

**ESCUELA SUPERIOR POLITECNICA DEL LITORAL**

**Facultad de Ingeniería en Mecánica y Ciencias de la  
Producción**

“Soldabilidad de varillas con resaltes de acero al carbono  
laminadas en caliente para hormigón armado”.

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## DEDICATORIA

A mis padres que dieron todo de si  
para brindarme una excelente  
educación y formación en lo personal  
y profesional.



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## **RESUMEN**

El presente trabajo desarrolla la calificación de un proceso de soldadura para barras corrugadas de acero al carbono, tratando de seleccionar los procedimientos de soldadura y materiales de aporte mas comúnmente usados en el ámbito de la construcción.

Actualmente el mercado de la construcción carece de los parámetros que rigen el uso de empalmes soldados en las barras corrugadas de acero al carbono, aun cuando el Código Ecuatoriano de la Construcción delega la responsabilidad de fijar estos parámetros al Código D1.4 de la Sociedad Americana de Soldadura.

En un principio se analizan los fundamentos teóricos, partiendo de la clasificación de los aceros y el uso de las barras corrugadas de acero al carbono en la construcción, donde a partir de la definición de soldabilidad de los aceros, se determinan las características de las barras de acero al carbono que influyen en esta al momento de determinar la soldabilidad de la misma.

Luego se selecciona el proceso de soldadura, para esto se usa como guía el Código D1.4 de la Sociedad Americana de Soldadura, donde partimos de la selección del tipo de junta, procedimiento y metal de aporte, para luego en base a esta información determinar de los parámetros de soldadura.

Finalmente se elaboran las probetas, siguiendo los parámetros definidos, donde luego de realizar los ensayos y análisis indicados por el Código D1.4 se procede con la calificación del proceso de soldadura y del soldador.

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## ABREVIATURAS

|                 |                         |
|-----------------|-------------------------|
| %C              | Porcentaje de Carbono   |
| %Cr             | Porcentaje de Cromo     |
| %Cu             | Porcentaje de Cobre     |
| %Mn             | Porcentaje de Manganeso |
| %Mo             | Porcentaje de Molibdeno |
| %N              | Porcentaje de Nitrógeno |
| %Ni             | Porcentaje de Níquel    |
| %O              | Porcentaje de Oxígeno   |
| %P              | Porcentaje de Fósforo   |
| %S              | Porcentaje de Azufre    |
| %Si             | Porcentaje de Silicio   |
| %V              | Porcentaje de Vanadio   |
| atm             | atmósfera               |
| cm <sup>3</sup> | Centímetros al cubo     |
| Fe              | Hierro                  |
| g               | gramos                  |
| I               | Corriente               |
| Kg              | Kilogramo               |
| KJ              | Kilo Joule              |
| m               | metro                   |
| min             | minutos                 |
| ml              | Mililitros              |
| mm              | Milímetro               |
| mm <sup>2</sup> | Milímetro al cuadrado   |
| Mpa             | Mega Pascales           |
| °C              | Grados Centígrados      |
| Q               | Calor                   |
| S               | Velocidad de soldadura  |
| V               | Voltaje                 |

## **SIMBOLOGIA**

|      |                                            |
|------|--------------------------------------------|
| ASTM | American Standard for Testing of Materials |
| AWS  | American Welding Society                   |
| CE   | Carbono Equivalente                        |
| CEC  | Código Ecuatoriano de la Construcción      |
| GMAW | Gas Metal Arc Welding                      |
| GTAW | Gas Tungsten Arc Welding                   |
| INEN | Instituto Ecuatoriano de Normalización     |
| SAW  | Shielded Arc Welding                       |
| SMAW | Shielded Metal Arc Gas                     |
| Sut  | Esfuerzo ultimo a la tracción              |
| Sy   | Esfuerzo a la Fluencia                     |
| ZAC  | Zona Afectada por el Calor                 |

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## INTRODUCCION

La construcción de estructuras de hormigón armado usando aceros estructurales con uniones soldadas son viablemente económicas y técnicamente aceptables, ya que las uniones soldadas de los aceros estructurales no tienen influencia en la estructura de hormigón.

Siguiendo los lineamientos del Código Ecuatoriano de la Construcción (CEC), en su segunda parte (CPE INEN 5 Parte 2:1993), el cual indica en el literal 1.1.8 “Las especificaciones y practicas recomendadas de otras normas que no son del INEN, a las cuales se hace referencia en esta parte del Código, serán validas hasta cuando el INEN elabore sus equivalentes.”

El Capitulo 3 del CEC, sección 3.5 se refiere al acero de refuerzo, donde la sección 3.5.2 explica “las varillas de refuerzo que vayan a soldarse deben estar señaladas en los planos, debiéndose especificar los procedimientos de soldadura que se van a emplear. Las especificaciones ASTM para varillas de refuerzo, excepto la ASTM A706, deben complementarse para requerir un informe de las propiedades del material necesarias para cumplir con los procedimientos de soldadura especificados, en el Código de

Soldadura del Acero de Refuerzo (AWS D 1.4) de la Sociedad Americana de Soldadura (American Welding Society).

Debido al incremento en el costo de los materiales de construcción, los constructores hacen uso de cualquier método para disminuir sus costos de mano de obra, y uno de estos métodos es el de reemplazar los empalmes con alambre de una armadura de varilla, con puntos de soldadura. Esta practica fue analizada en la Tesis de Grado “Estudio Sobre el Efecto de los Puntos de Soldadura en las propiedades Mecánicas de los Hierros Corrugados de Producción Nacional”, dando como una de sus conclusiones (la No. 11) que “De los ensayos realizados, se concluye que estos aceros no son recomendables para ser soldados en las condiciones en que este trabajo actualmente se realiza”.

Sin embargo el Código D 1.4 en su sección 5.5 indica que los puntos de soldadura que no formaran parte permanente de una unión soldada, deberán ser prohibidos a menos que estos sean autorizados por un ingeniero calificado.

Sin embargo esto no debe ser motivo para evitar las uniones soldadas en las varillas de construcción, en vista que la tesis de grado

en referencia se realizó en el año 1981, es la intención de la presente investigación de tesis de grado el seguir los lineamientos del Código Ecuatoriano de la Construcción y determinar los procedimientos a seguir en concordancia con sus requisitos para demostrar la soldabilidad de los aceros estructurales de medio carbono.

# CAPITULO 1

## 1. METALURGIA DE LOS ACEROS Y DE LAS UNIONES SOLDADAS.

### 1.1. Propiedades Metalúrgicas de los aceros al carbono.

#### Aleaciones de hierro carbono

El hierro, como casi todos los metales, no se utiliza puro en la industria, sino compuesto por aleaciones. Las aleaciones son la unión de un metal con otros metales o metaloides, miscibles en estado de fusión, por lo menos en ciertas proporciones, y que forman un todo homogéneo cuando se solidifican.

Las aleaciones hierro-carbono (más exactamente, hierro carburo de hierro), se caracterizan por tres factores:

- Por su composición química

- Por su estructura
- Por su constitución

#### Composición de las aleaciones hierro carbono.

A la temperatura ambiente, con excepción de una pequeña parte disuelta en la ferrita, todo el carbono que contienen estas aleaciones hierro – carbono esta en forma de carburo de hierro  $\text{CFe}_3$ . Por eso a estas aleaciones se las conoce con el nombre de aleaciones hierro – carburo de hierro.

A temperaturas aun mayores, se disocia el carburo de hierro y queda el carbono en su totalidad formando solución sólida en el hierro (austenita).

Los aceros son aquellas aleaciones que tienen un contenido de carbono comprendido entre 0.03 y 1.76 % con características muy bien definidas. Estos metales con cualquier composición de carbono entre el rango anteriormente nombrado, pueden alearse con otros elementos, formando los denominados aceros aleados o aceros especiales. Una excepción son los aceros aleados que excepcionalmente pueden contener hasta el 2,5 % de carbono.

#### Estructura de los metales y aleaciones.

Los metales no tienen una forma exterior definida, pero tienen átomos perfectamente ordenados, en formas geométricas, y a esto deben una gran parte de sus características metálicas. A este orden o arquitectura interna se denomina estructura, formada en realidad por tres estructuras superpuestas: la estructura cristalina, la estructura granular y la estructura macrográfica.

La estructura cristalina esta formada por cristales, cuyas dimensiones van de acuerdo a las dimensiones atómicas, es decir, del orden de  $10^{-8}$  cm. Como no es posible observar los cristales, aun con los microscopios más potentes, se recurre a estudiarlos con métodos indirectos, como el de la difracción de los rayos X, cuando pasan a través de ellos.

La estructura micrográfica o granular tienen como elemento fundamental el grano, formado por agrupaciones de cristales. Estos granos pueden ser observados por un microscopio metalográfico y las dimensiones de los mismos van del orden de 0,2 a 0,02 mm.

