velocity of Straining:*

X1.6.1 Velocity of straining is likewise a variable that affects the notch behavior of steel. The impact test shows somewhat higher energy absorption values than the static tests above the transition temperature and yet, in some instances, the reverse is true below the transition temperature.

X1.7 *Correlation with Service:*

X1.7.1 While Charpy or Izod tests may not directly predict the ductile or brittle behavior of steel as commonly used in large masses or as components of large structures, these tests can be used as acceptance tests or tests of identity for different lots of the same steel or in choosing between different steels, when correlation with reliable service behavior has been established. It may be necessary to make the tests at properly chosen temperatures other than room temperature. In this, the service temperature or the transition temperature of full-scale specimens does not give the desired transition temperatures for Charpy or Izod tests since the size and notch geometry may be so different. Chemical analysis, tension, and hardness tests may not indicate the influence of some of the important processing factors that affect susceptibility to brittle fracture nor do they comprehend the effect of low temperatures in inducing brittle behavior.

X2. SUGGESTED METHODS OF MEASUREMENT

X2.1 *Position of the Center of Strike Relative to the Center of Gravity:*

X2.1.1 Since the center of strike can only be marked on an assembled machine, only the methods applicable to an assembled machine are described as follows:

X2.1.1.1 The fundamental fact on which all the methods are based is that when the friction forces are negligible, the center of gravity is vertically below the axis of rotation of a pendulum supported by the bearings only, (herein referred to as a free

hanging pendulum). Paragraph A1.3 limits the friction forces in impact machines to a negligible value. The required measurements may be made using specialized instruments such as transits, clinometers, or cathometers. However, simple instruments have been used as described in the following to make measurements of sufficient accuracy.

X2.1.1.2 Suspend a plumb bob from the frame. The plumb line should appear visually to be in the plane of swing of the striking edge.

X2.1.1.3 Place a massive object on the base close to the latch side of the tup. Adjust the position of this object so that when back lighted, a minimal gap is visible between it and the tup when the pendulum is free hanging.

X2.1.1.4 With a scale or depth gage pressed lightly against the striking edge at the center of strike, measure the horizontal distance between the plumb line and striking edge. (The dimension *B* in Fig. X2.1.)

X2.1.1.5 Similarly, measure the distance in a horizontal plane through the axis of rotation from the plumb line to the clamp block or enlarged end of the pendulum stem. (Dimension *A* in Fig. X2.1.)

X2.1.1.6 Use a depth gage to measure the radial distance from the surface contacted in measuring *A* to a machined surface of the shaft which connects the pendulum to the bearings in the machine frame. (Dimension *C* in Fig. X2.1.)

X2.1.1.7 Use an outside caliper or micrometer to measure the diameter of the shaft at the same location contacted in measuring *C*. (Dimension *D* in Fig. X2.1.)

X2.1.1.8 Substitute the measured dimensions in the equation

$$X = A + C + D/2 - B \quad (X2.1)$$

where:

X = deviation of the center of strike from a line from the center of rotation through the center of gravity.

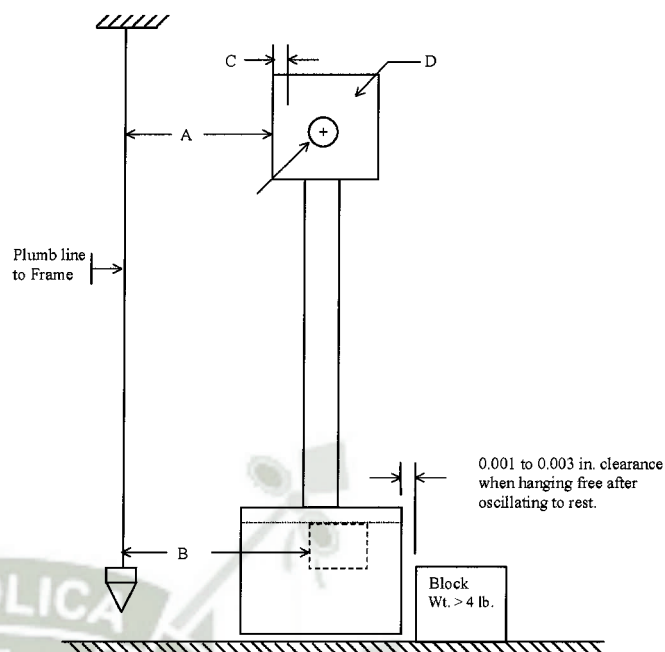


FIG. X2.1 Measurement of Deviation of Center of Strike from Vertical Plane through Axis of Rotation when Pendulum is Hanging Free

X3. CHARPY V-NOTCH VERIFICATION PROGRAM

X3.1 The National Institute of Standards and Technology (NIST) Standard Reference Materials Program (SRMP) conducts a Charpy machine qualification program originally developed by the U.S. Army. Under this program, verification specimens are used to certify Charpy impact machines to the requirements of these test methods.

X3.1.1 Purchasing Verification Specimens:

X3.1.1.1 Verification specimens may be obtained by contacting the SRMP sales office at the National Institute of Standards and Technology.⁸

X3.2 Verification Test Evaluation:

X3.2.1 To receive a written report on verification tests, mail the broken test specimens and questionnaire to: Charpy Pro-

gram Coordinator at NIST.⁹ NIST will evaluate the specimens and test results, and return a report. If a machine meets the direct and indirect verification requirements of ASTM Standard E 23, a letter of certification will be issued for the machine. If a machine is producing values outside the tolerances given in the ASTM E 23 standard, the report may suggest repair or replacement of certain machine parts, a change in testing techniques, or other adjustments.

X3.2.2 Questions on verification testing and results should be addressed to the Charpy Program Coordinator. Test results may be requested by phone or FAX, prior to the evaluation of broken specimens. To obtain informal results, the user must supply the lot code (for example, LL-xx, HH-xx, or SH-xx) and individual specimen identification numbers (stamped on the specimens), along with the absorbed energy values obtained during their test.

⁸ National Institute of Standards and Technology, Standard Reference Material Program, Building 202, Room 204, Gaithersburg, MD 20899. E-mail: srminfo@nist.gov.

⁹ Charpy Program Coordinator, NIST, Mail Code 853, 325 Broadway, Boulder, CO 80303-3328.

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**Anexo 4. Standard Hardness Conversion Tables for
Metals Relationship Among Brinell Hardness,
Vickers Hardness, Rockwell Hardness, Superficial
Hardness, Knoop Hardness, and Scleroscope
Hardness (E140-97e2)**

ASTM E140-97

ASTM E140-97 TABLE 1												
HRC	HRA	15 N	30 N	45 N	HV		HRC	HRA	15 N	30 N	45 N	HV
68	85.6	93.2	84.4	75.4	940		43	72.0	82.0	62.0	46.7	423
67	85.0	92.9	83.6	74.2	900		42	71.5	81.5	61.3	45.5	412
66	84.5	92.5	82.8	73.3	865		41	70.9	80.9	60.4	44.3	402
65	83.9	92.2	81.9	72.0	832		40	70.4	80.4	59.5	43.1	392
64	83.4	91.8	81.1	71.0	800		39	69.9	79.9	58.6	41.9	382
63	82.8	91.4	80.1	69.9	772		38	69.4	79.4	57.7	40.8	372
62	82.3	91.1	79.3	68.8	746		37	68.8	78.8	56.8	39.6	363
61	81.8	90.7	78.4	67.7	720		36	68.4	78.3	55.9	38.4	354
60	81.2	90.2	77.5	66.6	697		35	67.9	77.7	55.0	37.2	345
59	80.7	89.8	76.6	65.5	674		34	67.4	77.2	54.2	36.1	336
58	80.1	89.3	75.7	64.3	653		33	66.8	76.6	53.3	34.9	327
57	79.6	88.9	74.8	63.2	633		32	66.3	76.1	52.1	33.7	318
56	79.0	88.3	73.9	62.0	613		31	65.8	75.6	51.3	32.5	310
55	78.5	87.9	73.0	60.9	595		30	65.3	75.0	50.4	31.3	302
54	78.0	87.4	72.0	59.3	577		29	64.6	74.5	49.5	30.1	294
53	77.4	86.9	71.2	58.6	560		28	64.3	73.9	48.6	28.9	286
52	76.8	86.4	70.2	57.4	544		27	63.8	73.3	47.7	27.8	279
51	76.3	85.9	69.4	56.1	528		26	63.3	72.8	46.8	26.7	272
50	75.9	85.5	68.5	55.0	513		25	62.8	72.2	45.9	25.5	266
49	75.2	85.0	67.6	53.8	498		24	62.4	71.6	45.0	24.3	260
48	74.4	84.5	66.7	52.5	484		23	62.0	71.0	44.0	23.1	254
47	74.1	83.9	65.8	51.4	471		22	61.5	70.5	43.2	22.0	248
46	73.6	83.5	64.8	50.3	458		21	61.0	69.9	42.3	20.7	243
45	73.1	83.0	64.0	49.0	446		20	60.5	69.4	41.5	19.6	238
44	72.5	82.5	63.1	47.8	434							

ASTM E140-97 TABLE 2

HRB	HB	HRA	15T	30T	45T	HV		HRB	HB	HRA	15T	30T	45T	HV
100	240.0	61.5	93.1	83.1	72.9	240		80.0	150.0	49.5	86.6	69.7	52.8	150.0
99	234.0	60.9	92.8	82.5	71.9	234		79.0	147.0	48.9	86.3	69.1	51.8	147.0
98	228.0	60.2	92.5	81.8	70.9	228		78.0	144.0	48.4	86.0	68.4	50.8	144.0
97	222.0	59.5	92.1	81.1	69.9	222		77.0	141.0	47.9	85.6	67.7	49.8	141.0
96	216.0	58.9	91.8	80.4	68.9	216		76.0	139.0	47.3	85.3	67.1	48.8	139.0
95	210.0	58.3	91.5	79.8	67.9	210		75.0	137.0	46.8	85.0	66.4	47.8	137.0
94	205.0	57.6	91.2	79.1	66.9	205		74.0	135.0	46.3	84.7	65.7	46.8	135.0
93	200.0	57.0	90.8	78.4	65.9	200		73.0	132.0	45.8	84.3	65.1	45.8	132.0
92	195.0	56.4	90.5	77.8	64.8	195		72.0	130.0	45.3	84.0	64.4	44.8	130.0
91	190.0	55.8	90.2	77.1	63.8	190		71.0	127.0	44.8	83.7	63.7	43.8	127.0
90	185.0	55.2	89.9	76.4	62.8	185		70.0	125.0	44.3	83.4	63.1	42.8	125.0
89	180.0	54.6	89.5	75.8	61.8	180		69.0	123.0	43.8	83.0	62.4	41.8	123.0
88	176.0	54.0	89.2	75.1	60.8	176		68.0	121.0	43.3	82.7	61.7	40.8	121.0
87	172.0	53.4	88.9	74.4	59.8	172		67.0	119.0	42.8	82.4	61	39.8	119.0
86	169.0	52.8	88.6	73.8	58.8	169		66.0	117.0	42.3	82.1	60.4	38.7	117.0
85	165.0	52.3	88.2	73.1	57.8	165		65.0	116.0	41.8	81.8	59.7	37.7	116.0
84	162.0	51.7	87.9	72.4	56.8	162		64.0	114.0	41.4	81.4	59	36.7	114.0
83	159.0	51.1	87.6	71.8	55.8	159		63.0	112.0	40.9	81.1	58.4	35.7	112.0
82	156.0	50.6	87.3	71.1	54.8	156		62.0	110.0	40.4	80.8	57.7	34.7	110.0
81	153.0	50.0	86.9	70.4	53.8	153		61.0	108.0	40.0	80.5	57	33.7	108.0
								60.0	107.0	39.5	80.1	56.4	32.7	107.0

Last Updated on 6/14/99

By Norman Souza

**Anexo 5. Metallurgical Preparation Grinder /
Polisher – Instruction Manual**



Metallurgical Preparation Grinder/Polisher

Instruction Manual

Beijing TIME High Technology Ltd.

First 、 the use

In the process of preparing the metallographic test sample, the grinding and polishing of sample are the two extremely important procedures, which are usually finished by the metallographic test sample pre-grinding machine and the metallographic test sample buffing machine. To adapt to the needs of the development of the industry, the science and technology in our country, the company newly designed the TMP-1A infinitely variable speed grinding and polishing machine, which can complete each procedures such as the rough grinding, the fine grinding, the dry grinding, the wet grinding, the attrition and the polishing for all kinds of test sample only by exchanging the grinding pan (fix price forward delivery, pan mill). For the request of expanding the preparation of different test samples, the diameter of polish and polishing pan of this machine is bigger than the domestic similar product, which may increase the effective working surface 20%-30% and has more choices of different link speed in the working surface. The machine is the quite and ideal metallographic equipment of preparing sample.

Second、 main parameter

The diameter of sandpaper: 230mm

The diameter polishing pan: 220mm

Rotational speed: 50~1400 r/min (infinitely)

Electric motor: BY806frequency conversion electric machine, 0.55KW, 220V, 0-50Hz

External dimensions: 740×410×340mm

Net weight: 65kg



Third、 the structure outlines

TMP-1A infinitely variable speed grinding and polishing machine takes frequency converter and BY806 frequency electric motor as the power supply, transmitting the energy to the main axle through the o-type 950 triangle belts, causing the turntable rotating. Because the grinding pan, the polishing pan and the abrasive pan all has three locating holes and the guide slots, so when the pans are being installed, it only need push the three positioning pins into the guide slots at first, and then rotate the plate to make the pinhole fitting-in the positioning pin conveniently to install the plate. The switch of power and frequency button is installed on the front panel. The operation is extremely convenient and device frequency button which can realize all kinds of different rotational speeds only rotating the switch.

Fourth、 the installment and the use

Installment

1. Put this machine on the smooth work table and take down the packing plastic housing.
2. Inspect whether various components of the machine is complete or not, complete the clearing.
3. Put through the water inlet pipe and the discharge pipe, pay attention on the altitude of draining water place should be lower than the freeing port.
4. Insert the plug adapter into the electric outlet. Before the insertion, you should inspect whether the supply voltage is congruous, whether the ground connection of line is reliable.
5. Turn on the switch, inspect the rotation direction of the grinding pan. The turntable should revolve according the counter clockwise; it should be adjusted promptly if it does not.