La estructura macrográfica tiene como elemento fundamental la fibra, que se forma cuando los granos del metal se alargan o se estrechan

en procesos manufacturados como el laminado. Se puede observar a simple vista, cuando se pone de relieve en medios adecuados.

#### Estructura cristalina del hierro puro. Puntos críticos.

En las estructuras cristalinas, los átomos de los metales están situados, como en la mayoría de los sólidos, ordenadamente en los puntos o nudos de una red especial geométrica, constituida por repetición de una forma elemental denominada cristal.

Las tres redes espaciales que caracterizan, casi sin excepción, a los metales son: La red cúbica centrada, la red cúbica centrada en las caras y la red hexagonal compacta.

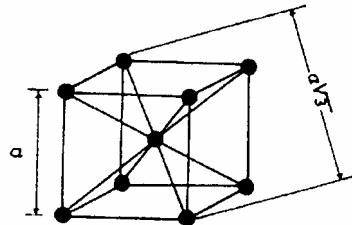


FIGURA 1.1 CRISTAL DE RED CÚBICA CENTRADA

En la red espacial cúbica centrada (Fig. 1.1), los átomos se encuentran en los vértices y en el centro de un cubo. El cristal elemental está compuesto de dos átomos, uno en el centro y otro en el vértice, debido a que cada vértice, es común a otros ocho cubos y, por

tanto, le corresponde a cada uno  $1/8$  de vértice, y como son ocho los vértices, a cada cubo le corresponderá  $8 \times 1/8 = 1$  átomo de vértice. El número de coordinación, que es el número de átomos vecinos equidistantes, es igual a ocho.

En la red cúbica centrada en las caras (Fig. 1.2), los átomos están situados en los vértices y centro de cada cara del cubo. El cristal esta formado por cuatro átomos, uno de vértice ( $8 \times 1/8 = 1$ ) y tres de cara ( $6 \times 1/2 = 3$ ), ya que cada cara es común a dos cristales y hay seis caras. El número de coordinación es 12.

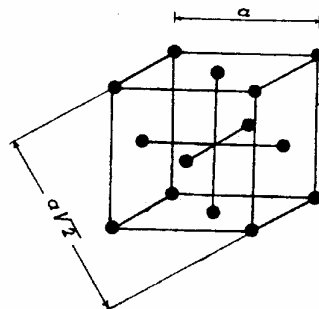


FIGURA 1.2 CRISTAL DE RED CÚBICA CENTRADA EN CARAS

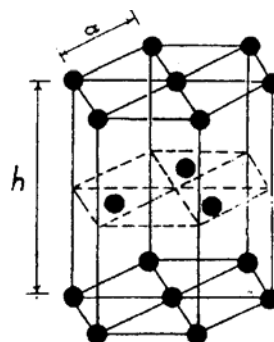


FIGURA 1.3 CRISTAL DE RED HEXAGONAL COMPACTA

Finalmente, en la red hexagonal compacta (Fig. 1.3), los átomos están situados en los vértices de un prisma recto de base hexagonal, en los centros de sus bases y en los centros de los tres triángulos equiláteros no adyacentes situados en una sección recta a mitad de la altura del prisma. Además, entre la altura del prisma  $h$  y el lado de los hexágonos debe existir relación.

Entonces, la distancia de los átomos del centro de las bases a los tres átomos de la sección intermedia es igual al parámetro  $a$ . Si esta relación no llega a cumplirse, la red ya no es compacta, y el número de coordinación no será 12 sino 6.

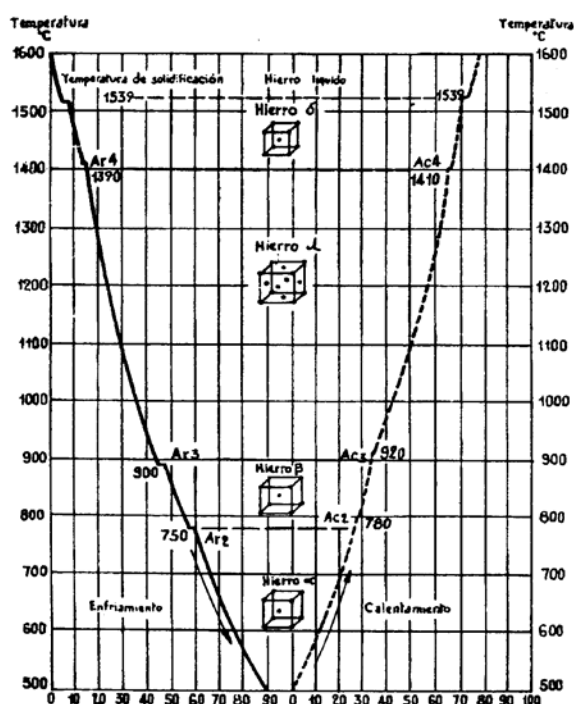


FIGURA 1.4 FORMACIÓN DE LAS VARIEDADES CRISTALINAS DEL HIERRO PURO.

Cuando se enfría una probeta recién fundida, se observa que se solidifica a temperatura constante a 1539 °C (Fig. 1.4). Si sigue la temperatura aun descendiendo, hasta que la estructura de la probeta cambie, se observa un cambio en la velocidad de descenso de temperatura, debido a un desprendimiento de calor. Se producen otras detenciones a los 900 °C y 750 °C. Estas temperaturas corresponden a los puntos críticos, y se representan  $Ar_4$  (1390 °C),  $Ar_3$  (900 °C),  $Ar_2$  (750 °C).

Si calentamos la probeta en lugar de enfriarla desde la temperatura ambiente, se observa el mismo fenómeno, pero a temperaturas ligeramente superiores:  $Ac_2$  (780 °C),  $Ac_3$  (920 °C),  $Ac_1$  (1410 °C).

La diferencia entre los puntos críticos cuando se calienta o se enfría la probeta se debe a las velocidades en que se desarrollan los procesos, y se explica como la resistencia que oponen los sistemas cristalinos a transformarse.

Si el proceso de enfriamiento o calentamiento se hiciese a una velocidad supremamente lenta, se obtendrían otras temperaturas críticas, pero las mismas en calentamiento y enfriamiento. Para el hierro puro son  $A_2 = 768$  °C,  $A_3 = 910$  °C,  $A_4 = 1400$  °C, y marcan los

puntos de transformación de los cristales de hierro en otras variedades alotrópicas.

### Variedades alotrópicas del hierro puro.

El hierro, como otros metales presenta cambios de estructura al pasar por las temperaturas a los puntos críticos.

Así, hasta el punto  $A_2$  (768 °C), el hierro cristaliza en la variedad alfa. De  $A_2$  a  $A_4$  (910°C a 1440 °C), en la variedad gamma y de  $A_4$  hasta la fundición, a 1539 °C, cristaliza en la variedad delta. (Fig. 1.5)

| <b>ESTADOS ALOTROPICOS DEL HIERRO PURO</b> |                    |                                                                                      |            |                        |
|--------------------------------------------|--------------------|--------------------------------------------------------------------------------------|------------|------------------------|
| Temperaturas                               | Formas Alotropicas | Sistema cristalino                                                                   | Parámetros | Propiedades Magnéticas |
| HASTA<br>768°                              | $\alpha$           |  | 2,86Å      | MUY MAGNETICA          |
| a<br>910°                                  | $\beta$            |  | 2,90Å      | DEBILMENTE MAGNETICA   |
| a<br>1440°                                 | $\gamma$           |  | 3,60Å      | NO MAGNETICA           |
| a<br>1539°                                 | $\delta$           |  | 2,93Å      | DEBILMENTE MAGNETICA   |

FIGURA 1.5 ESTADOS ALOTRÓPICOS DEL HIERRO PURO.

La variedad alfa (Fig. 1.1) pertenece a la red especial cúbica centrada, es decir, con un átomo en cada vértice de un cubo y otro en el centro.

La distancia entre los átomos es de 2,86 Ångstrom. El hierro alfa no disuelve prácticamente al carbono, no llegando al 0,008% la temperatura ambiente, siendo la máxima solubilidad de 0,02% a 723 °C. el hierro alfa es magnético.

La variedad beta existe de 768°C a 910°C. Cristalográficamente es igual a la alfa, y únicamente la distancia entre los átomos (parámetro) es algo mayor: 2,9 Ångstrom a 800°C, y 2,905 Ångstrom a 900°C. Este incremento de parámetro puede ser atribuido a la dilatación normal por el aumento de temperatura. Como la única variación que se observa con respecto al hierro alfa es el no ser magnética, por eso muchos autores denominan a esta variedad del hierro alfa como no magnético.

La variedad gamma se presenta de 900 °C a 1400 °C. Cristaliza en la red cúbica centrada en las caras (Fig. 1.2), o sea, con los átomos dispuestos en los vértices de cubo y además centrados en las caras. La distancia entre parámetros es de 3,6 Ångstrom a 910 °C, llegando hasta 3,68 a 1400 °C.