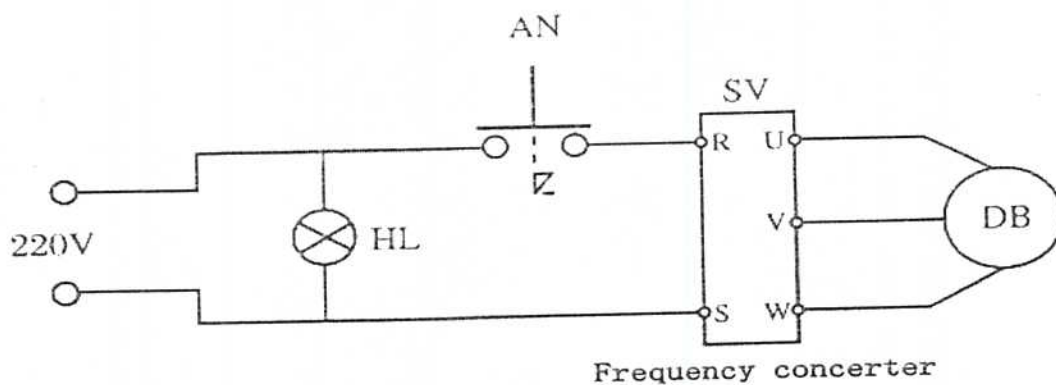
The use

1. Take down the plastic cover first, exchange the grinding pan and polishing pan needed, (when charging it must be completely cleaned), then install the plastic cover, rotate the switch to the rotational speed position needed, then do the polish work.
2. **Pre-polish:** Install the grinding pan first, put in the waterproof abrasive paper into the plate, and open the feed valve to make the clear water unceasingly pour into the abrasive plate. Because of the centrifugal force function, water in the abrasive plate is thrown out, that is atmospheric pressure press the waterproof abrasive paper on the pan surface tightly, but the water volume should not be oversize, only continuously be flowing in.
3. **Polishing:** Install the polish plate, and after smearing little machine oil on the polish pan, paste the polishing fabric on the pan surface, but pay attention the fabric pasted has to be smoothly on the surface. And then the polishing work can be started only after the polishing liquid or cream and water are dropt on the surface of the fabric. The common wool fabric usually adopts the paste way for the guarantee of safe use. Once it chooses the thin fabric (for example wool and so on) as the polishing fabric, you may use the immediate appendix (ferrule) to button the fabric on the surface, after it is moistened.
4. When closing down you should close the feel valve first and then turn off the engine, in order to avoid the outflow of water into the bearing seat, damaging the bearing, affecting the normal use of the equipment.
5. **The use of frequency:** (1) turn on the switch, and then it displays 50r/min (the low speed). (2) Frequency: First press button, now the turn pan should revolve according the counter clockwise, press button, it display that the speed is high. It is the best speed when display 1400r/min. If you want to have low speed, you can press button. When you turn down the machine, you should press the button, then the turn pan stops.

Fifth 、 the maintenance

1. It is not allowed to add the oversized pressure on to the test sample when polishing, in order to avoid the damage caused by the electric motor overloads.
2. Strictly forbid the polishing work using already cracked sandpaper or fabric to avoid affecting the polish quality and the accident.
3. You should complete the cleaning maintenance promptly; flush the depositing contamination in water removal channel for the convenient of the drain. You should promptly cover the plastic lid when the machine is out of service to avoid the leaking of sundries into the plate.
4. You should change the motor lubricating grease of the machine in time after longing run; generally change once in 12 mouths.

Electric appliance line diagram:



Product certificate

Product title: Metallurgical Preparation Grinder/Polisher

The product model: TMP-1A

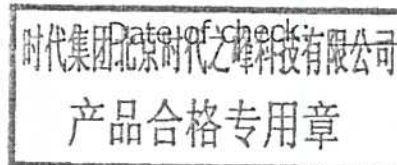
Inspection record:

1. The quality of manufacture and the assembly conforms to the blueprint requirement.
2. The flat jump amount of polish pan < 0.20mm.
3. Rotate steadily, the noise is small.
4. The components are complete, the external appearance are neat.

The product is permitted to be distributed though checking:

Check person: 检 4

Section chief of check: WeiHong Zhang 张卫江



Packing List

Contract serial number:

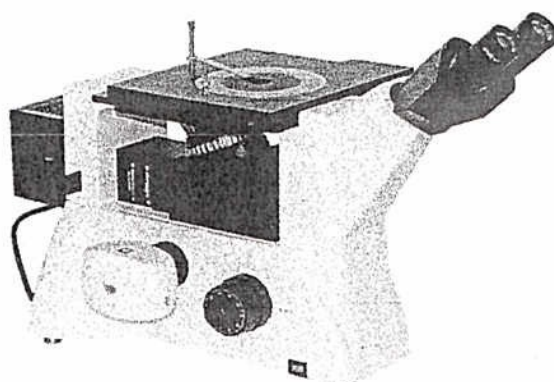
packing serial number:

Model	Product title	Unit	Quantity
TMP-1A	Metallurgical Preparation Grinder/Polisher	piece	1
Product appendix	unit	quantity	note
grinding pan	piece	1	Installed on the charging pan
polishing disc	piece	1	
waterproof abrasive paper	sheet	4	Φ230
ferrule	piece	1	
inlet and discharge pipe	root	1/1	Φ10, Φ25
technology document	1. A copy of product instruction booklet 2. A copy of product certificate		



Anexo 6. Metallografic Microscope DX70A

Metallographic Microscope DX70A



- ◆ Infinity optical system
- ◆ Wide angle big ocular
- ◆ Infinity long working distance flat field objective
- ◆ Movable 5-Hole objective convertor
- ◆ Rotatable large table
- ◆ Light-Dark field optional
- ◆ Simple polarization device integrated
- ◆ Side position image sync output

Purpose of Use:

Advanced infinity optical system DX70A, reversed metallographic microscope is used for metallurgical analysis and inspection. The sample do not need to be mounted for observation. Can be used for surface painting, flows inspection and analysis. Possessed scientific research class function to other integrated metallographic microscope.

DX70A Microscope is used to serve many companies from mining area for their need of inspection and analysis requirements. Also be widely used in the field of technical education. Be able to equip with camera and image analysis system.

Main specification:

Drawtube	Reversed, hinge dual eyes tube, obliquity angle 45°, pupillary 55-75mm, diopter $\pm 5\%$ adjustable
Image output	Side position image sync output, standard port, be suitable for image record system
Dual layer mechanical table	242x200mm, coaxial movement 30x30mm, double support to bear heavy sample.
Plate table	$\Phi 130$ mm, rotatable 360°, Hole diameter $\Phi 10/\Phi 20/\Phi 40$ mm
Focus device	Coaxial big/small movement, up/down 30mm, fine tuning 2 μ m, focus positioning and fasten control device
Light field lighting	Preset diameter variable aperture and sight field diaphragm, adjustable halogen lamp 12V/30W
Polarization device	Preset polarization detection and adjusting propeller.
Color filter	Y/G/B/Neutro/transparence
Power supply	AC220V/50Hz/60Hz/40VA
Package	50x36x63 Cm ³ , weight 13.7kg

Amplify rate:

Model (DX70A)	
Amplify rate	100 $\times$, 200 $\times$, 500 $\times$, 1000 $\times$
Objective	10 $\times$, 20 $\times$, 50 $\times$, 100 $\times$ Dry (Long working distance)
Objective convert	5-hole ball bear positioning
Wide angle eyepiece	WF10 $\times$ /22mm (aperture $\Phi 30$ mm)
Scale	10 $\times$ zooming, scale 0.1/22mm, micro scale 0.01/1mm

Parameter:

Infinity long working distance flat field objective ∞			Ocular 10 $\times$ /22	
Amplify	Aperture NA	Work distance mm	Objective field mm	Overall amplify
10 $\times$	0.25	20.2	$\Phi 2.20$	100 $\times$
20 $\times$	0.40	8.80	$\Phi 1.10$	200 $\times$
50 $\times$	0.70	3.28	$\Phi 0.44$	500 $\times$
100 $\times$	0.85	0.40	$\Phi 0.22$	1000 $\times$

Standard Accessory

- (1) Frame (2) Ocular tube (3) Output port (4) Infinity objective ∞ (5) Wide angle ocular (6) Graduation ocular
 (7) Micrometer (8) Plate table (9) Sample gripping (10) Color filter group (11) Polaroid group
 (12) Light source (13) Power cable (14) dust cover (15) Tools (16) Spare parts (17) Documents

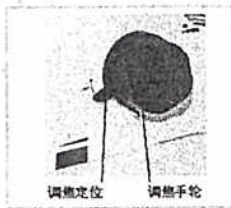
Optional system

- ① Infinity long working distance flat field objective
 ② Image processing system (+V)
 ③ Digital camera system (+U)
 ④ Digital video system (+D)
 ⑤ Metallographic analysis system (+VS)
 ⑥ PC and Printer
 ⑦ Metallurgical preparation equipments (other catalogue)

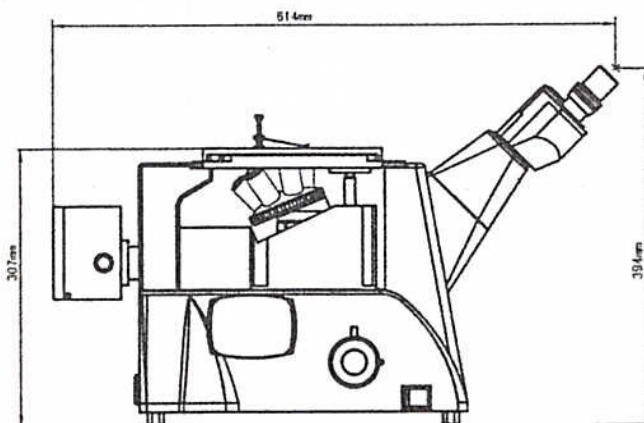
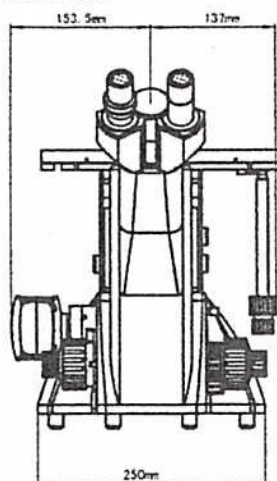
Optional parts

Infinity long working distance flat field objective ∞				Ocular 10 $\times$ /22		Optional
type	Amplify	Aperture NA	Work distance mm	Objective field mm	Overall amplify	
PLL Dry ocular	5 $\times$	0.10	26.1	Φ 4.40	50 $\times$	Yes
	40 $\times$	0.60	3.68	Φ 0.55	400 $\times$	Yes
	60 $\times$	0.70	3.18	Φ 0.36	600 $\times$	Yes
	80 $\times$	0.80	1.28	Φ 0.27	800 $\times$	Yes

Structure sketch



Dimension



**Anexo 7. User Handbook WinWdw Electronic
Universal Testing Machine Measuring Control
Software**

User Handbook

WinWdw Electronic Universal Testing
Machine Measuring Control Software

TIME Group Inc

Please read carefully the manual and use and maintenance testing system according to the manual.

State:

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Windows is trademark of Microsoft company.

Hp is the registered trademark of Hewlett-Packard in U.S.A.

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Chapter 1 General

1.1 Introduction to Function

It uses virtual instrument technology, is designed for tensile, compression, and bending etc. all kinds of tests of computer controlled electronic universal testing machine. It can be used in Win98, Win2000, and Windows XP etc. many sorts of operation system. It can realize open & closed loop control and have auto program controlled programmer, which can edit test process according to actual need and set every procedure so as to conduct all sorts of tests. It can conduct auto data analysis according to "ISO 6892", also can carry out person-machine communication to analyze manually, meanwhile it can also do data processing of artificial plate and cloth synthetically material according to standard offered by users. It, which can be perfected and updated according to information from users, is developed by us.

1.2 Description to feature of main function

If is used for all kinds of metallic and nonmetallic tests of computer controlled electronic universal testing machine. It can perform real-time measuring, display, control, data processing and results output.

Description of function and feature as following:

- (1) By right of management, different class operators have different operating purview. Operational menu is also different, which makes operation easy and protect system;
- (2) Real-time measuring and display load, peak value, deformation and displacement signals; Realize real-time acquisition and control, also precise timing and quick sampling;
- (3) Realize real-time screen display of test curve of load-deformation and

load-displacement and stress-strain. Allow to switch to observe. Zoom out and zoom in of curve are easy;

(4) Have save, setting, loading of test parameters. Zeroing and calibration are carried out by software. All parameters can be saved and loaded easily so as to make it easy switching that one load frame is fitted with multiple load cells without limit of quantity;

(5) Support many kinds of control modes, including constant displacement, constant load, constant stress etc. closed-loop control mode and give standard reference curve when high class operator debugs closed-loop parameters so as to make users observe the effects of parameters on closed-loop;

(6) Supply auto program-controlled programmer for special users. Users can combine many sorts of control modes and rate flexibly by regulation to edit control program of self need according to need. Measuring control software can control testing process automatically according to setting of users;

(7) Use person-machine communication to analyze data. Processing means meet “GB/T 228-2002 Metal Material Ambient Tensile Test Method”, which can calculate elastic module, yield strength, and specified non-proportional elongation strength automatically, also can artificially intervene analysis process so as to raise accuracy of analysis. It can also conduct other data processing according to standard offered by users;

(8) Test data can store in form of text file for easy research. Use WORD, EXCEL etc. Software to handle test data further, meanwhile data communication is easy on internet;

(9) Record and save data curve of whole test process and have demonstration function, which realizes reappearance of test curve process. Also carry out curve superposition contrast for contrast analysis;

(10) Print test report according to users' need. Users can select report output information and test results and content of test curve, meeting all sorts of needs;

(11) Realize digital zeroing and auto-calibrating, of load and deformation, not only be easy to operate, but also improve reliability of machine. All kinds of parameters system setups are stored in form of files for easy saving and recovery;

(12) Use keyboard and mouse to carry out test process control and parameters loading;

(13) identify automatically and support external spot-acting control to make holding specimen easy;

(14) Have overload protection and define specimen rupture automatically and stop automatically.

Add and reduce above functions depending on users' need.

1.3 Requirement of Software and Hardware

- The software is used with match of computer bus measuring control card amplifier unit of Jinan Shijin Group Ltd...
- Operation system: Windows serials operation system.
- All kinds of general commercial printer and driving program.
- Unless another specified, generally, testing is done within ambient temperature of $10^{\circ}\text{C} \sim 35^{\circ}\text{C}$. For some tests, test temperature should be $23^{\circ}\text{C} \pm 5^{\circ}\text{C}$.
- Testing machine should be placed at environment without magnetic interfere.

1.4 Scope

- Suitable for computer controlled electronic universal testing machine.
- Others.

A large, faint watermark of the Universidad Católica de Santa María logo is centered in the background. It features a shield with a cross, a book, and a lamp, with the text "UNIVERSIDAD CATOLICA DE SANTA MARIA" and the year "1961" below it.

**Anexo 8. Thermo Scientific Thermolyne Furnace
Benchtop Muffle Type 47900 and 48000
Installation and Operation Manual**

Installation and Operation Manual

**Thermo Scientific
Thermolyne Furnace
Benchtop Muffle
Type 47900 and 48000**

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Safety Information

Alert Signals



Warning

Warnings alert you to a possibility of personal injury.



Caution

Cautions alert you to a possibility of damage to the equipment.



Note

Notes alert you to pertinent facts and conditions.



Hot Surface

Hot surfaces alert you to a possibility of personal injury if you come in contact with a surface during use or for a period of time after use.

Your Thermo Scientific Thermolyne Type Benchtop Muffle Furnace has been designed with function, reliability and safety in mind. It is your responsibility to install it in conformance with local electrical codes. For safe operation, please pay attention to the alert signals throughout the manual.

This manual contains important operating and safety information. You must carefully read and understand the contents of this manual prior to the use of this furnace.

Warnings

To avoid electrical shock, this furnace must:

1. Use a properly grounded electrical outlet of correct voltage and current handling capacity.
2. Be disconnected from the power supply prior to maintenance and servicing.
3. Have the door switch operating properly.