El cubo de hierro gamma tiene más volumen que el de hierro alfa, y por tanto, hay menos cubos en la misma masa de hierro; pero como el

cubo de hierro gamma tiene más átomos que el cubo de hierro alfa, el número total de átomos en masas del mismo volumen es el mismo, sea hierro alfa o hierro gamma.

El hierro gamma disuelve fácilmente al carbono, creciendo la solubilidad desde 0,85% a 723 °C hasta 1,76% a 1130 °C, para decrecer hasta 0,12% a 1487 °C. El hierro gamma no es magnético.

La variedad delta se inicia a los 1400 °C, observándose una reducción en el parámetro hasta 2,93 Ångstrom y el retorno al cubo con átomos centrados en el cuerpo, es decir, a un modelo igual al hierro alfa, que también es magnético. Su máxima solubilidad del carbono es 0,07% a 1487 °C. Esta variedad es poco interesante desde el punto de vista industrial. A partir de 1539 °C, se inicia la fusión del hierro puro

#### Estructura micrográfica. El grano.

El proceso de solidificación de casi todos los metales usados en la industria como el hierro, cobre, aluminio, plata magnesio, etc., se inicia a partir de puntos de la masa metálica llamados centros o núcleos de solidificación, que muchas veces son partículas de impurezas.



FIGURA. 1.6 FORMACIÓN DE DENDRITAS.

De estos núcleos, crecen los cristales en forma arborescente (Fig. 1.6). El primer paso es la formación de un eje principal y después ejes secundarios en ángulo recto, y de estos a su vez, los ejes terciarios y así sucesivamente crece la cristalización por alargamiento progresivo y multiplicación de las dendritas, hasta que todos los intersticios queden llenos, entonces la cristalización se detiene cuando las dendritas encuentran los cristales de núcleos vecinos. (Fig. 1.7).

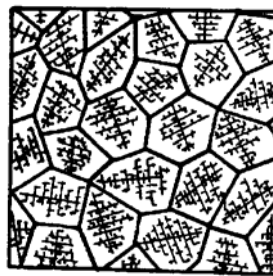


FIGURA. 1.7 FORMACIÓN DE LOS GRANOS.

La denominación de estructura micrográfica se debe a que si se observa en un microscopio de 500 a 100 aumentos, previamente

atacando con un reactivo la superficie del metal, se observa su superficie como un mosaico formado por los bordes de los granos.

Este tipo de cristalización se denomina dendrítica. El conjunto de los cristales formados a partir de cada centro de cristalización constituye un grano sin forma geométrica, pero con una constitución cristalina perfectamente ordenada.

#### Importancia del tamaño de grano.

El tamaño de grano tiene un notable efecto en las propiedades mecánicas del metal, estos según su tratamiento y proceso de formación, dan características muy distintas.

La temperatura, los elementos aleantes y el tiempo de impregnación térmica afectan el tamaño del grano, siendo fácilmente predecibles los efectos del crecimiento de grano provocados por el tratamiento térmico.

Los granos son de forma irregular y su tamaño oscila entre 0,02 mm. y 0,2 mm. y depende principalmente:

- del proceso de fabricación del metal, pues por ejemplo los aceros desoxidados con aluminio son de grano más fino que los desoxidados con silicio, y
- de los procesos térmicos que son tratados. Por ejemplo, el grano del acero crece al calentar el material a partir de los 850 °C; sin embargo existen algunos aceros que pueden alcanzar temperaturas relativamente altas (alrededor de 982 °C) con muy poco crecimiento de grano, pero conforme aumenta la temperatura, existe un rápido crecimiento de grano. Estos aceros se conocen como aceros de grano fino, pudiendo producirse una gama amplia de tamaños de grano en un mismo acero.

En metales, por lo general, es preferible un tamaño de grano pequeño que uno grande. Los metales de grano pequeño tienen mayor resistencia a la tracción, mayor dureza y se distorsionan menos durante el temple, así como también son menos susceptibles al agrietamiento. El grano fino es mejor para herramientas y dados. Sin embargo, en los aceros el grano grueso incrementa la endurecibilidad, la cual es deseable a menudo para la carburización y también para el acero que se someterá a largos procesos de trabajo en frío.

### Clasificación de los tamaños de grano.

Existen diversos métodos para determinar el tamaño de grano, como se ven en un microscopio. El tamaño de grano se determina por medio de la cuenta de los granos en cada pulgada cuadrada bajo un aumento de 100X (Fig. 1.8). El tamaño de grano especificado es por lo general, el tamaño de grano austenítico. Un acero que se temple apropiadamente debe exhibir un grano fino.

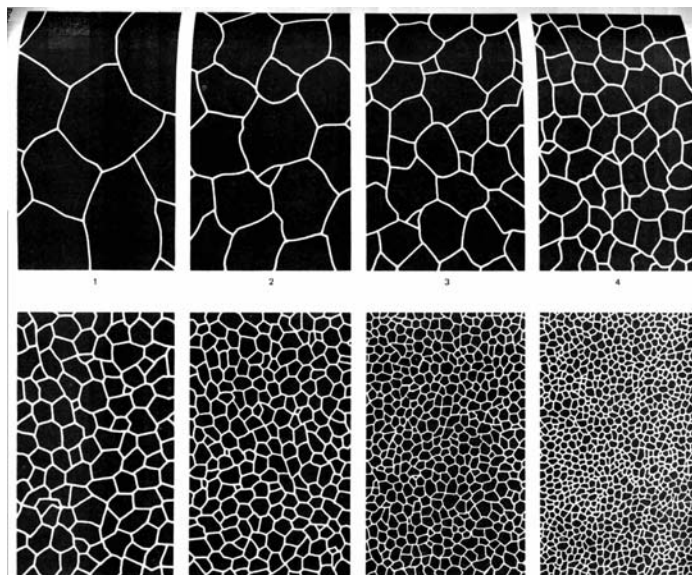


FIGURA. 1.8 REPRESENTACIÓN DEL TAMAÑO REAL DE LOS GRANOS TAL COMO APARECE CUANDO SE AUMENTA SU TAMAÑO 100X.

En el diagrama de fases de la aleación hierro carbono (Fig. 1.9), se muestra en el eje vertical la temperatura y en el eje horizontal la composición química.

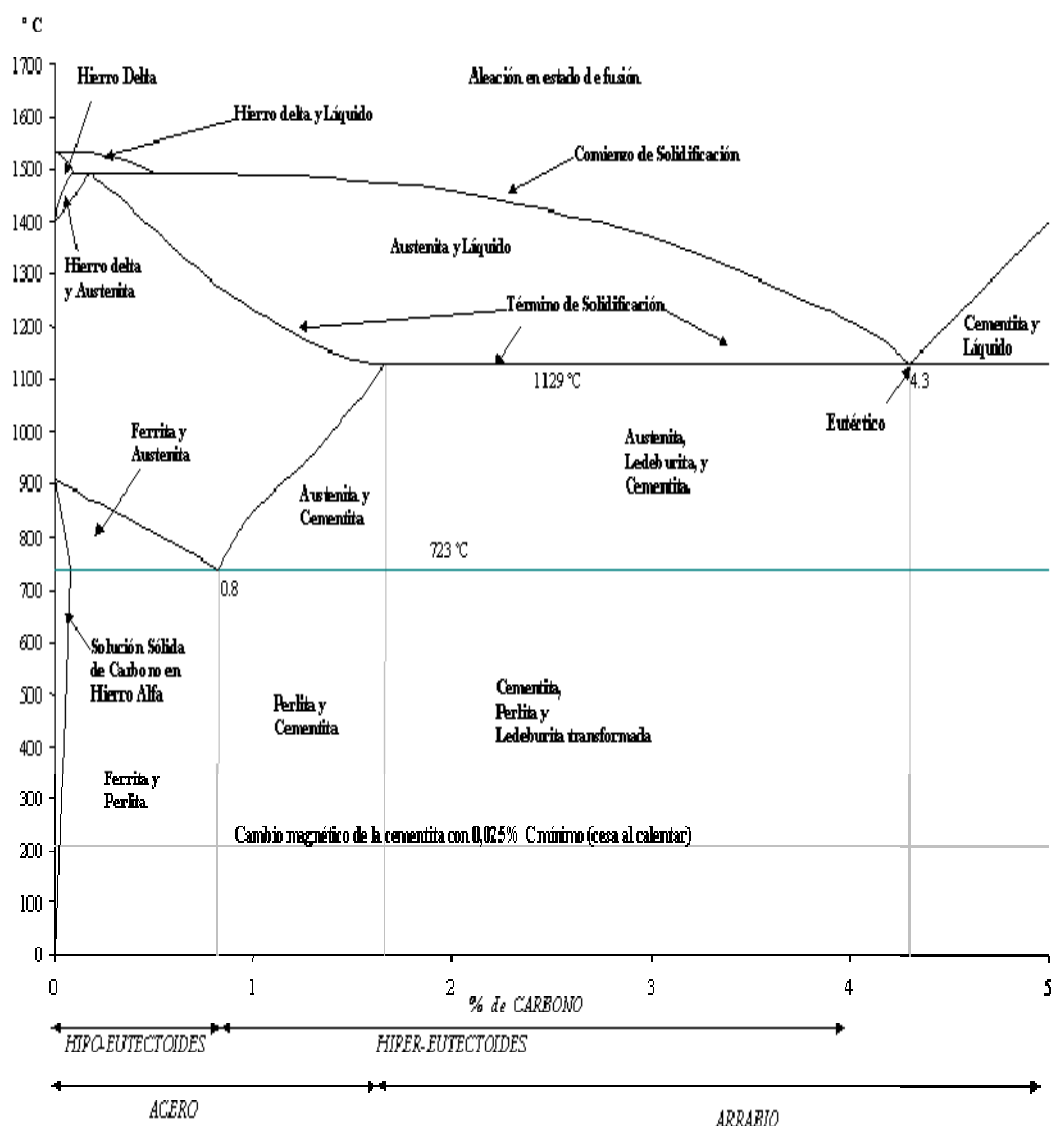


FIGURA. 1.9 DIAGRAMA DE EQUILIBRIO ESTABLE DE ALEACIÓN HIERRO CARBONO.