To avoid personal injury:

1. Do not use in the presence of flammable or combustible materials; fire or explosion may result. This device contains components which may ignite such material.
2. Caution: Hot Surface - Avoid Contact. To avoid burns, do not touch the exterior or interior surfaces of this furnace during use or for a period of time after use.
3. Always wear safety glasses or a safety shield and high temperature gloves when loading or unloading the furnace. Long sleeved, fire retardant clothing and a fire retardant apron is also recommended.
4. Refer servicing to qualified personnel.



Warning

Refer servicing to qualified personnel.

Warning

This warning is presented for compliance with California Proposition 65 and other regulatory agencies and only applies to the insulation in this product. This product contains refractory ceramic, refractory ceramic fiber or fiberglass insulation, which can produce respirable dust or fibers during disassembly. Dust or fibers can cause irritation and can aggravate pre-existing respiratory diseases. Refractory ceramic and refractory ceramic fibers (after reaching 1000°C) contain crystalline silica, which can cause lung damage (silicosis). The International Agency for Research on Cancer (IARC) has classified refractory ceramic fiber and fiberglass as possibly carcinogenic (Group 2B), and crystalline silica as carcinogenic to humans (Group 1).

The insulating materials can be located in the door, the hearth collar, in the chamber of the product or under the hot plate top. Tests performed by the manufacturer indicate that there is no risk of exposure to dust or respirable fibers resulting from operation of this product under normal conditions. However, there may be a risk of exposure to respirable dust or fibers when repairing or maintaining the insulating materials, or when otherwise disturbing them in a manner which causes release of dust or fibers. By using proper handling procedures and protective equipment you can work safely with these insulating materials and minimize any exposure. Refer to the appropriate Material Safety Data Sheets (MSDS) for information regarding proper handling and recommended protective equipment. For additional MSDS copies, or additional information concerning the handling of refractory ceramic products, please contact the Customer Service Department at 1-800-438-4851.

Introduction



Caution

Do not exceed operating temperatures shown in "General Specifications." Exceeding these limits will result in severely reduced element life.

Intended Use

The Type F47900 and F48000 furnaces are general purpose laboratory and heat treating furnaces. For optimum element life, we recommend observing these temperature ranges: from 100°C (212°F) to 1093°C (2000°F) continuous use or from 1093°C (2000°F) to 1200C (2192°F) for intermittent use. Continuous use is operating the furnace for more than 3 hours and intermittent use is operating the furnace for less than 3 hours.

All furnaces consist of: 1) a vented heating chamber; 2) a temperature controller; and 3) a door safety switch for operator safety.

General Usage

Do not use this product for anything other than its intended usage.

Principles of Operation

The furnace chamber is heated by open coil electric resistance elements and is insulated with ceramic fiber insulation. The controller is located under the furnace chamber and is well insulated from the heat generated in the furnace chamber. A door safety switch removes power to the heating elements whenever the furnace door is opened. The temperature is controlled by one of three types of controllers.

General Specifications

Type F47900 Models

Dimensions in Inches (cm):

Chamber: 5 (12.7) W x 4 (10.2) H x 6 (15.2) D
Overall: 11.25 (28.6) W x 18 (45.7) H x 15.5 (39.4) D
Chamber volume: 120 cu. in. (2.0 liters)

Weight: 37 lb. (16.8 kg)

Electrical Ratings:

Volts:	220-240	100	120
Amps:	4.2	7.5	8.3
Watts:	1000	750	1000
Frequency:	50/60	50/60	50/60
Phase:	1	1	1

Temperature:

Operating Range: 2000°F (1093°C) continuous
2192°F (1200°C) intermittent

Type F48000 Models

Dimensions in Inches (cm):

Chamber: 7 (17.8) W x 5 (12.7) H x 10 (25.4) D
Overall: 13.25 (33.7) W x 19 (48.3) H x 19.5 (49.5) D
Chamber volume: 350 cu. in. (5.8 liters)

Weight: 56 lb. (25.4 kg) (all models except -33)
58 lb. (26.3 kg) (-33 models only)

Electrical Ratings:

Volts:	220-240	120	208	220-240*
Amps:	7.5	15	7.5	6.5*
Watts:	1800	1800	1560	1560*
Frequency:	50/60	50/60	50/60	50/60*
Phase:	1	1	1	1*

* -33 models only

Temperature:

Operating Range: 2000°F (1093°C) continuous
2192°F (1200°C) intermittent

Environmental Conditions

Operating: 17°C to 27°C; 20% to 80% relative humidity, non-condensing. Installation Category II (overvoltage) in accordance with IEC 664. Pollution degree 2 in accordance with IEC 664.

Altitude Limit: 2,000 meters.

Storage: -25°C to 65°C; 20% to 80% relative humidity

Declaration of Conformity

We hereby declare under our sole responsibility that this product conforms with the technical requirements of the following standards (220-240 Volt Models Only):

EMC:

EN 61326-1 Electrical Equipment for
Measurement, Control, and
Laboratory Use; Part I:
General Requirements

Safety: EN 61010-1 Safety Requirements
for Electrical Equipment
for Measurement,
Control and Laboratory
Use; Part I: General
Requirements

EN 61010-2-010 Part II: Particular
Requirements for
Laboratory Equipment
for the Heating of
Materials

per the provisions of the Low Voltage Directive
2006/95/EC.

The authorized representative located within the
European Community is:

Electrothermal House
Unit 12A
Purdeys Industrial Estate
Purdys Way
Rochford, Essex, SS4 1ND
United Kingdom

Tel: +44 (0) 1702 303350

Copies of the Declaration of Conformity are
available upon request.

Unpacking

1. Visually check for any physical damage to the shipping container.
2. Inspect the equipment surfaces that are adjacent to any damaged area.
3. Open the furnace door and remove the packing material from inside the furnace chamber.
4. Vacuum the chamber prior to use to remove the insulation dust due to shipment. (The Type 48000 furnace is supplied with one ceramic shelf.)
5. Retain the original packaging material if reshipment is foreseen or required.

Installation



Caution

Be sure ambient temperature does not exceed 40°C (104°F). The recommended ambient temperature is 17°C - 27°C. Ambients above this level may result in damage to the controller.



Caution

Allow at least six inches of space between the furnace and any combustible surface. This permits the heat from the furnace case to escape so as not to create a possible fire hazard.



Warning

To avoid electrical shock, this furnace must always use a properly grounded outlet of correct voltage and current handling capacity.

Site Selection

Install furnace on a sturdy surface and allow adequate space for ventilation.

Electrical Connections

The electrical ratings are located on the specification plate on the back of the furnace.

Consult customer service if your electrical service is different than those listed on the specification plate. Be sure the front power switch is in the OFF position before connecting the furnace to your electrical supply.

Operation, All Models



Warning

To avoid personal injury do not use in the presence of flammable or combustible chemicals; fire or explosion may result. This device contains components which may ignite such materials.



Hot Surface

Caution: Avoid Contact. To avoid burns, this furnace must not be touched on the exterior or interior surfaces during use or for a period of time after use.



Warning

Always wear safety glasses or a safety shield and high temperature gloves when loading or unloading the furnace. Long sleeved, fire retardant clothing and a fire retardant apron is also recommended.



Warning

To avoid electrical shock, the door safety switch must be operating properly.

Power Switch

Both the ON/OFF power switch and the digital display will illuminate when power is switched ON. The furnace will begin to heat to its controller's current setpoint. (See the instructions for your type of controller for information on checking and setting the setpoint.)

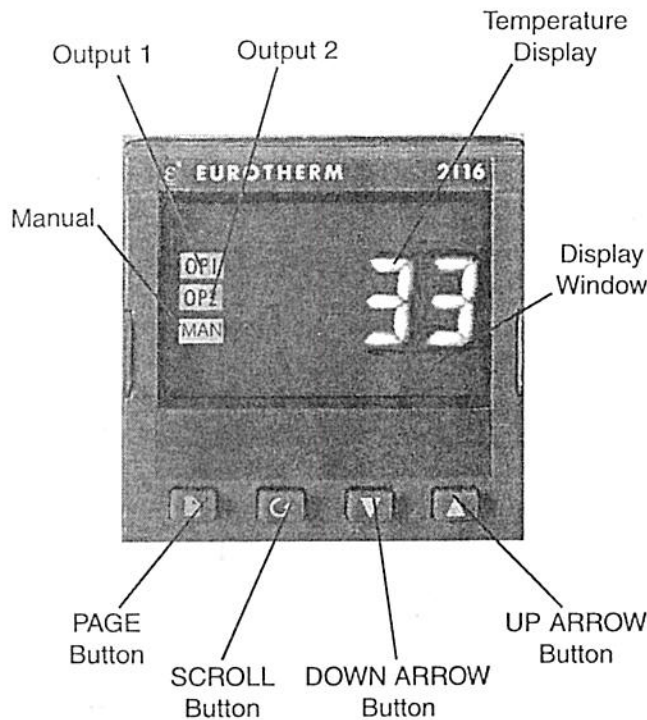
Cycle Light

The amber cycle light will illuminate whenever the power is being applied to the heating elements. The cycle light will turn on and off as the furnace reaches the setpoint.

Door Safety Switch

The door safety switch removes power from the heating elements when the door is opened. Open and close the door a few times; note that the amber CYCLE light will switch off when the door is opened. If this condition is not true, consult the Troubleshooting section before proceeding. This check must be done when the furnace is heating and the cycle light is illuminated.

Single Setpoint Models & Single Setpoint Models w/OTP



Single Setpoint Models



Note

If at any time you want to return to the HOME DISPLAY, simultaneously press the PAGE and SCROLL buttons.

The **single setpoint model** furnace controller is a single setpoint controller which provides a single digital display to indicate the current chamber temperature or setpoint temperature. This temperature controller features sensor break protection and self-tuning capability.

The **single setpoint model w/ OTP** furnace controller is a single setpoint controller which provides a single digital display to indicate the current chamber temperature or setpoint temperature. This temperature controller features sensor break protection, self-tuning capability and over temperature protection (OTP) with an additional OTP relay device.

Basic Operation

When the controller is turned ON it will perform a short self-test and then display the measured value (process value) in the HOME DISPLAY.

Buttons and Indicators

OP1 (Output 1): Illuminates when the logic output is ON.

OP2 (Output 2): Illuminates when the relay output is ON (will go out during an alarm situation).

PAGE button: Allows you to select a new list of parameters.

SCROLL button: Allows you to select a parameter within a list of parameters.

DOWN button: Allows you to decrease a value.

UP button: Allows you to increase a value.

To View or Change the Setpoint

To view the setpoint, press and release the UP or DOWN buttons. If you want to change the setpoint, continue pressing until the desired setpoint value is displayed and then release the button. A few seconds after the button is released, the controller will accept the new value and revert to the HOME DISPLAY.

To View the Display Units

From the HOME DISPLAY press the SCROLL button. The display will show the temperature units in °C/F/K and then return to the HOME DISPLAY. (Call Customer Service if you require a different temperature unit.)

To View the % Output Power

From the HOME DISPLAY press the SCROLL button twice. Press and release the UP or DOWN button to view the % output power. This value is a read-only value and cannot be changed.

Controller Parameters

Home display

°C: Temperature units in Celsius. Temperature units can not be changed without entering the configuration. Contact Customer Service if a different temperature unit is required.

OP: % output power demand.

IdHi: Deviation high alarm.

Al List

IdHi: Deviation high alarm.

Atun List

tunE: One-shot autotune enable.

Pid List

Pb: Proportional band (in display units).

ti: Integral time in seconds.

td: Derivative time in seconds.

ACCS List Code: Access code (Code needed to enter or change the other configuration parameters which are not normally accessible.) Not accessible.

Alarms

The controller will flash an alarm message in the home display if an alarm condition is detected.

2FSH: Measured value full scale high alarm.

IdHi: Measured value deviation high alarm.

S.br: Sensor break: check that sensor is connected correctly.

L.br: Loop break: check that the heating circuits are working properly.



Note

The following alarm messages are factory default settings and may vary if you have changed the configuration of your controller:

IDHi: = 50°C

2FSH = 1225°C

Ld.F: Heater Circuit fault: indication of either an open or short solid state relay, a blown fuse, missing supply or open circuit heater.

Sensor Break Protection

This controller provides sensor break protection in the event the thermocouple opens. If an open thermocouple condition occurs, the digital display will blink "S.br" and the power to the heating element will be shut OFF (Cycle light will extinguish).

Over-Temperature Protection (OTP)

The OTP will be in effect during any alarm condition when the temperature of the furnace has deviated beyond the limit. The "Deviation High" alarm is the only alarm value which can be changed. To change it, press the SCROLL button until "IdHi" appears on the display. Press the UP or DOWN button to select the OTP value you desire. We recommend a value of 20° above your working temperature to provide protection for your workload.

In addition to over-temperature protection, units containing a single setpoint controller w/OTP feature a mechanical OTP relay device which disconnects power from the elements in an alarm condition (only in furnaces with OTP relay). See models listed on front page.



Note

Furnace must be at ambient temperature before starting a tune.



Note

"Stat" and "Sp.rr" in Sp list must be set to OFF or "tunE" will not initiate.



Note

Tune has completed when "tunE" stops flashing on display.

Tuning

This controller incorporates a self-tuning feature which determines the optimum control parameters for the best temperature accuracy with your load and setpoint. Use this feature the first time you use your furnace and each time you change either your setpoint or the type of load you are heating. We recommend you use this feature to provide the best temperature accuracy the controller can attain. To use the tuning feature:

1. Adjust the setpoint to your desired value.
2. Press the PAGE button until display reads, "Atun."
3. Press the SCROLL button. Display will read, "tunE."
4. Press the UP or DOWN button to select, "on."
5. Simultaneously press the PAGE and SCROLL buttons to return to the HOME DISPLAY. The display will alternately flash between "tunE" and the HOME DISPLAY while tuning is in progress.
6. The controller will then turn the heating on and off to induce an oscillation. When the measured value reaches the required setpoint the first cycle will end.
7. Tuning will be complete after two oscillation cycles and then the tuner will turn itself off.
8. Normal control function will resume after the controller calculates tuning parameters.

Single Ramp & Dwell



Note

These instructions are used with the Single Setpoint models with OTP only
(See models listed on front page).



Mode 1 (Opt. 1)



Mode 2 (Opt. 2)



Mode 3 (Opt. 3)



Mode 4 (Opt. 4)



Mode 5 (Opt. 5)

Functions

This type of controller has single ramp and dwell programming capabilities. The Ramp and Dwell can be configured to five different modes.

1. Mode 1 (Opt. 1) is a Ramp (if needed) to the Setpoint temperature, a Dwell, and then a cool down.
2. Mode 2 (Opt. 2) is the same as mode 1, except the controller continues to heat at the Setpoint after the Dwell has completed. (This mode does not cool down.)
3. Mode 3 (Opt. 3) is the same as mode 1, except the Dwell time includes the Ramp (if needed).
4. Mode 4 (Opt. 4) is the same as mode 2, except the Dwell time includes the Ramp (if needed).
5. Mode 5 (Opt. 5) is a Dwell (delay time) before the controller Ramps (if needed) to the Setpoint temperature.

Program Overview

- A program mode can be set by changing the "tm.OP" variable to "Opt. 1, Opt. 2, Opt. 3, Opt. 4, or Opt. 5.
- A Ramp rate may be set by changing the "SPrr" variable to a value. The Ramp rate units are in degrees per minute.
- The Dwell time can be set by changing the "dwell" variable to the desired value. Dwell time units are in minutes.