En el extremo izquierdo se encuentra la composición 100% Fe y 0% C y en el extremo derecho se encuentra la composición 100% C y 0% Fe. En la figura se muestra solamente hasta 5% C y 95% Fe por ser la

zona de mayor interés ya que contiene los aceros y las fundiciones de mayor uso.

Este verdadero mapa de ordenamientos cristalinos nos muestra cómo el metal al solidificar se dispone en diversas formas. Al variar la temperatura, los cristales ganan o pierden energía y buscan una nueva ordenación tratando siempre de permanecer estables.

#### Estructura macrográfica. La fibra.

La fibra se forma cuando el material es sometido a algún tipo de transformación en un proceso mecánico. Cuando los metales se laminan o se forjan, es decir, cuando se aumenta su longitud y se reduce su sección, todas las impurezas como sopladuras, inclusiones, segregaciones, etc., se aplastan y se alargan en la misma dirección. La fibra se la puede observar a simple vista, después de atacar su superficie con un reactivo.

Mientras más impurezas contengan un metal, más evidente será la observación de la fibra. Por otra parte, las propiedades mecánicas del material varían según la dirección de orientación de la fibra. Entonces, si la orientación esta en sentido transversal a la fibra, las propiedades

mecánicas son peores que si estas impurezas estarían en sentido longitudinal. (Fig. 1.10).

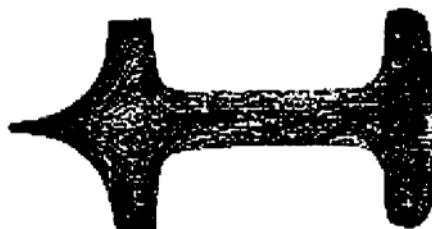


FIGURA. 1.10 CABEZA DE BIELA CORRECTAMENTE FORJADA CON LA FIBRA ADAPTADA A LA CONFIGURACIÓN DE LA PIEZA.

Cuando los metales son muy impuros, debe procurarse que trabajen en dirección a la fibra, en la dirección en que la pieza deba soportar los mayores esfuerzos.

#### Constitución de las aleaciones hierro carbono.

Antes de observar el metal al microscopio, es necesario pulir la superficie y atacar con un reactivo, entonces se observara un conjunto de manchas o varias clases repartidas con relativa uniformidad (Fig. 1.11)

Estas manchas corresponden a elementos simples y compuestos que no están íntimamente mezclados, y estos se han denominado constituyentes:

- Metales puros, como la ferrita, que es hierro puro.
- Compuestos químicos, como la cementita, que es carburo de hierro. ( $\text{CFe}_3$ ).
- Soluciones sólidas, en las que los átomos del metal disuelto están intercalados en los cristales del metal disolvente (soluciones sólidas de inserción) o los sustituyen parcialmente (soluciones sólidas de sustitución).
- Compuestos intermetálicos, denominados así porque son compuestos intermedios entre compuestos químicos y soluciones sólidas.

En las aleaciones hierro carbono, se pueden encontrar hasta once constituyentes: ferrita, cementita, perlita, austenita, martensita, trostita, sorbita, bainita, etc., cuyas características son las siguientes:

Ferrita: Es una solución sólida de carbono en hierro alfa, pero su solubilidad es tan pequeña a temperatura ambiente, que se considera como hierro alfa puro. La máxima solubilidad es de 0,02% a 723 °C (Fig. 1.11).

Cristaliza en BCC, siendo el mas blando dúctil de todos los constituyentes. Posee una dureza de 90 Brinell y una resistencia a la rotura de 28 Kg./mm<sup>2</sup>. Es magnética.



FIGURA. 1.11 CRISTALES DE FERRITA X 1000. ACERO NORMALIZADO HEVA EMG DE 0,05% DE C.

Cementita: Carburo de hierro ( $\text{CFe}_3$ ). Es el constituyente más duro y frágil de los aceros. 700 Brinell. Es magnética hasta los 210 °C. Cristaliza en la red ortorrómbica.

Perlita: Constituyente formado por 86,5% de ferrita y el 13,5% de cementita. Tiene una dureza de 200 Brinell, con una resistencia a la rotura de 80 Kg./mm<sup>2</sup> y un alargamiento del 15%.



FIGURA. 1.12 PERLITA LAMINAR X 1000. ACERO NORMALIZADO HEVA TD DE 0,88% DE C.

Tiene una estructura laminar formada por laminas de cementita y ferrita, y se observa con facilidad cuando ha sido formada con enfriamiento lento (Fig. 1.12). La perlita sorbítica es aquella que se observa borrosa y por un enfriamiento brusco. Si la perlita se calienta durante algún tiempo por debajo de la temperatura crítica ( $723\text{ }^{\circ}\text{C}$ ), esta adoptada la forma de glóbulos incrustados en la masa ferrítica, recibiendo el nombre de perlita globular.

Austenita: Es el mas denso de los constituyentes y formado por inserción de carbono en hierro gamma (Fig. 1.13). La máxima solubilidad se logra a  $1130\text{ }^{\circ}\text{C}$  y es de 1,76%. Se forma en solitario a los  $723\text{ }^{\circ}\text{C}$  ( $A_1$  punto critico inferior), y a partir de la temperatura superior ( $A_3$  o  $A_{cm}$ ) o enfriando rápidamente una probeta con alto contenido de carbono, la totalidad de acero corresponde a austenita.



FIGURA. 1.13 AUSTENITA X 200. ATAQUE ELECTROLÍTICO CON ACIDO OXÁLICO AL 10%.

Sin embargo esta austenita formada por rápido enfriamiento, es inestable y se transforma con el tiempo en ferrita y perlita o cementita

y perlita. La austenita esta formada por cristales cúbicos de hierro gamma con átomos intercalados en las aristas y en el centro (Fig. 1.14).

Su dureza es de 300 Brinell, resistencia a la rotura 100 Kg./mm<sup>2</sup> y un alargamiento de 30%. No es magnética.

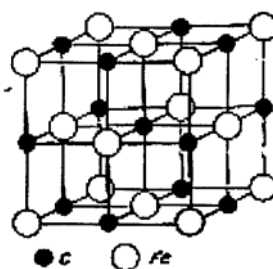


FIGURA. 1.14 CRISTAL ELEMENTAL DE AUSTENITA CON LOS ÁTOMOS DE HIERRO GAMMA EN LOS VÉRTICES Y DE CENTRO DE CARAS DE UN CUBO.

Martensita: Es el segundo constituyente mas duro después de la cementita. Es una solución de carbono de hierro alfa, que se obtiene por enfriamiento muy rápido al elevarse la temperatura previamente hasta su conformación austenítica.

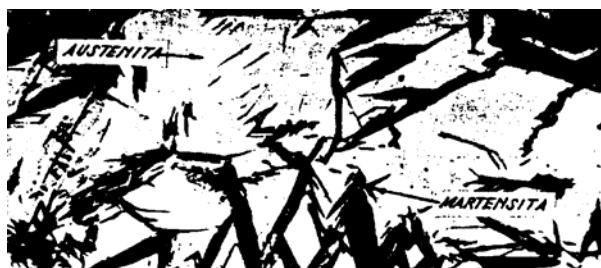


FIGURA. 1.15 AGUJAS DE MARTENSITA SOBRE FONDO DE AUSTENITA X 1000. ACERO TEMPLADO HEVA DM A 1200 °C EN AGUA SALADA.

La martensita se presenta en forma de agujas (Fig. 1.15) y se cristaliza en la red tetragonal en lugar de cristalizarse en la red cúbica centrada, como es la del hierro alfa, debido a la deformación por la inserción de los átomos de carbono (Fig. 1.16).

Por eso se explica su dureza, debido a la tensión por la deformación interna, que se realiza también en frío.

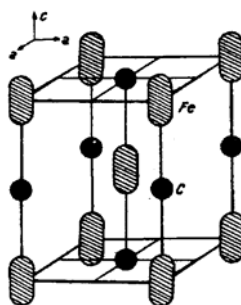


FIGURA. 1.16 CRISTAL ELEMENTAL DE MARTENSITA CON LOS ÁTOMOS DE HIERRO EN LOS VÉRTICES Y CENTRO DE UN PARALELEPÍPEDO.

Su composición varía hasta un máximo de 0,89% de C, aumentando su dureza de 50 a 68 Rockwell C, resistencia de 175 a 250 Kg./mm<sup>2</sup> y alargamiento de 2,5% a 5 %. Es magnética.

Trostita: Se produce por enfriamiento rápido de la austenita entre las temperaturas de 500 °C y 600 °C, manteniéndola a esa temperatura hasta que toda la austenita se transforma en trostita. También se puede producir al enfriar la austenita a una velocidad inferior a la

crítica de temple, que corresponde a la velocidad necesaria para que toda la austenita se transforme en martensita. (Fig. 1.17).

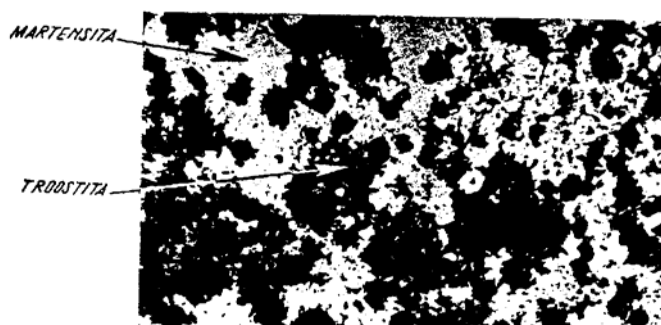


FIGURA. 1.17 TROSTITA SOBRE UNA MATRIZ MARTENSÍTICA X 250

Esta se presenta en nódulos compuestos de laminillas radiales de cementita sobre ferrita, similar a la perlita, pero más finas. Posee una dureza de 450 Brinell, una resistencia de 250 Kg./mm<sup>2</sup> y su alargamiento de 7,5%.

Sorbita: Se produce de manera similar a la trostita, pero entre las temperaturas de 600 °C y 650 °C.



FIGURA. 1.18 SORBITA X 500. ACERO TEMPLADO Y REVENIDO HEVA TSD DE 0,30% DE C, 0,65% DE CR Y 3% DE NI.

Así mismo se produce la sorbita al enfriar la austenita a velocidad bastante superior a la crítica de temple. Por eso se debe a que aparezca en los aceros forjados y laminados, en donde velocidad de enfriamiento no es la suficientemente rápida ni lenta para el temple, peor para formar otros constituyentes (Fig. 1.18).

Se presenta formando laminillas aun mas finas que la trostita y similares a la perlita. Tiene una dureza de 350 Brinell, resistencia de 100 Kg./mm<sup>2</sup> y un alargamiento de 15%.

Bainita: En forma similar se forma en transformación isotérmica de la austenita, entre 250 °C y 550 °C, con un enfriamiento rápido. A diferencia de las dos anteriores, no se produce en un temple defectuoso, sino por un temple isotérmico o bainítico, donde la austenita se transforma íntegramente en bainita.

Se aceptan dos bainitas la superior de aspecto arborescente, que se forma entre 500 °C y 550 °C y la inferior de 300 °C y 400 °C. Estas dos están constituidas por una matriz ferrítica con placas de carburo.

Inclusiones metálicas.

Aparte de los constituyentes enunciados en los aceros aleados, existen otros elementos como los siguientes:

Como carburos: Cromo, molibdeno, wolframio, magnesio y vanadio combinados con el carbono, formando compuestos de carburo de dureza más alta que la martensita. Estos se observan en forma de granos brillantes.

Disueltos en ferrita: El níquel, cromo, aluminio, silicio, manganeso y fósforo pueden encontrarse en la ferrita disueltos.

Emulsionados: El cobre en porcentajes superiores al 0,60% y el plomo pueden encontrarse formando bolsas muy pequeñas, dando a este propiedades especiales.

#### Impurezas.

Las impurezas se refieren a las inclusiones de sulfuro oxido de aluminio, silicatos, etc., que proceden de los refractarios de los hornos, de las escorias o de los procesos de oxidación y desoxidación. Estas impurezas, en general, perjudican las propiedades de los aceros.

#### Tratamientos térmicos.

Los tratamientos térmicos son procesos en los cuales se someten los metales y aleaciones a condiciones específicas de calentamiento y enfriamiento con el objeto de darles características especiales para su trabajo.

Sin embargo, estos tratamientos no modifican la composición química del metal, pero si su constitución, estructura y estado mecánico.

Cuando se modifica su constitución, varia el estado alotrópico y el estado que se encuentra al carbono del hierro; se modifica su estructura variando el tamaño de grano y el reparto de los constituyentes. El estado mecánico queda afectado por las tensiones a que quedan sometidos los materiales, principalmente después del temple.

#### Ensayos metalográficos.

La metalografía es la disciplina que estudia microscópicamente las características estructurales de un metal o de una aleación. Sin duda, el microscopio es la herramienta más importante del metalurgista tanto desde el punto de vista científico como desde el técnico. Es posible determinar el tamaño de grano, forma y distribución de varias fases e inclusiones que tienen gran efecto sobre las propiedades mecánicas

del metal. La microestructura revelará el tratamiento mecánico y térmico del metal y, bajo un conjunto de condiciones dadas, podrá predecirse su comportamiento esperado.

La experiencia ha demostrado que el éxito en el estudio microscópico depende en mucho del cuidado que se tenga para preparar la muestra. El microscopio más costoso no revelará la estructura de una muestra que haya sido preparada en forma deficiente. El procedimiento que se sigue en la preparación de una muestra es comparativamente sencillo y requiere de una técnica desarrollada sólo después de práctica constante. El último objetivo es obtener una superficie plana, sin ralladuras, semejante a un espejo. Las etapas necesarias para preparar adecuadamente una muestra metalográfica.

#### Examen microscópico de los metales.

Los detalles de la estructura de los metales no son fácilmente visibles, pero las estructuras de grano de los metales pueden verse con un microscopio. Las características del metal, el tamaño de grano y el contenido de carbono pueden determinarse estudiando la micrografía (Fig. 1.19)



FIGURA. 1.19 EJEMPLO DE VISUALIZACIÓN DE ESTRUCTURAS DE GRANO TIPO.

El porcentaje aproximado de carbón puede estimarse por medio de porcentaje de perlita (zonas oscuras) en los aceros al carbono recocidos. Para este propósito, se utilizan un microscopio metalúrgico y técnicas asociadas de foto microscopia. El microscopio metalúrgico de luz reflejada es similar a aquellos utilizados para otros propósitos, excepto que contiene un sistema de iluminación dentro del sistema de lentes para proveer iluminación vertical.

Algunos microscopios también tienen un retículo y una escala micrométrica para medir la imagen aumentada. Otro retículo que se utiliza contiene los diferentes tamaños de grano a aumentos de 100X y se utiliza para comparar o medir el tamaño de grano relativo. Los filtros y polarizadores se utilizan en la iluminación o el sistema óptico para reducir el brillo y mejorar la definición de las estructuras de grano. En poder de aumento del microscopio puede determinarse si se

multiplica el poder de la lente objetivo por el del ocular. Por tanto, un lente objetivo de 40X con un ocular de 12.5X agrandaría la imagen hasta 500X.



FIGURA. 1.20 FOTOMICROSCOPIO METALOGRÁFICO.

Los microscopios de platina invertida ofrecen un diseño más moderno. En este instrumento la muestra se coloca boca abajo en la platina. Se utiliza un microscopio de platina invertida, junto con una cámara de video y un monitor de TV de circuito cerrado. El poder del microscopio es de 400X, pero se pierde algo de resolución. La mayor ventaja de este arreglo se obtiene en la visualización de grupo. Los instrumentos de metalografía también permiten una observación en grupo del aumento metalúrgico. La imagen se proyecta sobre una pantalla de

brillo mate. En los grandes laboratorios metalúrgicos se utilizan modelos de gran tamaño. Muchos instrumentos metalográficos tienen la capacidad de producir microfotografías de color instantáneas o estándar. Para obtener fotografías existen adaptadores para la mayoría de los microscopios. Los acaparadores de manga sencilla pueden utilizarse con una cámara SLR de 35mm para la toma de foto micrografías. Con este arreglo simple, el obturador se abre y se permite la entrada de la luz durante pocos segundos (6 a 8 segundos con una película Panatomic-X de 32 ASA). El enfoque se realiza sobre el vidrio mate de la cámara.