- The program Status can be set by changing the "StAt" variable to "run" or "oFF." This variable will start or stop the program.



Note

The program must be stopped and the controller must be displaying the actual temperature before beginning the Setup.

Program Setup

1. Press the PAGE button until the "SP" is displayed.
2. Press the SCROLL button once, "SPrr" (Ramp Rate) will be displayed, set the desired Ramp rate with the UP or DOWN buttons, if the ramp to setpoint feature is needed. If the Ramp rate is not needed, then set to "OFF" with the UP or DOWN buttons.
3. Press the SCROLL button once, "tm.OP" (Ramp & Dwell mode) will be displayed, select the desired mode with the UP or DOWN buttons. (Opt. 1, Opt. 2, Opt. 3, Opt. 4, Opt. 5)
4. Press the SCROLL button once, "dwEll" will be displayed, set the desired Dwell time with the UP or DOWN buttons. (Dwell in minutes.)
5. Press the PAGE button until the Actual temperature is displayed.

Running the Program

1. Press the SCROLL button until "StAt" is displayed, set to "run" with the UP or DOWN buttons.
2. Press the PAGE button to display Actual temperature.

Stopping the Program

Press the SCROLL button until "StAt" is displayed, set to "oFF" with the UP or DOWN buttons.

Clearing the Flashing End

Press the PAGE and SCROLL buttons at the same time.

Verifying a Running Program

Press the SCROLL button until "StAt" is displayed. The display will show "run" if the program is running, or "oFF" if it is not running. Press the PAGE button to display Actual temperature.

8 Segment & 4x16 Segment Programmable Models w/OTP



Note

The controller will return to the HOME DISPLAY if left idle for more than a few seconds.

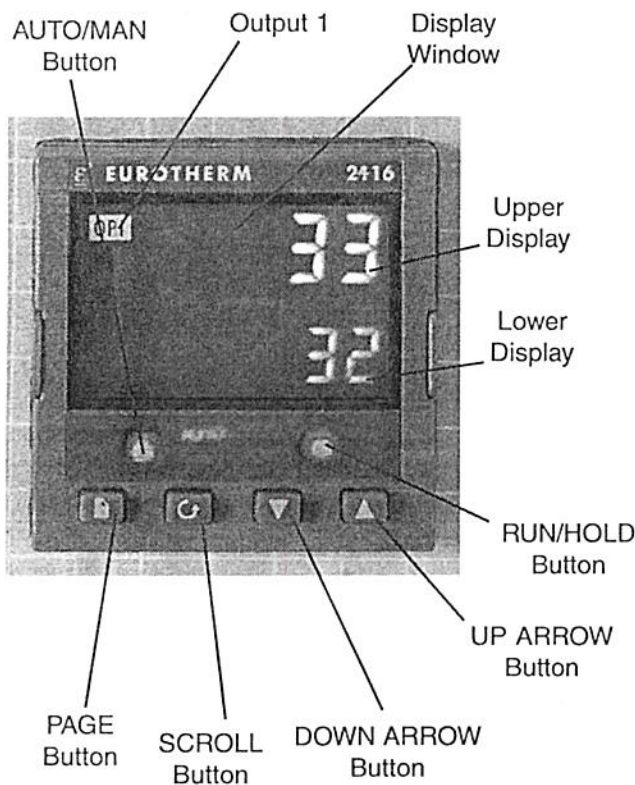


Note

Once the desired parameter has been selected, depressing either the UP or DOWN button will change the parameter value. In all cases, the value shown on the display is the current working value of that parameter.

The **8 segment programmable** controller consists of a microprocessor based three-mode PID (Proportional, Integral, Derivative), programmable temperature controller with over-temperature protection and appropriate output switching devices to control the furnace. The digital readout continuously displays chamber (upper display) and setpoint (lower display) temperatures unless the SCROLL or PAGE button is depressed. The programmable controller can be used as a single setpoint controller or as a programmable controller. The 8 segment digital model enables eight segments of programming.

The **4x16 segment programmable** controller consists of a microprocessor based three-mode PID (Proportional, Integral, Derivative), programmable temperature controller with over-temperature protection and appropriate output switching devices to control the furnace. The digital readout continuously displays chamber (upper display) and setpoint (lower display) temperatures unless the SCROLL or PAGE button is depressed. The programmable controller can be used as a single setpoint controller or as a programmable controller. The 4 program controller has four 16 segment programs.



Basic Operation

When the controller is turned ON, it will perform a short self-test and then change to the HOME DISPLAY. The HOME DISPLAY shows the measured temperature (process value) in the upper display and the desired value (setpoint) in the lower display.

To Change the Setpoint

If you want to change the setpoint, press the UP or DOWN button until the desired setpoint value is displayed in the lower display and then release the button.

To View Display Units

From the HOME DISPLAY press the SCROLL button. The display will briefly show the temperature units in °C/F/K and then return to the HOME DISPLAY. (If you require a different temperature unit call Customer Service.)

To View the % Output Power

From the HOME DISPLAY press the SCROLL button twice. This value is a read-only value and cannot be changed.

Buttons and Indicators

OP1 (Output 1): illuminates when the heating output of the temperature controller is on.

AUTO/MAN: (Auto/Manual Mode): when the controller is in the automatic mode the output automatically adjusts to keep the temperature or process value at the setpoint. The "AUTO" light will illuminate. The manual mode has been disabled through factory configuration. Call Customer Service for further information.

RUN/HOLD (Run/Hold button):

- Starts a program when pressed once—RUN light illuminates.

- Holds a program when pressed again—HOLD light illuminates.
- Cancels hold and continues running when pressed again—HOLD light is off and RUN light illuminates.
- Exits a program when the button is held down for two seconds—RUN and HOLD lights are off.
- At the end of a program the RUN light will flash.
- During holdback the HOLD light will flash.

PAGE button: allows you to choose a parameter from a list of parameters.

SCROLL button: allows you to choose a parameter within a list of parameters.

UP button: allows you to increase the value in the lower display.

DOWN button: allows you to decrease the value in the lower display.

Controller Parameters

Home Display

°C: measured temperature in Celsius.

Temperature units can not be changed without entering the configuration. Contact Customer Service if a different temperature unit is required.

OP: % output power demand; displayed in lower display (cannot be changed).

C.id: Controller identification number.

PrG: Program number (displayed when a program is running; 4x16 programmable models only.)

IdHi: Deviation High Alarm

tunE: One-shot autotune enable.

run LiSt (Program Run List)

PrG: Currently running program (only used on 4x16 programmable models)

StAt: Displays the program status [OFF, run (running active program), hoLd (program on hold), HbAc (waiting for process to catch up), End (program completed)] in the lower display. The controller will default to "OFF."

FAST: Fast run through program (no/YES). The controller will default to "no."

SEG.d: Flash active segment type in the lower display of the home display (no/YES). The controller will default to "no."

ProG LiSt (Program Edit List)

PrG.n: Press the UP or DOWN ARROW to select the program number (program number will be displayed in lower display on 4x16 programmable models only.)

Hb: Press the UP or DOWN ARROW to select the holdback type [OFF (disables holdback), Lo (deviation low holdback), Hi (deviation high holdback) or bAnd (deviation band holdback)] for the entire program. The controller will default to "OFF."

Hb.U: Press the UP or DOWN ARROW to select the holdback value (in display units).

rmP.U: Press the UP or DOWN ARROW to tog-

gle between ramp units (SEc, min or Hour).
Controller will default to "SEc."

dwL.U: Press the UP or DOWN ARROW to toggle between dwell units (SEc, min or Hour).
Controller will default to "SEc."

Cyc.n: Press the UP or DOWN ARROW to set the number of program cycles (1 to 999 or cont). The controller will default to "cont."

SEG.n: Press the UP or DOWN ARROW to select the segment number (1-8 in 8 segment models, 1-16 in 4x16 models).

tYPE: Press the UP or DOWN ARROW to select the segment type [End (end of program), rmP.r = ramp rate (ramp to a specified setpoint at a set rate), rmp.t = ramp time (ramp to a specified temperature in a set time), dwELL (to maintain a constant temperature for a set time), StEP (climb instantaneously from current to specified temperature), cALL (to call a program as a subroutine, available only on 4x16 programmable models)]. The controller will default to "End." Other parameters used with tYPE include; tGt target setpoint), Rate (rate of temperature increase) and dur (time to target setpoint or time to dwell).

End.t: End segment type: dwELL (dwell continuous), rSEt (reset) and S OP (End Segment Output power level).

AL LiSt (Alarm List)

IdHi: Deviation High Alarm.

Atun LiSt: (Autotune List)

tunE: One-shot autotune enable.

drA: Adaptive tune enable.

drA.t: Adaptive tune trigger level in display units. Range = 1 9999.

Pid LiSt

G.SP (Gain Setpoint): Is the temperature at which the controller switches from the (SEt1) PID values to the (SEt 2) PID values.

Pb: Proportional band in display units. (SEt 1)

ti: Integral time in seconds. (SEt 1)

td: Derivative time in seconds. (SEt 1)

Pb2: Proportional band. (SEt 2)

ti2: Integral time in seconds. (SEt 2)

td2: Derivative time in seconds. (SEt 2)

ACCS LiSt (Access List)

Access Code (Code needed to enter or change the other configuration parameters which are not normally accessible.) Not accessible.



Note

The following alarm messages are factory default settings and may vary if you have changed the configuration of your controller:

IDHi: = 50°C
2FSH = 1225°C

Alarms

The controller will flash an alarm message in the home display if an alarm condition is detected.

IdHi: PV deviation high alarm.

2FSH: PV full scale high alarm.

LCr: load current low alarm.

HCr: load current high alarm.

S.br: Sensor break: check that sensor is connected correctly.

L.br: Loop Break: Check that the heating circuits are working properly.

Ld.F: Heater Circuit Fault: indication of either an open or short solid state relay, a blown fuse, missing supply or open circuit heater.

SSr.F: Solid state relay failure indications in a solid state relay: indicates either an open or short circuit in the SSR.

Htr.F: Heater failure: Indication that there is a fault in the heating circuit: indicates either a blown fuse, missing supply or open circuit heater.

Sensor Break Protection

This controller provides sensor break protection in the event the thermocouple opens. If an open thermocouple condition occurs, the digital display will Blink "S.br" and the power to the heating element will be shut OFF (Cycle light will extinguish).

Over-Temperature Protection (OTP)

The OTP will be in effect during any alarm condition when the temperature of the furnace has deviated beyond the limit. The "Deviation High" alarm is the only alarm value which can be changed. To change it, press the SCROLL button until "idHi" appears on the display. Press the UP or DOWN button to select the OTP value you desire. We recommend a value of 20° above your working temperature to provide protection for your workload.

To Operate the Controller as a Single Setpoint Controller

1. Switch the circuit breaker to the "ON" position. The setpoint temperature presently set in the controller will appear in the lower display. (The upper display indicates the actual chamber temperature.)
2. To change the setpoint, press the UP or DOWN button until the desired setpoint value is displayed; then release the button.
3. The furnace will begin to heat if the new setpoint temperature is higher than the present chamber temperature.

Programming the Controller

The controller is capable of varying temperature or process value with time through programming. A program is stored as a series of segments and can be run once, repeated a set number of times or run continuously. To create a customized program using the controller parameters listed under "Controller Parameters" at the beginning of this section, follow the procedures outlined in the proceeding sections of this manual.

Creating a New Program or Editing an Existing Program (4x16 Segment Programmable Models Only)

The same steps are used when creating a new program and editing an existing program with the exception being that a new program starts with all its segments set to End in the TYPE parameter. Temporary changes can be made to these param-

eters when the program is in the hold state but permanent changes must be made in the reset state. Follow the steps below to create or edit a program.

1. Press the PAGE button until you reach the program list (ProG LiSt).
2. Press the SCROLL button until display reads, "PrG.n."
3. Press the UP or DOWN button to select a number for a new program or to edit an existing program.

Hb: Holdback

Holdback consists of a value and a type. If the measured value lags behind the setpoint by an undesirable amount during a ramp or dwell, the holdback feature can be used to freeze the program at its current state (the HOLD light will flash). The program will resume when the error comes within the holdback value.

OFF: holdback is disabled.

Lo (Deviation Low Holdback): holds the program back when process variable deviates below the setpoint by more than the holdback value.

Hi (Deviation High Holdback): holds the program back when process variable deviates above the setpoint by more than the holdback value.

bAnd (Deviation Band Holdback): combines the features of the high and low deviation holdback in that it holds the program back when the process variable deviates above or below the setpoint by more than the holdback value.

To set the holdback type:

1. Press the PAGE button until you reach the program list (ProG LiSt).
2. Press the SCROLL button until display reads, "Hb."
3. Press the UP or DOWN button to toggle between "bAnd, Hi, Lo and OFF."

Hb U: Holdback Value

To set the holdback value:

1. Press the PAGE button until you reach the program list (ProG LiSt).
2. Press the SCROLL button until display reads, "Hb.U."
3. Press the UP or DOWN button to enter a holdback value.



Note

The value set in this parameter is always for the entire program.

rmP.U: Setting Ramp Units

Ramp units are time units which are used in "rmP.r" segments (ramp to a setpoint at degrees per second, minute or hour) and "rmP.t" segments (ramp to setpoint in a specific amount of time). See "Setting the Segment Type" for an explanation on how to set a ramp segment.

1. Press the PAGE button until you reach the program list (ProG LiSt).
2. Press the SCROLL button until display reads, "rmP.U."
3. Press the UP or DOWN button to toggle between seconds, minutes and hours.

dwL.U: Setting Dwell Units

Dwell units are time units which are used in "dwELL" segments (amount of time to remain at a specific temperature). See "Setting the Segment Type" for an explanation on how to set a dwell segment.

1. Press the PAGE button until you reach the program list (ProG LiSt).
2. Press the SCROLL button until display reads, "dwL.U."
3. Press the UP or DOWN button to toggle between seconds, minutes and hours.

CYC.n: Setting the Number of Cycles

Set the number of times a group of segments or programs are to be repeated by following the steps listed below.

1. Press the PAGE button until you reach the program list (ProG LiSt).
2. Press the SCROLL button until display reads,"CYC.n."
3. Press the UP or DOWN button to select the number of cycles you want to run or, press the DOWN button to select "cont." so the program will run continuously.

Setting the Segment Type

There are five segment types. Proceed with the following steps according to the type of segment you have selected.

**Note**

The program ramp rate is designed to reduce the heatup rate or cooling rate that the furnace normally exhibits. When not using this feature, the furnace will operate at its maximum heating and cooling capability.

**Note**

When the program ramp has ended or has been reset, the furnace will continue to maintain setpoint temperature. It will not cool to ambient temperature unless the setpoint is set to ambient temperature by the program or by the operator.

rmP.r (Ramp)

To ramp linearly at a set rate to a specified temperature:

1. Press the PAGE button until you reach the program list (ProG LiSt).
2. Press the SCROLL button until display reads, "tYPE."
3. Press the UP or DOWN button until display reads, "rmP.r."

Steps 4 and 5 are used in the 4 program model only. If you are using an 8 segment program, skip to step 6.