#### Preparación de la muestra.

La muestra debe seleccionarse de la zona de la pieza que necesita examinarse y en la orientación apropiada. Es decir, si el flujo de grano o la distorsión es importante, puede ser que una sección transversal de la parte no muestre granos alargados; únicamente una tajada paralela a la dirección de laminado revelaría adecuadamente los granos alargados debido al laminado. Algunas veces se requiere más de una muestra. Usualmente, una soldadura se examina por medio de una sección transversal.

Los materiales blandos (de dureza menor a 35 Rockwell C) pueden seccionarse por aserrado, pero los materiales más duros deben cortarse con un disco agresivo. Las sierras de corte metalúrgico con hojas abrasivas y flujo de refrigerante son las herramientas que se usan para este propósito. La muestra no debe sobrecalentarse, no importa si es dura o blanda. Las estructuras de grano pueden alterarse con una alta temperatura de corte.



FIGURA. 1.21 CORTADORAS DE PRECISIÓN DE HILO DIAMANTADO.

Las muestras pequeñas o de forma incomoda deben montarse de alguna manera para facilitar el pulido intermedio y final. Alambres, varillas, pequeñas muestras de hoja metálica, secciones delgadas, etc. Deben montarse en un material adecuado o sujetarse rígidamente en una monta mecánica.



FIGURA. 1.22 PREPARACIÓN DE PROBETAS METALOGRÁFICAS, EQUIPO DE EMBUTICIÓN EN CALIENTE, Y MUESTRAS EMBUTIDAS.

A menudo, se utiliza los plásticos termofijos conformándolos con calor y presión alrededor de la muestra. La resina termo fijada que más se emplea para montar muestras es la baquelita.

#### Pulido de la muestra.

Los granos y otras características de los metales no pueden verse al menos que la muestra se desbaste y se pule para eliminar las ralladuras. Se utilizan diferentes métodos de pulido tales como el electrolítico, el rotatorio o el de vibración. El procedimiento más común consiste en desbastar primero la superficie de la muestra en una lijadora de banda y luego a mano con papel abrasivo de varios grados, desde el número de partícula de 240 hasta de 600.

Pulido intermedio: La muestra se pule sobre una serie de hojas de esmeril o lija con abrasivos más finos, sucesivamente. El primer papel es generalmente no. 1, luego 1/0, 2/0, 3/0 y finalmente 4/0. Por lo

general, las operaciones de pulido intermedio con lijas de esmeril se hacen en seco; sin embargo, en ciertos casos, como el de preparación de materiales suaves, se puede usar un abrasivo de carburo de silicio. Comparado con el papel esmeril, el carburo de silicio tiene mayor rapidez de remoción y, como su acabado es a base de resina, se puede utilizar con un lubricante, el cual impide el sobrecalentamiento de la muestra, minimiza el daño cuando los metales son blandos y también proporciona una acción de enjuague para limpiar los productos removidos de la superficie de la muestra, de modo que el papel no se ensucie.

Pulido fino: El tiempo utilizado y el éxito del pulido fino dependen en mucho del cuidado puesto durante los pasos de pulido previo. La última aproximación a una superficie plana libre de ralladuras se obtiene mediante una rueda giratoria húmeda cubierta con un paño especial cargado con partículas abrasivas cuidadosamente seleccionadas en su tamaño. Existe gran diversidad de abrasivos para efectuar el último pulido. En tanto que muchos harán un trabajo satisfactorio parece haber preferencia por la forma gamma del óxido de aluminio para pulir materiales ferrosos. Otros abrasivos para pulido final que se emplean a menudo son la pasta de diamante, óxido de cromo y óxido de magnesio.



FIGURA. 1.23. EQUIPO DE DESBASTE MEDIANTE DISCO ABRASIVO, Y EQUIPO DE PULIDO SEMIAUTOMÁTICO CON PASTA DE ALÚMINA.

La selección de un paño para pulir depende del material que vaya a pulirse y el propósito del estudio metalográfico. Se pueden encontrar paños de lanilla o pelillo variable, desde aquellos que no tienen pelillo (como la seda) hasta aquellos de pelillo intermedio (como paño de ancho, paño de billar y lonilla) además de aquellos de pelillo profundo (como el terciopelo). También se pueden encontrar paños sintéticos para pulir con fines de pulido general, de los cuales el gamal y el micro paño son los que se utilizan más ampliamente. Una muestra pulida en forma de cuadro mostrará únicamente las inclusiones no metálicas; además, estará libre de ralladuras.

### Ataque químico de la muestra.

El propósito del ataque químico es hacer visibles las características estructurales del metal o aleación. El proceso debe ser tal que queden claramente diferenciadas las partes de la micro estructura. Esto se logra mediante un reactivo apropiado que somete a la superficie pulida a una acción química. Los reactivos que se utilizan consisten en ácidos orgánicos o inorgánicos y los álcalis disueltos en alcohol, agua u otros solventes.

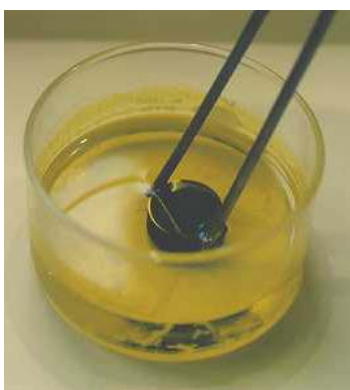


FIGURA. 1.24 ATAQUE QUÍMICO POR INMERSIÓN.

Las muestras pueden ahora atacarse durante el tiempo necesario sumergiéndolas boca abajo en una solución contenida en una caja de Petri. Un método opcional consiste en aplicar el reactivo con un gotero para ojos. Si el tiempo de ataque es demasiado corto, la muestra quedará subatacada y los límites de grano y otras configuraciones se verán desvanecidos e indistintos cuando se observen en el microscopio.

TABLA 1

REACTIVOS MAS COMUNES USADOS PARA EL ATAQUE QUIMICO  
DE ACERO AL CARBONO

| REACTIVO                           | COMPOSICION                                                                     | OBSERVACIONES                                                                                                                                                                                                                  |
|------------------------------------|---------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Nital                              | 2 a 5% de ácido nítrico en alcohol metílico.                                    | Obscurece la perlita en aceros al carbono<br><br>Diferencia la perlita de la martensita: revela los límites de grano de la ferrita, muestra la profundidad del núcleo en los aceros nitrurados.<br><br>Tiempo: 5 a 60 segundos |
| Picral                             | 4 g de ácido pícrico en 100 ml de alcohol metílico.                             | Para aceros al carbón y de baja aleación es tan bueno como el nital para revelar los límites de grano de la ferrita. Tiempo 5 a 120 segundos.                                                                                  |
| Ácido clorhídrico y ácido pícrico. | 5 g de ácido clorhídrico y 1 g de ácido pícrico. En 100 ml de alcohol metílico. | Revela los granos de austenita en los aceros templados y en los templados y revenidos.                                                                                                                                         |

Si el tiempo de ataque es demasiado largo, la muestra se sobre ataca y quedará muy oscura, mostrando colores no usuales. El tiempo de ataque debe controlarse muy cuidadosamente.

La acción del ataque se detiene al colocar la muestra bajo una corriente de agua. Límpiase la muestra con alcohol y utilice una secadora de pelo para terminar de secarla. Cuídese de no frotar la muestra pulida y atacada con alguna tela o con los dedos, porque esto altera la condición superficial del metal.

## **1.2. Regiones de la Soldadura por Fusión.**

Cuando dos piezas de metal son soldadas, la gran cantidad de calor suministrado al proceso funde el material sólido, el cual rápidamente se enfría y solidifica nuevamente según se va alejando la fuente de calor. Próxima al área de la soldadura, o zona de fusión se encuentra la Zona Afectada por el Calor (ZAC). Tal como lo indica su nombre la ZAC implica que el calor de la soldadura afectó el material pero este no se fundió.

El calor ocasiona cambios en el material. Los tres estados básicos de la materia son: sólido, líquido y gas, pero para muchos materiales existen múltiples fases sólidas a diferentes temperaturas o combinaciones de temperatura y presión. Al nivel del mar (1 atm) el agua ( $H_2O$ ) forma diferentes clases de hielo, cada uno con una diferente fase sólida. El hierro tiene tres transformaciones de fase de estado sólido según aumenta desde la temperatura ambiente hasta la temperatura de fusión ( $1535\text{ }^{\circ}\text{C}$ ). El carbono también tiene diferentes fases sólidas, incluyendo el grafito y los diamantes, sin embargo nadie puede confundir el grafito con el diamante, cada uno sigue siendo carbono, solo que en una estructura cristalina diferente.

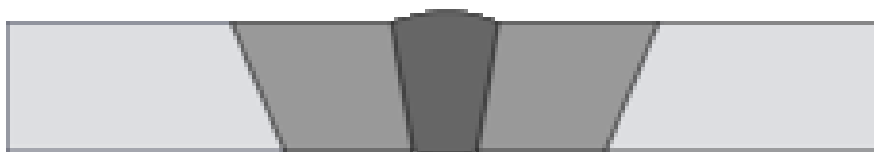


FIGURA. 1.25 SECCIÓN TRANSVERSAL DE SOLDADURA A TOPE.

En la Figura 1.25 la zona en gris oscuro representa la soldadura por fusión, la zona gris representa la zona afectada por el calor (ZAC) y la zona gris claro representa al material base.

La Zona Afectada por el Calor (ZAC) es la zona del material base que ha sufrido una alteración de su microestructura debido a un proceso de soldadura o al calor extremo ocasionado por un proceso de corte.

Donde el calor proveniente de un proceso de soldadura y el subsiguiente enfriamiento causa este cambio en el área próxima a la soldadura. La extensión y magnitud de los cambios en las propiedades dependen principalmente del material base, el material de aporte y la cantidad de calor inflingida al elemento debido al proceso de soldadura.

La conductividad térmica del material base juega un rol muy importante, ya que si la conductividad térmica es alta, la tasa de enfriamiento del material también es alta, por lo que la ZAC es relativamente pequeña. Así también una baja conductividad ocasiona un lento enfriamiento y una gran ZAC.

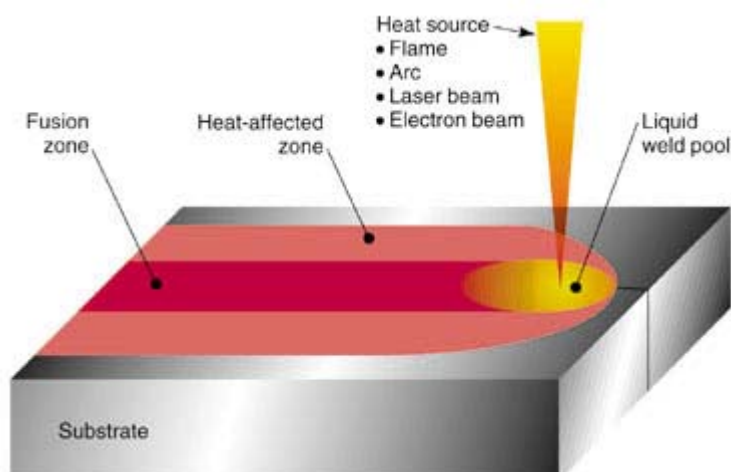


FIGURA. 1.26 EJEMPLO DE VISUALIZACIÓN DE SOLDADURA POR FUSIÓN.

La cantidad de calor impuesta por el proceso de soldadura también juega un rol muy importante, tal como un proceso de soldadura oxy-acetilenica usa una gran cantidad de calor la misma que deposita en el material base, incrementando así su ZAC; un proceso de soldadura por láser imprime una cantidad limitada de calor concentrado dando como resultado una ZAC mas pequeña. La soldadura por arco o SMAW (Shielded Metal Arc Gas) recae entre estos dos extremos teniendo como única variable la cantidad de calor para el proceso de soldadura. Para calcular el calor debido al proceso de soldadura se utiliza la siguiente formula:

$$Q = \left( \frac{V * I * 60}{S * 1000} \right) * Eficiencia$$

Donde **Q** es la entrada de calor (KJ/mm), **V** es el voltaje (V), **I** es la corriente (A), y **S** es la velocidad de soldadura (mm/min). La eficiencia depende del proceso de soldadura usado; para el proceso SMAW tiene un valor de 0,75; para el GMAW y SAW es 0,90 y para el GTAW es 0.80

### **1.3.Principios de Soldabilidad.**

#### Templabilidad y Soldabilidad.

Los aceros que tienen difícil soldabilidad son aquellos que tienen **TEMPLABILIDAD ALTA**. La templabilidad en un acero es la capacidad de generar **MARTENSITA**. Los elementos de adición que conceden características elevadas a los aceros aumentan a la vez su poder de temple, es decir que por la presencia de estos elementos se inhibe la descomposición de la austenita en perlita durante tiempos relativamente largos y con ello se logra transformar la austenita en martensita aún a bajas velocidades de enfriamiento y, por consiguiente su poder de agrietamiento.

Bajo en concepto anterior y teniendo en cuenta los efectos de la soldadura en la ZAC, se puede comprobar que un gradiente de temperatura originada por la difusión del calor, va desde la solidificación del acero (1535°C) hasta la temperatura ambiente.

Debido a que se alcanza la temperatura de temple en la zona próxima al cordón (900°- 700°C), la cual se convierte en zona sensible y si se origina un enfriamiento brusco, esta zona será susceptible de formarse martensita, con lo que se originan zonas frágiles en estos aceros de difícil soldabilidad, agravándose este efecto cuando se trata de aceros de baja aleación.

Es necesario recordar que los aceros de alta templabilidad son los aceros al carbono, cuyo contenido de carbono son  $> 0,45$ . Estos aceros, si se calientan a  $T^{\circ} > 723^{\circ}\text{C}$  necesitan enfriamientos bruscos para obtener un temple severo. Pero también presentan alta templabilidad, los aceros de baja aleación cuando el CE es  $> 0,65\%$ , teniendo en cuenta siempre además del CE, el  $\%C$  debido a que este elemento es el principal formador de estructura martensítica.

Otro factor importante y muy significativo, es el Ciclo Térmico, su influencia en el charco de soldadura y en la ZAC determinará la microestructura y por lo tanto las propiedades. Este ciclo térmico depende del proceso de soldadura, de la energía introducida y de las dimensiones de la pieza a soldar.

La soldabilidad de estos tipos de acero es riesgosa en la medida que se desconozcan los parámetros del procedimiento como: Análisis químico, templabilidad, geometría de la pieza, embridamiento, etc.

En la práctica, el soldador generalmente subsana el desconocimiento de estos parámetros precalentando, para evitar los problemas de rajaduras.

Uno de los métodos más rápidos para determinar la soldabilidad es conocer la templabilidad del acero, por lo que es necesario conocer el término CARBONO EQUIVALENTE.

#### Carbono Equivalente.

Este término fue desarrollado como una fórmula para normalizar la composición química del acero en un solo número que nos indica como la composición química podría afectar el endurecimiento o templabilidad del material, lo que nos serviría para seleccionar la temperatura de precalentamiento más adecuada.

Hay muchas fórmulas que por mucho tiempo se han utilizado, sin embargo el Código D 1.4 utiliza dos dependiendo de la materia prima utilizada:

Para todas las barras de acero, excepto aquellas designadas como ASTM A 706, el carbono equivalente (CE) debe ser calculado usando la composición química, como se muestra en el reporte de ensayos del molino, según la siguiente formula:

$$C.E. = \%C + \frac{\%Mn}{6} \quad (1.1)$$

Para las barras de acero designadas como ASTM A 706, el carbono equivalente (CE) deberá ser calculado usando la composición química,

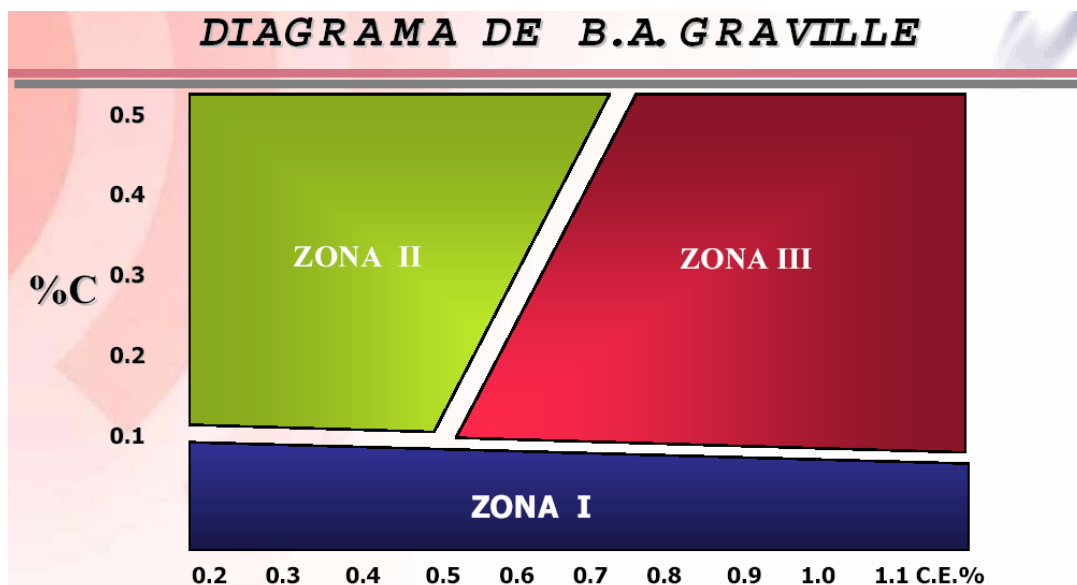
como se muestra en el reporte de ensayos del molino, según la siguiente formula:

$$C.E. = \%C + \frac{\%Mn}{6} + \frac{\%Cu}{40} + \frac{\%Ni}{20} + \frac{\%Cr}{10} - \frac{\%Mo}{50} - \frac{\%V}{10} \quad (1.2)$$

#### Clasificación de los aceros Según su Templabilidad.

El Diagrama de B.A. Graville (Fig. 1.27) muestra la susceptibilidad de los aceros a la fisuración, relacionando el CE% / C%, que nos dará pautas para diseñar el procedimiento de soldadura donde debemos incluir: tratamiento térmico pre y post soldadura, de manera que puedan evitar microestructuras susceptibles de fisuración. La sensibilidad a la fisura en este diagrama se atribuye sólo a la composición química del acero y a la predisposición de algunos aceros de formar martensita.