4. Press the SCROLL button until display reads "Hb."
5. Press the UP or DOWN button to toggle between "bAnd, Hi, Lo and OFF."
6. Press the SCROLL button until display reads, "tGt."
7. Press the UP or DOWN button to set a target setpoint.
8. Press the SCROLL button until display reads, "rAtE."
9. Press the UP or DOWN button to select a value in ramp units (seconds, minutes or hours; set in the "rmP.U" parameter).

rmP.t

To ramp to a specified temperature at a set time:

1. Press the PAGE button until you reach the program list (ProG LiSt).
2. Press the SCROLL button until display reads, "tYPE."

3. Press the UP or DOWN button until display reads, "rmPt."
4. Press the SCROLL button until display reads, "tGt."
5. Press the UP or DOWN button to set a target setpoint.
6. Press the SCROLL button until display reads, "dur."
7. Press the UP or DOWN button to select a time in ramp units (seconds, minutes or hours; set in the "rmP.U" parameter).

dwEll

To maintain a constant temperature for a specified time:

1. Press the PAGE button until you reach the program list (ProG LiSt).
2. Press the SCROLL button until display reads, "tYPE."
3. Press the UP or DOWN button until display reads, "dwEll."
4. Press the SCROLL button until display reads, "dur."
5. Press the UP or DOWN button to select a time in dwell units (seconds, minutes or hours; set in the "dwL.U" parameter).

StEP

To climb instantaneously from the current temperature to a specified temperature.

1. Press the PAGE button until you reach the program list (ProG LiSt).

2. Press the SCROLL button until display reads, "tYPE."
3. Press the UP or DOWN button until the display reads, "StEP."
4. Press the SCROLL button until display reads, "tGt."
5. Press the UP or DOWN button to set a target setpoint.

cALL (Running Multiple Programs; 4x16 Segment Programmable Models Only)

To call a program as a subroutine:

If you want to run multiple programs, you can program the controller to "call" or link one program to another. This makes it possible to run one program at any time during another program and also return to the original program if desired.

1. Press the PAGE button until you reach the program list (ProG LiSt).
2. Press the SCROLL button until display reads, "tYPE."
3. Press the UP or DOWN button until display reads, "cALL."
4. Press the SCROLL button until display reads, "PrG.n."
5. Press the UP or DOWN button to select a program number to be linked.
6. Press the SCROLL button until display reads, "CYC.n."
7. Press the UP or DOWN button to select the number of cycles the linked program is to be run.

End

To end or repeat a program:

1. Press the PAGE button until you reach the program list (ProG LiSt).
2. Press the SCROLL button until display reads, "tYPE."
3. Press the UP or DOWN button until display reads, "End."
4. Press the SCROLL button until display reads, "End.t."
5. Press the UP or DOWN button to toggle between "dwell" (an indefinite dwell), "S OP" (End Segment Output Power) and "rSET" (reset).

Setting the Target Setpoint (4x16

Segment Programmable Models Only)

1. Press the PAGE button until you reach the program list (ProG LiSt).
2. Press the SCROLL button until display reads, "tGt."
3. Press the UP or DOWN button to set the target setpoint temperature.

Running a Program (8 Segment Programmable Models)

To run a program, press the RUN/HOLD button. (The RUN light will illuminate.)

Running a Program (4x16 Segment Programmable Models)

To run a program, press the RUN/HOLD button. (The RUN light will illuminate) or:

1. Press the PAGE button until you reach the run list (run LiSt).
2. Press the SCROLL button until display reads, "PrG."
3. Press the UP or DOWN button to select the program number you want to run.
4. Press the RUN/HOLD button once to start the program. (The RUN light will illuminate.)

Holding a Program

To put a running program on hold, press the RUN/HOLD button. (The HOLD light will illuminate.)

Cancelling a Program

To cancel a program, hold the RUN/HOLD button down until the RUN and HOLD lights go off.

Tuning your Furnace

The purpose of tuning your furnace is to match the characteristics of your controller to the characteristics of the process being controlled. Good control is evidenced by: stable, straight-line control of the setpoint temperature with no fluctuations; No overshoot or undershoot of the setpoint temperature; rapid restoration of the setpoint



Note

Display will flash "tu.ER" if an error occurs during tuning. To clear the error and restart tuning, simultaneously press the PAGE and SCROLL buttons and follow the steps outlined in "Autotuning."



Note

To stop the tuning function, simultaneously press the PAGE and SCROLL buttons.

temperature when external disturbances cause deviations from the setpoint.

This controller has automatic tuning features which install optimum tuning parameters to give the best temperature accuracy. No manual loading of tuning parameters is needed. We recommend that you tune the furnace to your specific application to obtain the best results. To provide the best temperature accuracy possible, use these features when you install your furnace and whenever you change your application or procedure.

Tuning Error

The display will flash "tu.ER" if an error occurs during tuning. To clear the error and restart tuning, simultaneously press the PAGE and SCROLL buttons and follow the steps outlined in "Autotuning."

Gain Scheduling

G.SP: Gain Scheduling

Gain scheduling is the automatic transfer of control between two sets of PID values. The 2416 controller does this at a presettable process value. Gain scheduling is used for difficult control processes which show large changes in their response time or sensitivity at high or low temperatures, or when heating or cooling.

The G.SP gain schedule setpoint is factory set at 700° C. The G.SP must be adjusted to 200°C from the desired setpoint temperature when tuning.

Setting the Transfer Point

If gain scheduling has been enabled, "G.SP" will appear at the top of the PID list. This sets the value at which the transfer will occur. When the process value is below this level, PID1 will be active and when it is above, Pid2 will be active. Set a value between the control regions that show the greatest change to achieve the best point of transfer.

Tuning

The two sets of PID values can be manually set or automatically tuned. To tune automatically you must tune above and below the transfer point G.SP. If the process value is below the transfer point G.SP, the calculated values will automatically be inserted into the (SEt 1) set and if the process value is above G.SP, the calculated values will automatically be inserted into the (SEt 2).

Autotuning

The Autotune feature automatically sets up the PID values in the control parameters to suit new process conditions.

To tune your furnace using autotuning:

1. Load your furnace with a load similar to your normal load and close the door.
2. Set the setpoint temperature.
3. Press the PAGE button until the display reads, "Atun LiSt."
4. Press the SCROLL button until "tunE OFF" is displayed.
5. Press the UP or DOWN button to select "on."

6. Simultaneously press the PAGE and SCROLL buttons to return to the HOME DISPLAY. The display will flash "tunE" while tuning is in progress.

Adaptive Tuning

Adaptive tuning continuously evaluates tuning parameters. Adaptive tuning automatically installs new values if better accuracy is possible. Adaptive tuning should be used when the characteristics of a process change due to load or setpoint changes or, in a process that can not handle the oscillation caused by a one-shot tune.

To tune your furnace using adaptive tuning:

1. Load your furnace with a load characteristic of those you intend to heat in it.
2. Press the PAGE button until display reads, "Atun LiSt."
3. Press the SCROLL button until "drA OFF" is displayed.
4. Press the UP or DOWN button to select "on."
5. Press the SCROLL button until "drA.t" is displayed.
6. Press the UP or DOWN button until the desired trigger value is achieved.
 - For best results, use only the center two-thirds of the furnace chamber.
 - If you are heating a number of small parts, spread them throughout the center two-thirds of the furnace chamber.

- Keep objects away from the thermocouple.
- Use insulated tongs and mittens when loading and unloading the furnace.
- Always wear safety glasses.
- Never come into contact with the heating elements. Hitting the elements with tongs or laying the load against them will cause the elements to burn out prematurely.

Furnace Loading

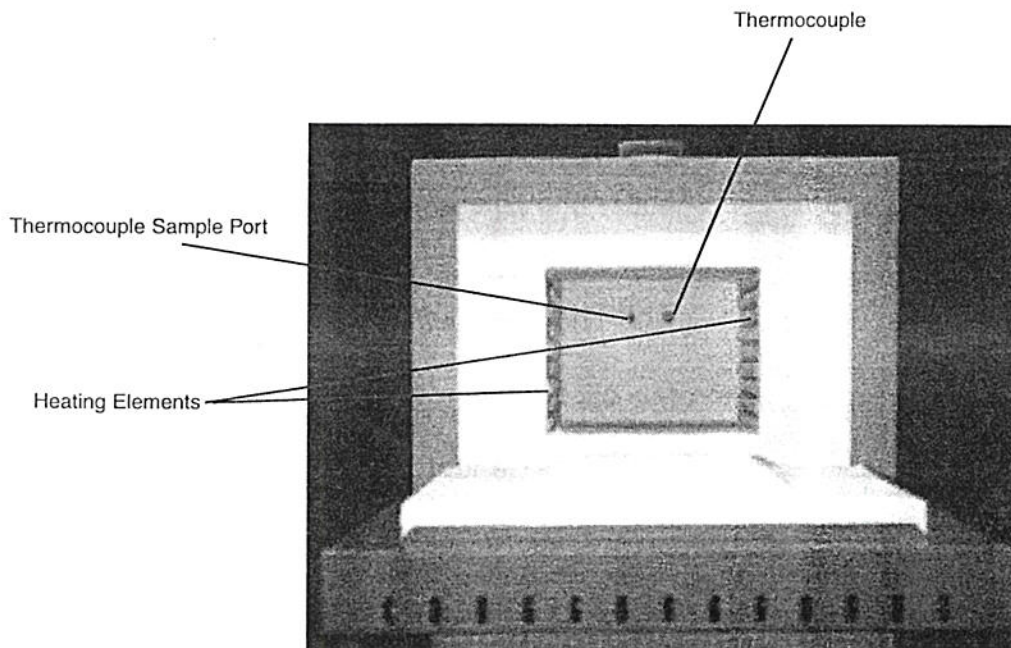


Caution

Do not overload your furnace chamber. If the load is to be heated uniformly, it should not occupy more than two-thirds of the furnace chamber. Maintain at least a 3/4" gap between the load and elements. Failure to observe this caution could result in damage to the furnace components.

This unit is equipped with a venting system on the top of the furnace. This is for the removal of fumes from the chamber of the unit.

Contamination is a major cause of element failure, therefore, remove all fume forming material before heating. (e.g. clean cutting oil from tool steel).



Preventive Maintenance

Housekeeping is vital to your electric furnace – KEEP IT CLEAN. Run your furnace up to 871°C (1600°F) empty occasionally to burn off the contamination that may exist on the insulation and elements. Maintain 871°C (1600°F) for at least 4 hours to ensure complete ashing of foreign materials.

Element life is reduced somewhat by repeated heating and cooling. If the furnace is to be used again within a few hours, it is best to keep it at the operating temperature or at a reduced level such as 260°C (500°F). We highly recommend that you replace the thermocouple periodically (once every six months) to ensure temperature accuracy.

General Cleaning Instructions

Wipe exterior surfaces with a lightly dampened cloth containing a mild soap solution. The Troubleshooting section is intended to aid in defining and correcting possible service problems. When using the chart, select the problem category that resembles the malfunction. Then proceed to the possible causes category and take necessary corrective action.

Problem	Possible Causes
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Troubleshooting

Corrective Action

Cycle light does not illuminate.	The furnace is not connected to power supply.	Reconnect furnace to power supply.
	Incorrect power source.	Connect to correct power source.
	ON and OFF power switch defective.	Replace power switch.
	Defective cycle light.	Replace cycle light.
	Door switch malfunction.	Realign or replace furnace door safety switch.
Furnace does not heat.	No power.	Check power source and fuses or breakers.
	Defective electrical hookup.	Repair electrical hookup.
	Thermocouple has oxidized and opened the circuit.	Replace thermocouple.
	Controller malfunction.	Replace controller.
	Heating elements burned out.	Replace defective elements.
	Door switch malfunction.	Realign or replace door safety switch.
	Defective OTP relay.	Replace relay.
	Defective solid state relay.	Replace relay.
Door switch does not cut power to heating elements.	Door switch not functioning.	Realign or replace door safety switch.
Problem (cont.)	Possible Causes (cont.)	Corrective Action (cont.)

Controller over-temp. does not cut power to furnace chamber.	Alarm output device malfunction.	Replace controller.
	OTP relay malfunction.	Replace relay.
	Element shorted to ground.	Replace faulty element.
Slow heatup.	Low line voltage.	Install line of sufficient size and voltage (isolate furnace from other electrical loads).
	Heavy load in chamber.	Lighten load in chamber to allow heat to circulate.
	Wrong heating element.	Install proper element.
	Heating element burned out.	Replace element.
Repeated element burnout.	Overheating furnace.	Keep furnace under maximum temperature. Closer supervi- sion of control setting.
	Heating harmful materials.	Enclose material in container. Clean up spills in and on chamber. Ventilate chamber by leaving top vent slightly open when heating known harmful reagents.
	Contamination from previous burnout.	Replace insulation material.
Inaccurate temp. readout.	Oxidized or contaminated thermocouple.	Replace thermocouple.
	Poor thermocouple connection.	Tighten connections.
Problem (cont.)	Possible Causes (cont.)	Corrective Action (cont.)

TROUBLESHOOTING

Improper loading procedures.	Use proper loading procedures.
Poor ventilation of control.	Clear area around furnace control.
Thermocouple connections reversed.	Reconnect thermocouple correctly.

Maintenance and Servicing



Warning

To avoid electrical shock, this furnace must always be disconnected from the power supply prior to maintenance and service.

Perform only maintenance described in this manual. Contact an authorized dealer or our factory for parts and assistance.

Refer servicing to qualified personnel.



Note

The ceramic hearth collar may crack. This is a normal condition and will not affect the performance of the hearth collar.

To Replace a Heating Element

1. Disconnect the furnace from the power supply.
2. Remove the back terminal cover of the furnace. (Note placement and connection of wires.)
3. Loosen the nuts on the terminal points of the four heating element lead wires and remove the element wires from the terminals.
4. Loosen the thermocouple hold-down clip and carefully remove the thermocouple from the rear of the furnace chamber.
5. Remove both the back of the furnace and the blanket insulation.
6. Grasp the element lead wires and pull out both elements and the back chamber insulation.
7. Replace the defective element.
8. Reverse the disassembly procedure, making sure you thread all element lead wires through the insulating porcelain bushings on the back of the furnace and cut off any excess element lead wire after securing the leads to the terminal points.
9. Reconnect the furnace to the power supply.
10. Test the operation of the furnace.

To Replace a Chromel/Alumel Thermocouple (All Furnaces)

1. Disconnect the furnace from the power supply.
2. Remove both back covers. (Note placement and connection of wires.)
3. Remove the clip holding the thermocouple in place (1 screw), and remove the two screws on the thermocouple terminals.
4. Remove the thermocouple. (Note: first pull the thermocouple straight out of the hole in the chamber to avoid damage to the insulation.)
5. Guide the looped ends of the new thermocouple through the plastic bushings with the red (-) lead to the right as you face the back of the furnace.
6. Insert the thermocouple straight through the hole in the chamber.
7. Secure the thermocouple with clip and screw. Connect the looped ends of the thermocouple to the terminals with "+" to "+" (yellow) and "-" to "-" (red) wires. A polarity test of the thermocouple and lead wire is easily made with the use of a magnet. On a Chromel/Alumel thermocouple and lead wire, the non-magnetic wire is positive (+) and the magnetic wire is negative (-).

8. Replace both back covers.
9. Reconnect to the power supply.
10. Test the operation of the furnace.

To Replace Door Switches (Micro-Switch)

1. Disconnect the furnace from the power supply.
2. Remove the screws on the front dial and the screws and lock washers on the back cover.
3. Slide the control section forward.
(Note: do not pull excessively on the internal wires.)
4. Disconnect the wires from the door switch. (Note the connection placement of the wires to the micro-switch.)
5. Remove the screws and nuts from the micro-switch.
6. Insert new micro-switches and secure with the screws and nuts removed in step 5.
7. Reconnect the wires to the new door switch.
8. To realign the door switches, see the following section, "To Realign Door Switches."

9. Slide the control section back and replace the screws and lock washers described in step 2.
10. Reconnect to the power supply.
11. Test the operation of the door switches. (See next section, step 8.)

To Realign Door Switches (Micro-Switch):

1. Disconnect the furnace from the power supply.
2. Remove the lower rear cover.
3. With the door closed, loosen the screws on the micro-switch bracket and gently push the switch bracket forward until you hear a click.
4. Open and close the door; the switch should click when the door is opened approximately 3" and 1" to 2" before the door is closed. Slide the switches backward to increase the distance, forward to decrease the distance.
5. Tighten the two screws to secure the switches. Check the operation of the switch as described in step 4 after tightening the screws.
6. Replace the back cover.
7. Reconnect to power supply.
8. To test the operation of the door

switch: move the power switch on, set the control to a setting high enough to keep the control from cycling, open and close the door; the cycle light should turn OFF when the door is opened approximately 3" and turn back ON 1" to 2" before the door is closed.

To Replace the Controller

The controller plugs into a panel mounting sleeve which should be left permanently installed in the furnace housing. To remove the controller, release the side clips and slide the controller out. Do not attempt to dismantle this unit further; replace it with a Thermolyne loaner or a new unit.

Replacement Parts

Single Setpoint Models



Warning
Replace fuses with same type
and rating.

F47910, F47910-26, F47910-33, F47910-33CN, F47914, F47915, F48010, F48010-26, F48010-33, F48010-33CN, F48014, F48015-60, F48018

<u>Part number</u>	<u>Description</u>	<u>QTY.</u>	<u>Notes</u>
CN71X96	Controller	1	F48010-33, F48010-33CN only.
CN71X73	Controller	1	All Models except F48010-33 and F48010-33CN
CAX94	Line Filter	1	"-33" models only.
EL479X1A	Element	2	120 & 240 volt F47900 models only.
EL479X2A	Element	2	100 volt F47900 models only.
EL480X1A	Element	2	120 & 240 volt F48000 models only, except "-33" models.
EL480X2A	Element	2	208 volt F48000 models only.
EL1205X1	Element	2	"-33" F48000 models only.
FZX4	Line Fuse	2	100 & 120 volt F47900 models only
FZX29	Line Fuse	2	120 volt F48000 models only
FZX30	Line Fuse	2	208 & 240 volt models only.
PLX76	Pilot Light	1	100 & 120 volt models only.
PLX82	Pilot Light	1	208 & 240 volt models only.
RYX34	S.S. Relay	1	All Models
SWX163	Door Switch	2	All Models
SWX143	Power Switch	1	100 & 120 volt models only
SWX144	Power Switch	1	208 & 240 volt models only.
TRX136	Terminal Block	1	All Models
TC1165X1	Thermocouple	1	All Models

Single Setpoint Models with OTP

F47920, F47920-26, F47920-33, F47920-33CN, F47924, F47925, F48020, F48020-26, F48020-33, F48020-33CN, F48025, F48025-60, F48028

<u>Part number</u>	<u>Description</u>	<u>QTY.</u>	<u>Notes</u>
CN71X100	Controller	1	F48020-33 and F48020-33CN only.
CN71X99	Controller	1	All Models except F48020-33, F48020-33CN
CAX94	Line Filter	1	"-33 models only.
EL479X1A	Element	2	120 & 240 volt F47900 models only.
EL479X2A	Element	2	100 volt F47900 models only.
EL480X1A	Element	2	120 & 240 volt F48000 models only, except "-33" models.
EL480X2A	Element	2	208 volt F48000 models only.
EL1205 X1	Element	2	"-33" F48000 models only.
FZX4	Line Fuse	2	100 & 120 volt F47900 models only
FZX29	Line Fuse	2	120 volt F48000 models only
FZX30	Line Fuse	2	208 & 240 volt models only.
PLX76	Pilot Light	1	100 & 120 volt models only.
PLX82	Pilot Light	1	208 & 240 volt models only.
RYX34	S.S. Relay	1	All Models
RYX56	Mechanical Relay	1	100 & 120 volt models only.
RYX57	Mechanical Relay	1	208 & 240 volt models only.
SWX163	Door Switch	2	All Models
SWX143	Power Switch	1	100 & 120 volt models only
SWX144	Power Switch	1	208 & 240 volt models only.
TRX136	Terminal Block	1	All Models
TC1165X1	Thermocouple	1	All Models

8 Segment Programmable Models with OTP

F47920-80, F47920-26-80, F47920-33-80, F47920-33-80CN, F47924-80, F47925-80, F48020-80, F48020-26-80, F48020-33-80, F48020-33-80CN, F48025-60-80, F48028-80

<u>Part number</u>	<u>Description</u>	<u>QTY.</u>	<u>Notes</u>
CN71X97	Controller	1	-33 models only
CN71X74	Controller	1	All models except -33 models
CAX94	Line Filter	1	"-33" models only.
EL479X1A	Element	2	120 & 240 volt F47900 models only.
EL479X2A	Element	2	100 volt F47900 models only.
EL480X1A	Element	2	120 & 240 volt F48000 models only, except "-33" models.
EL480X2A	Element	2	208 volt F48000 models only.
EL1205X1	Element	2	"-33" F48000 models only.
FZX4	Line Fuse	2	100 & 120 volt F47900 models only.
FZX29	Line Fuse	2	120 volt F48000 models only.
FZX30	Line Fuse	2	208 & 240 volt models only.
PLX76	Pilot Light	1	100 & 120 volt models only.
PLX82	Pilot Light	1	208 & 240 volt models only.
RYX34	S.S. Relay	1	All Models
RYX56	Mechanical Relay	1	100 & 120 volt models only.
RYX57	Mechanical Relay	1	208 & 240 volt models only.
SWX163	Door Switch	2	All Models
SWX143	Power Switch	1	100 & 120 volt models only
SWX144	Power Switch	1	208 & 240 volt models only.
TRX136	Terminal Block	1	All Models
TC1165X1	Thermocouple	1	All Models

4 X 16 Segment Programmable Models with OTP

F47950, F47950-26, F47950-33, F47950-33CN, F47954, F47955, F48050, F48050-26, F48050-33, F48050-33CN, F48055-60, F48058

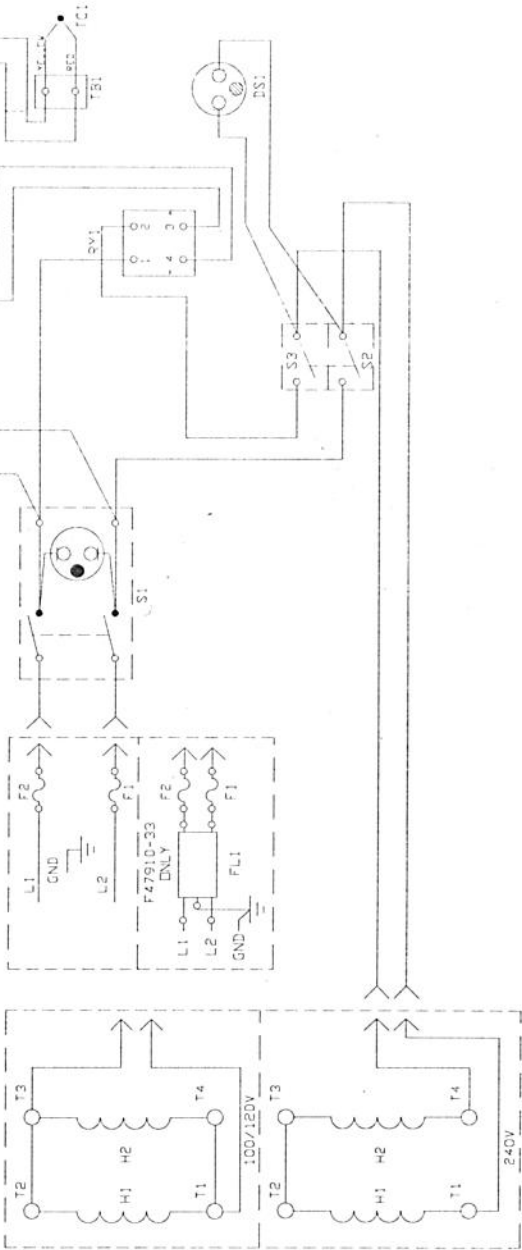
<u>Part number</u>	<u>Description</u>	<u>QTY.</u>	<u>Notes</u>
CN71X98	Controller	1	-33 models only
CN71X75	Controller	1	All models except -33 models
CAX94	Line Filter	1	"-33" models only.
EL479X1A	Element	2	120 & 240 volt F47900 models only.
EL479X2A	Element	2	100 volt F47900 models only.
EL480X1A	Element	2	120 & 240 volt F48000 models only, except "-33" models.
EL480X2A	Element	2	208 volt F48000 models only.
EL1205X1	Element	2	"-33" F48000 models only.
FZX4	Line Fuse	2	100 & 120 volt F47900 models only.
FZX29	Line Fuse	2	120 volt F48000 models only.
FZX30	Line Fuse	2	208 & 240 volt models only.
PLX76	Pilot Light	1	100 & 120 volt models only.
PLX82	Pilot Light	1	208 & 240 volt models only.
RYX34	S.S. Relay	1	All Models
RYX56	Mechanical Relay	1	100 & 120 volt models only.
RYX57	Mechanical Relay	1	208 & 240 volt models only.
SWX163	Door Switch	2	All Models
SWX143	Power Switch	1	100 & 120 volt models only
SWX144	Power Switch	1	208 & 240 volt models only.
TRX136	Terminal Block	1	All Models
TC1165X1	Thermocouple	1	All Models

Wiring Diagrams

SINGLE SETPOINT CONTROL

Diagram Component List

Ref. No.	Description	Model No. and Our Part No.(s)
		F47910 F47910-26 F47910-33 & F47910-33CN F47914 F47915
CN1	Control	CN71X73
DS1	Pilot Light	PLX104
F1	Fuse	FZX30
F2	Fuse	FZX30
FL1	Filter	CAX98
H1	Heating Element	EL479X1A
H2	Heating Element	EL479X1A
RY1	Relay, Solid State	RYX34
S1	Switch, Power	SWX144
S2	Switch, Door	SWX163
S3	Switch, Door	SWX163
TB1	Terminal Block	TRX136
TC1	Thermocouple	TC1165X1

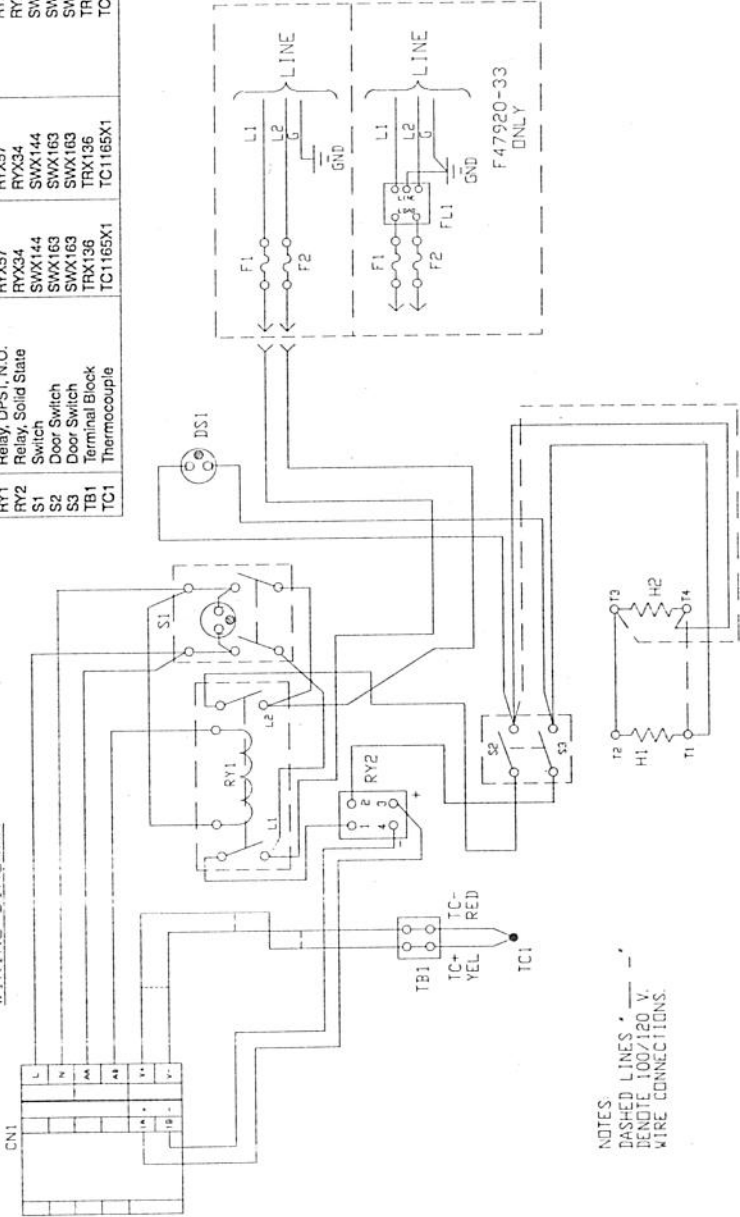


WIRING DIAGRAMS SINGLE SETPOINT CONTROL W/OTP

Diagram Component List

Ref. No.	Description	Model No. and Our Part No.(s)	F47920	F47920-26	F47920-33 & F47920-33CN	F47924	F47925
CN1	Control	CN71X99	CN71X99	PLX82	PLX82	PLX76	CN71X99
DS1	Pilot Light	PLX82	PLX82	PLX82	PLX82	PLX76	PLX76
F1	Fuse	FZX30	FZX30	FZX30	FZX30	FZX4	FZX4
F2	Fuse	FZX30	FZX30	FZX30	FZX30	FZX4	FZX4
FL1	Filitor, EM1	EL479X1A	EL479X1A	EL479X1A	EL479X1A	EL479X2A	EL479X1A
H1	Heating Element	EL479X1A	EL479X1A	EL479X1A	EL479X1A	EL479X2A	EL479X1A
H2	Heating Element	EL479X1A	EL479X1A	EL479X1A	EL479X1A	EL479X2A	EL479X1A
RY1	Relay, DPST, N.O.	RYX57	RYX57	RYX57	RYX57	RYX56	RYX56
RY2	Relay, Solid State	RYX34	RYX34	RYX34	RYX34	RYX34	RYX34
S1	Switch	SWX144	SWX144	SWX144	SWX144	SWX143	SWX143
S2	Door Switch	SWX163	SWX163	SWX163	SWX163	SWX163	SWX163
S3	Door Switch	SWX163	SWX163	SWX163	SWX163	SWX163	SWX163
TB1	Terminal Block	TRX136	TRX136	TRX136	TRX136	TRX136	TRX136
TC1	Thermocouple	TC1165X1	TC1165X1	TC1165X1	TC1165X1	TC1165X1	TC1165X1

WIRING DIAGRAM



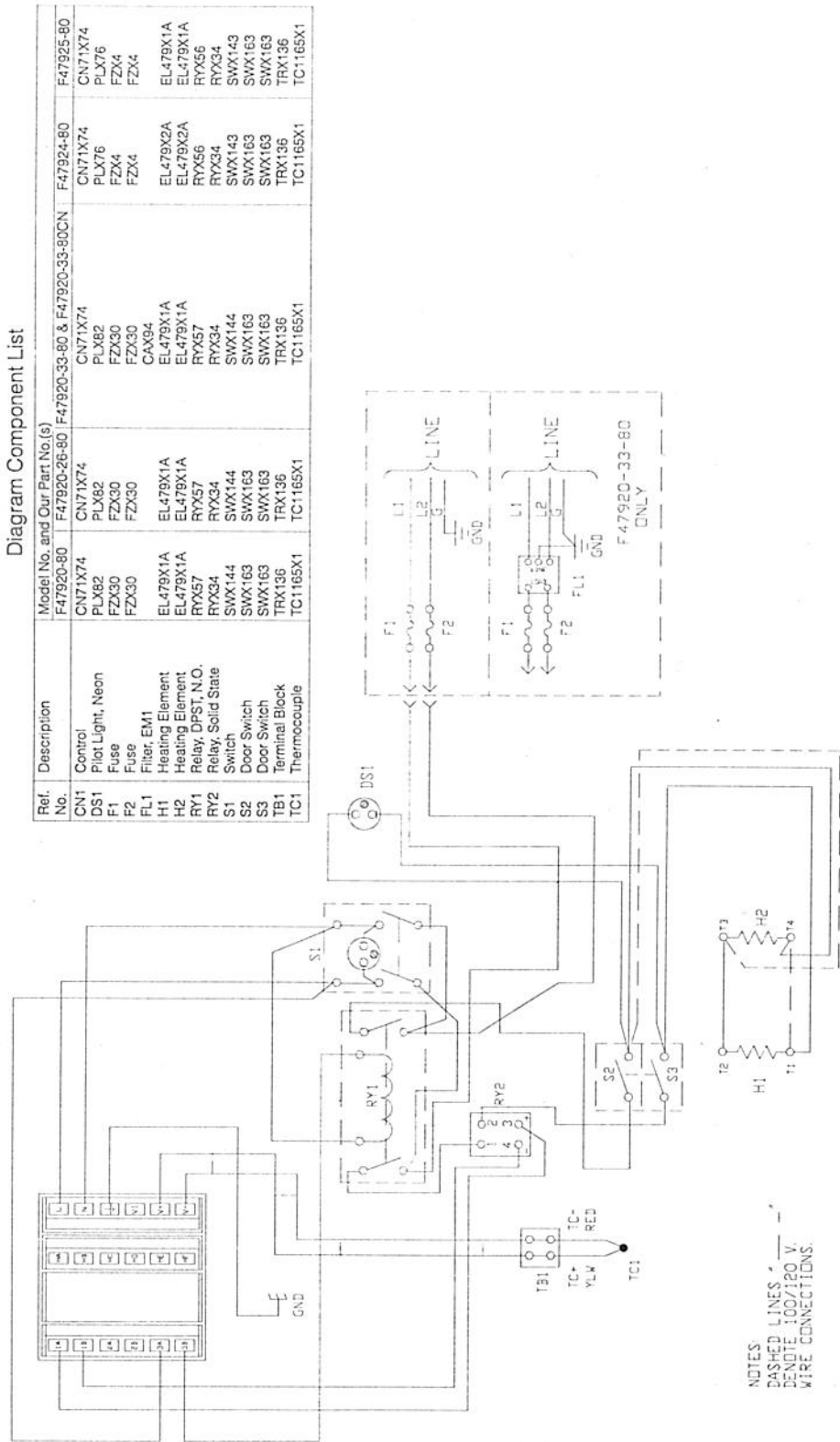
NOTES:

DASHED LINES
DENOTE 100/120 V.
WIRE CONNECTIONS.

WIRING DIAGRAMS

8 SEGMENT PROGRAMMABLE CONTROL

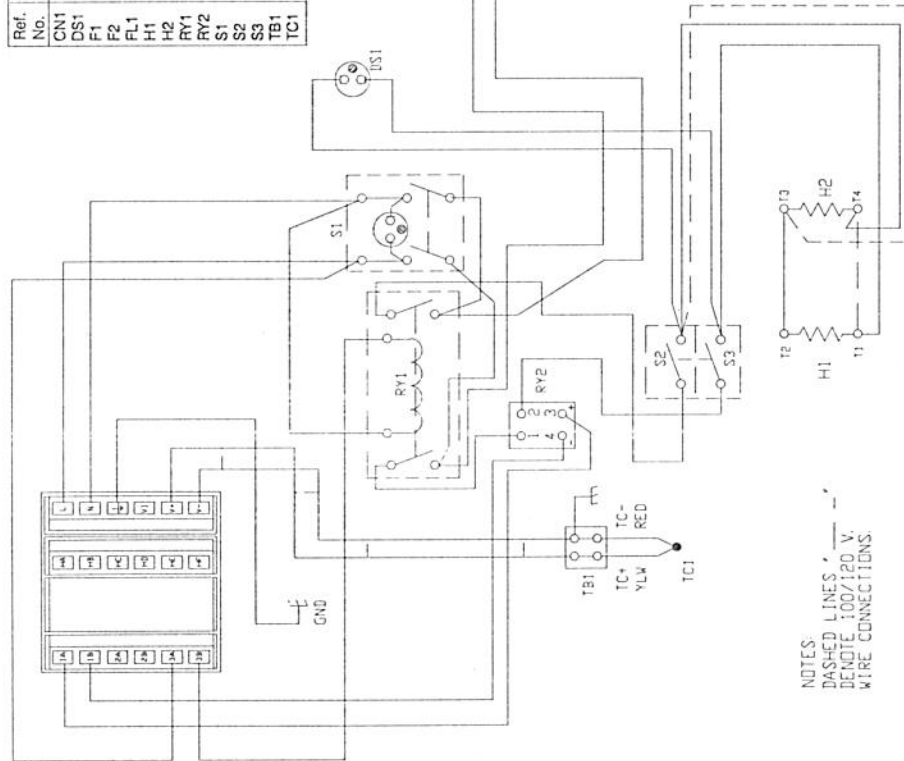
WIRING DIAGRAM



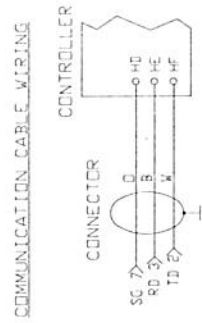
WIRING DIAGRAMS 4 x 16 SEGMENT PROGRAMMABLE CONTROL

Diagram Component List

Ref. No.	Description	Model No. and Our Part No.(s)	F47950-33 & F47950-33CN	F47954	F47955
CN1	Control	F47950	CN71X75	CN71X75	CN71X75
DS1	Pilot Light, Neon	F47950-26	PLX82	PLX76	PLX76
F1	Fuse		FZX30	FZX4	FZX4
F2	Fuse		FZX30	FZX4	FZX4
FL1	Filler, EM1		FZX30		
H1	Heating Element		EL479X1A	EL479X2A	EL479X1A
H2	Heating Element		EL479X1A	EL479X2A	EL479X1A
RY1	Relay, DPST, N.O.		RYX57	RYX56	RYX56
RY2	Relay, Solid State		RYX34	RYX34	RYX34
S1	Switch		SWX144	SWX143	SWX143
S2	Door Switch		SWX163	SWX163	SWX163
S3	Door Switch		SWX163	SWX163	SWX163
TB1	Terminal Block		TRX136	TRX136	TRX136
TC1	Thermocouple		TC1165X1	TC1165X1	TC1165X1



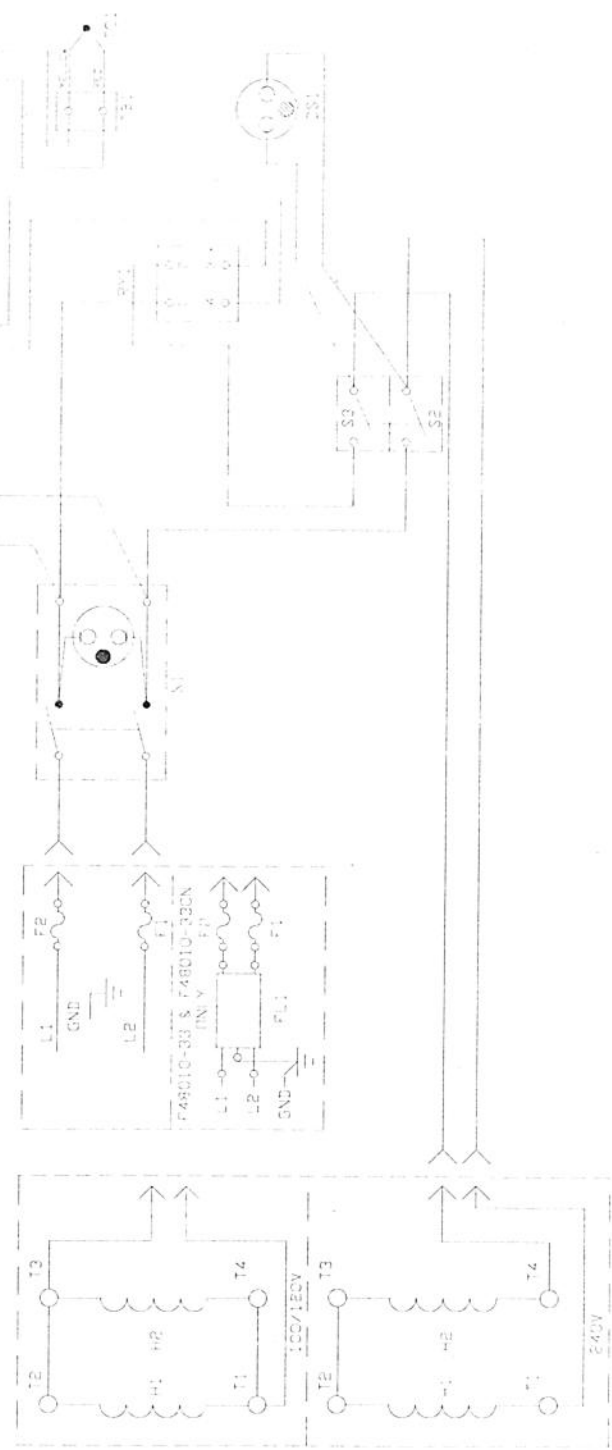
NOTES:
DASHED LINES * DENOTE 100/120 V.
WIRE CONNECTIONS.



WIRING DIAGRAMS
SINGLE SETPOINT CONTROL

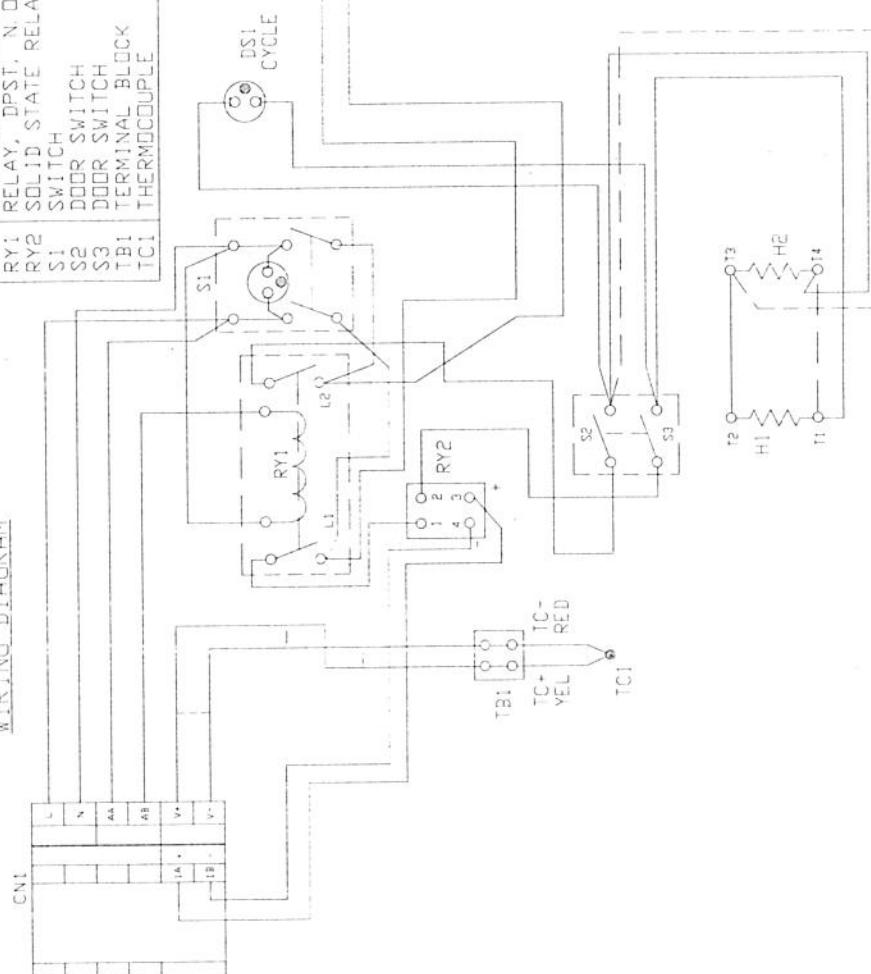
DIAGRAM COMPONENT LIST

REF. NO.	DESCRIPTION	F48010	F48010-26	F48010-33	F48014	F48015-60	F48018
CN:	CONTROL	CN71X73	CN71X73	CN71X95	CN71X73	CN71X73	CN71X73
JS:	PILOT LIGHT	PLX82	PLX82	PLX82	PLX76	PLX76	PLX82
F1:	FUSE	FZX30	FZX30	FZX30	FZX29	FZX29	FZX30
F2:	FUSE	FZX30	FZX30	FZX30	FZX29	FZX29	FZX30
FL1:	FILTER	EL480X1A	EL480X1A	CAX94	EL480X2A	EL480X1A	EL480X2A
H1:	HEATING ELEMENT	EL480X1A	EL480X1A	EL1205X1	EL480X2A	EL480X1A	EL480X2A
H2:	HEATING ELEMENT	EL480X1A	EL480X1A	EL1205X1	EL480X2A	EL480X1A	EL480X2A
RY:	RELAY, SOLID STATE	RYX34	RYX34	RYX34	RYX34	RYX34	RYX34
S1:	SWITCH, POWER	SWX144	SWX144	SWX144	SWX143	SWX143	SWX144
S2:	SWITCH, DDCR	SWX163	SWX163	SWX163	SWX163	SWX163	SWX163
S3:	SWITCH, DDCR	SWX163	SWX163	SWX163	SWX163	SWX163	SWX163
TB1:	TERMINAL BLOCK	TRX136	TRX136	TRX136	TRX136	TRX136	TRX136
TC1:	TERMINAL BLOCK	TC1165X1	TC1165X1	TC1165X1	TC1165X1	TC1165X1	TC1165X1



SINGLE SETPOINT CONTROL W/OTP

REF. NO.	DESCRIPTION	MODEL NO. AND OUR PART NO. (s)			
		F 48020	F 48020-33 F 48020-33CN	F 48025-60 CN71X99	F 48028
CN1	CONTROL	CN71X99	CN71X100	CN71X99	CN71X99
DS1	PILOT LIGHT, NEON	PLX82	PLX82	PLX76	PLX82
F1	FUSE	FZX30	FZX30	FZX29	FZX30
F2	FUSE	FZX30	FZX30	FZX29	FZX30
FL1	FILTER, EM1		CAX34		
H1	HEATING ELEMENT	EL480X14	EL1205X1	EL480X14	EL480X24
H2	HEATING ELEMENT	EL480X1A	EL1205X1	EL480X1A	EL480X2A
RY1	RELAY, DPST, N.O.	RYX57	RYX57	RYX56	RYX57
RY2	SOLID STATE RELAY	RYX34	RYX34	RYX34	RYX34
S1	SWITCH	SWX144	SWX144	SWX143	SWX144
S2	DOOR SWITCH	SWX163	SWX163	SWX163	SWX163
S3	DOOR SWITCH	SWX163	SWX163	SWX163	SWX163
TB1	TERMINAL BLOCK	TRX136	TRX136	TRX136	TRX136
TC1	TERMINAL COUPLE	TC1165X1	TC1165X1	TC1165X1	TC1165X1

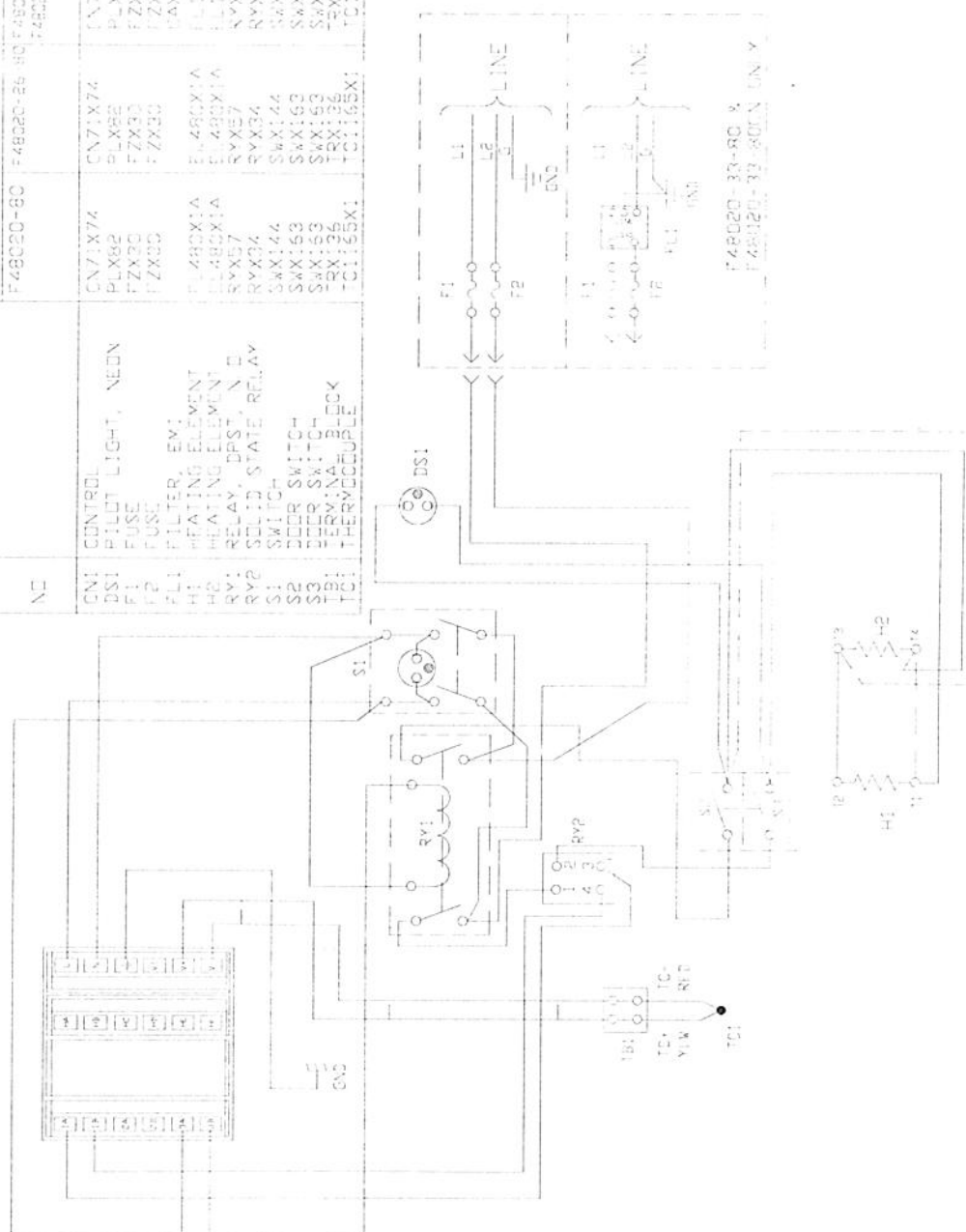


WIRING DIAGRAMS 8 SEGMENT PROGRAMMABLE CONTROL

WIRING DIAGRAM

DIAGRAM COMPONENT LIST

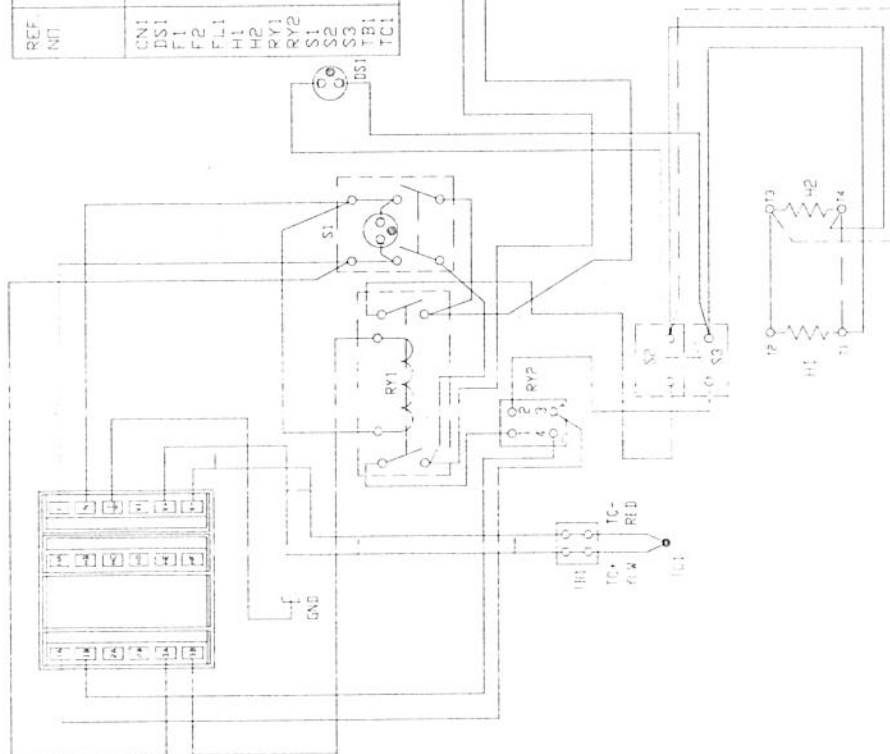
REF	DESCRIPTION	MODEL NO. AND EUR PART NO. (s)	
NO		F48020-60 F48020-25 HQ F48020-33-80 F48020-33-80N UN V	F48020-33-80 F48020-33-80N UN V
CN1	CONTROL	CN1: X74	CN1: X74
DS1	PILOT LIGHT, NEON	PLX82	PLX82
F1	FUSE	FZX30	FZX30
F2	FUSE	FZX30	FZX30
FL1	FILTER, EV:	CAK94	CAK94
H1	HEATING ELEMENT	EL480X1A	EL480X1A
H2	HEATING ELEMENT	EL480X1A	EL480X1A
RV1	RELAY, DPST, N D	RYX57	RYX57
RV2	SOLID STATE RELAY	RYX34	RYX34
S1	SWITCH	SWX144	SWX144
S2	DOOR SWITCH	SWX163	SWX163
S3	DOOR SWITCH	SWX163	SWX163
TC1	TC: THERMOCOUPLE	TC1: 165X1	TC1: 165X1



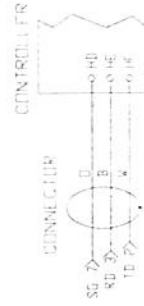
4 x 16 SEGMENT PROGRAMMABLE CONTROL

DIAGRAM COMPONENT LIST

REF. NO.	DESCRIPTION	MODEL NO. AND PART NO. (s)				EQUIP.
		F4801A	F4801B	F4801C	F4801D	
CN1	CONTROL	CN1X75	CN1X10B			CN1X75
DS1	PILOT LIGHT, NEON	PLX82	PLX82			PLX82
F1	FUSE	FZX30	FZX30			FZX30
F2	FUSE	FZX30	FZX30			FZX30
F3	FUSE	FZX30	FZX30			FZX30
F4	FUSE	FZX30	FZX30			FZX30
F5	FUSE	FZX30	FZX30			FZX30
F6	FUSE	FZX30	FZX30			FZX30
F7	FUSE	FZX30	FZX30			FZX30
F8	FUSE	FZX30	FZX30			FZX30
F9	FUSE	FZX30	FZX30			FZX30
F10	FUSE	FZX30	FZX30			FZX30
F11	FUSE	FZX30	FZX30			FZX30
F12	FUSE	FZX30	FZX30			FZX30
F13	FUSE	FZX30	FZX30			FZX30
F14	FUSE	FZX30	FZX30			FZX30
F15	FUSE	FZX30	FZX30			FZX30
F16	FUSE	FZX30	FZX30			FZX30
F17	FUSE	FZX30	FZX30			FZX30
F18	FUSE	FZX30	FZX30			FZX30
F19	FUSE	FZX30	FZX30			FZX30
F20	FUSE	FZX30	FZX30			FZX30
F21	FUSE	FZX30	FZX30			FZX30
F22	FUSE	FZX30	FZX30			FZX30
F23	FUSE	FZX30	FZX30			FZX30
F24	FUSE	FZX30	FZX30			FZX30
F25	FUSE	FZX30	FZX30			FZX30
F26	FUSE	FZX30	FZX30			FZX30
F27	FUSE	FZX30	FZX30			FZX30
F28	FUSE	FZX30	FZX30			FZX30
F29	FUSE	FZX30	FZX30			FZX30
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F31	FUSE	FZX30	FZX30			FZX30
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F39	FUSE	FZX30	FZX30			FZX30
F40	FUSE	FZX30	FZX30			FZX30
F41	FUSE	FZX30	FZX30			FZX30
F42	FUSE	FZX30	FZX30			FZX30
F43	FUSE	FZX30	FZX30			FZX30
F44	FUSE	FZX30	FZX30			FZX30
F45	FUSE	FZX30	FZX30			FZX30
F46	FUSE	FZX30	FZX30			FZX30
F47	FUSE	FZX30	FZX30			FZX30
F48	FUSE	FZX30	FZX30			FZX30
F49	FUSE	FZX30	FZX30			FZX30
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F56	FUSE	FZX30	FZX30			FZX30
F57	FUSE	FZX30	FZX30			FZX30
F58	FUSE	FZX30	FZX30			FZX30
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F61	FUSE	FZX30	FZX30			FZX30
F62	FUSE	FZX30	FZX30			FZX30
F63	FUSE	FZX30	FZX30			FZX30
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F66	FUSE	FZX30	FZX30			FZX30
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F71	FUSE	FZX30	FZX30			FZX30
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F74	FUSE	FZX30	FZX30			FZX30
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F77	FUSE	FZX30	FZX30			FZX30
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F83	FUSE	FZX30	FZX30			FZX30
F84	FUSE	FZX30	FZX30			FZX30
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F87	FUSE	FZX30	FZX30			FZX30
F88	FUSE	FZX30	FZX30			FZX30
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F243	FUSE	FZX30	FZX30			FZX30
F244	FUSE	FZX30	FZX30			FZX30
F245	FUSE	FZX30	FZX30			FZX30
F246	FUSE	FZX30	FZX30			



COMMUNICATION CABLE WIRING



Ordering Procedures

Please refer to the Specification Plate for the complete model number, serial number, and series number when requesting service, replacement parts or in any correspondence concerning this unit.

All parts listed herein may be ordered from the **Thermo Scientific** dealer from whom you purchased this unit or can be obtained promptly from the factory. When service or replacement parts are needed we ask that you check first with your dealer. If the dealer cannot handle your request, then contact our Customer Service Department at 800-438-4851.

Prior to returning any materials, please contact our Customer Service Department for a "Return Materials Authorization" number (RMA). Material returned without an RMA number will be refused.

WEEE Compliance

WEEE Compliance. This product is required to comply with the European Union's Waste Electrical & Electronic Equipment (WEEE) Directive 2002/96EC. It is marked with the following symbol. Thermo Fisher Scientific has contracted with one or more recycling/disposal companies in each EU Member State, and this product should be disposed of or recycled through them. Further information on Thermo Fisher Scientific compliance with these Directives, the recyclers in your country, and information on Thermo Scientific products which may assist the detection of substances subject to the RoHS Directive are available at www.thermo.com/

Great Britain



WEEE Konformität. Dieses Produkt muss die EU Waste Electrical & Electronic Equipment (WEEE) Richtlinie 2002/96EC erfüllen. Das Produkt ist durch folgendes Symbol gekennzeichnet. Thermo Fisher Scientific hat Vereinbarungen getroffen mit Verwertungs/Entsorgungsanlagen in allen EU-Mitgliederstaaten und dieses Produkt muss durch diese Firmen verwertet oder entsorgt werden. Mehr Informationen über die Einhaltung dieser Anweisungen durch Thermo Fisher Scientific, die Verwerter und Hinweise die Ihnen nützlich sein können, die Thermo Scientific Produkte zu identifizieren, die unter diese RoHS-Anweisung fallen, finden Sie unter www.thermo.com/

Deutschland



Conformità WEEE. Questo prodotto deve rispondere alla direttiva dell'Unione Europea 2002/96EC in merito ai Rifiuti degli Apparecchi Elettrici ed Elettronici (WEEE). È marcato col seguente simbolo. Thermo Fisher Scientific ha stipulato contratti con una o diverse società di riciclaggio/smaltimento in ognuno degli Stati Membri Europei. Questo prodotto verrà smaltito o riciclato tramite queste medesime. Ulteriori informazioni sulla conformità di Thermo Fisher Scientific con queste Direttive, l'elenco delle ditte di riciclaggio nel Vostro paese e informazioni sui prodotti Thermo Scientific che possono essere utili alla rilevazione di sostanze soggette alla Direttiva RoHS sono disponibili sul sito www.thermo.com/

Italia



Conformité WEEE. Ce produit doit être conforme à la directive européenne (2002/96EC) des Déchets d'Équipements Électriques et Électroniques (DEEE). Il est marqué par le symbole suivant. Thermo Fisher Scientific s'est associé avec une ou plusieurs compagnies de recyclage dans chaque état membre de l'union européenne et ce produit devrait être collecté ou recyclé par celles-ci. Davantage d'informations sur la conformité de Thermo Fisher Scientific à ces directives, les recycleurs dans votre pays et les informations sur les produits Thermo Scientific qui peuvent aider la détection des substances sujettes à la directive RoHS sont disponibles sur www.thermo.com/

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