Por otra parte, combinada con el efecto de tensiones locales o de las tensiones desarrolladas por embridado, la presencia del hidrógeno puede ser causa de roturas frágiles de las soldaduras y que por ello se debe emplear con estos aceros electrodos básicos.



Zona I : acero de poca susceptibilidad a la fisura

Zona II: Acero de alta templabilidad

Zona III: acero cuya microestructura resultante por efecto del calor es susceptible de fisuración bajo cualquier condición

FIGURA. 1.27 DIAGRAMA DE B. A. GRAVILLE.

Por consiguiente, cuando el poder de temple del acero especial aumenta se hacen intervenir dos factores:

- La temperatura de precalentamiento.
- El empleo de electrodos con pequeño contenido de hidrógeno, es decir, electrodos con revestimiento básico.

En el límite, cuando el acero es sumamente templable y forma estructuras frágiles en las zonas de transformación, son insuficientes

los artificios antes mencionados y se hace menester considerar el problema desde un nuevo punto de vista.

### Distorsión de las Estructuras Soldadas.

Durante el proceso de fabricación o de reparación de estructuras soldadas, se vive cara a cara con la distorsión de la soldadura, que afectan la integridad y comportamiento durante el servicio de la estructura. Por lo que es necesario predecir el tipo específico y cantidad de distorsión resultante de la operación de soldadura.

Durante la soldadura, hay ciclos de calentamientos y enfriamientos no uniformes en la soldadura y en el material base adyacente, lo que causa complejas tensiones térmicas, los esfuerzos resultantes de estas tensiones producen fuerzas internas que causan la contracción del material. Se presentan:

- Contracción transversal en las juntas a tope,
- Cambio angular en la junta tope,
- Cambio angular en una junta en T, y
- Distorsión longitudinal en la junta a filete.

Hay fórmulas empíricas de cuyo análisis se puede definir un método para controlar o minimizar la distorsión de una soldadura, pero que hay que adaptarlas a las condiciones reales del trabajo.

#### **1.4. Influencia de la composición química en la soldabilidad.**

Con la finalidad de analizar el efecto producido por los diferentes elementos de aleación de los aceros en su soldabilidad, se presenta un resumen de esta influencia publicada por diferentes autores.

##### Carbono.

Es el elemento base para fijar la soldabilidad y generalmente es considerado como el elemento aleante más importante en los aceros. A medida que aumenta la cantidad de carbono, incrementa la dureza, la resistencia a la tracción, así como la respuesta a los tratamientos térmicos de endurecimiento. Por otro lado, si se eleva el porcentaje de carbono, se reduce la soldabilidad, también interviene para aumentar la capacidad de templabilidad proporcionando una unión frágil o para formar precipitados de carburos complejos con los elementos aleantes del metal base.

El carbono puede existir disuelto en el hierro o en formas combinadas como la cementita ( $\text{CFe}_3$ ).

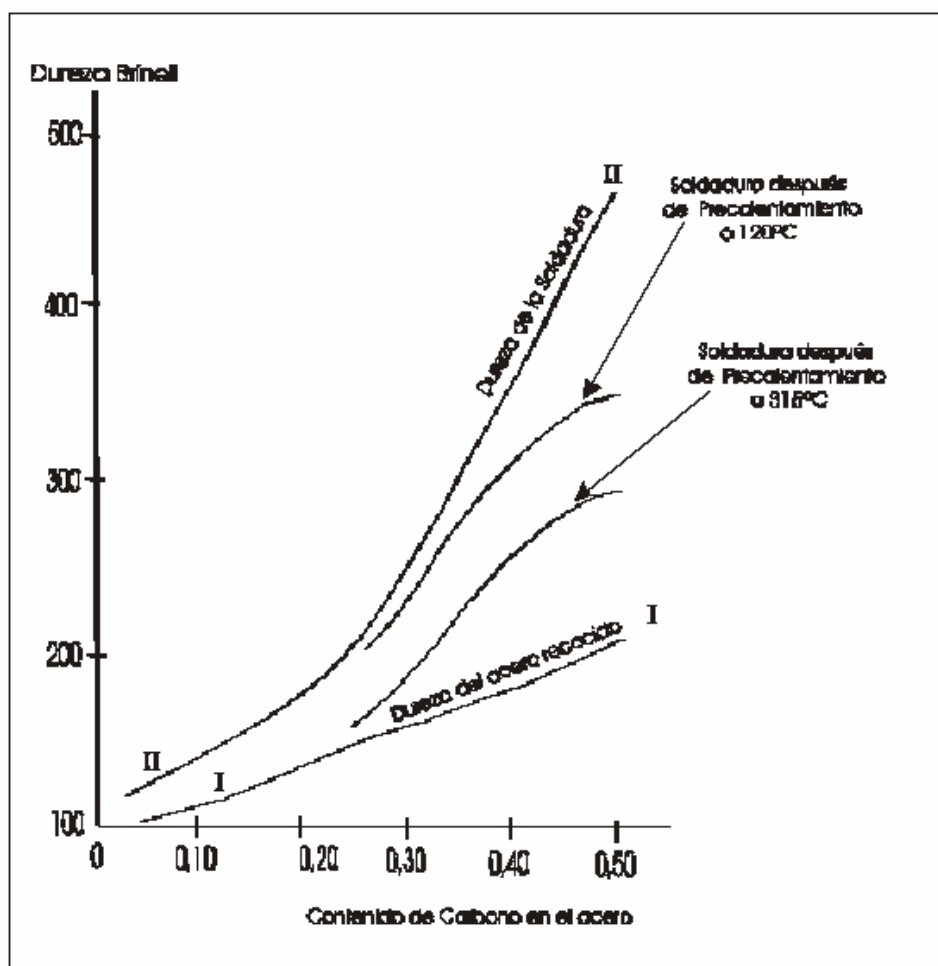


FIGURA. 1.28 VARIACIÓN DE LAS CARACTERÍSTICAS MECÁNICAS DE LA SOLDADURA POR ARCO EN FUNCIÓN DEL CONTENIDO DE CARBONO.

En la Fig. 1.28, se comparan las transformaciones experimentadas por los aceros al carbono en el momento de la soldadura por arco, caracterizadas por la dureza.

En este gráfico vemos que, el aumento a la concentración de carbono incrementa la diferencia de dureza entre el acero recocido (curva I) y el acero soldado (curva II). Esta es de:

- 30 a 40 Brinell, para el acero extradulce.
- 50 Brinell para el acero con 0.25% C. Esta concentración es un punto de inflexión.
- 80 a 100 Brinell para el acero con 0.30% C.
- Más de 250 Brinell para el de 0.50% C.

La curva de soldabilidad decrece en sentido inverso de la concentración de carbono del acero base, parece pues que la soldabilidad es menor a medida que la diferencia de dureza entre el acero recocido y el acero soldado es mayor.

El precalentamiento se aplica a los aceros carburados y a los aceros especiales porque reduce notablemente la diferencia de durezas, aumentando notablemente su soldabilidad.

Esta mejora es más sensible a medida que la temperatura de precalentamiento sea mayor. La fig. 1.28 muestra claramente el

desplazamiento de las curvas de dureza en función del desplazamiento del acero base, para 120°C y 315 °C.

### Manganeso

Considerado como un elemento gammógeno que favorece el temple, en general raramente su contenido sobrepasa del 2% en los aceros soldables, es un desoxidante energético y constituye un elemento importante en los electrodos y de las varillas de aporte por sus reacciones favorables con el metal líquido.

En los aceros que contienen por lo menos de 0.3 a 1.5% Mn, favorece en la desoxidación del acero, previene las inclusiones de sulfuro de hierro y aumenta la capacidad de endurecimiento, la presencia del manganeso incrementa la solubilidad del carbono en la austenita facilitando a formación de carburos.

En casos especiales en que se busque incrementar la dureza o resistencia al desgaste, el porcentaje de manganeso puede llegar hasta el 14% de manganeso generalmente para recubrimientos de piezas que van a sufrir esfuerzos de fricción.

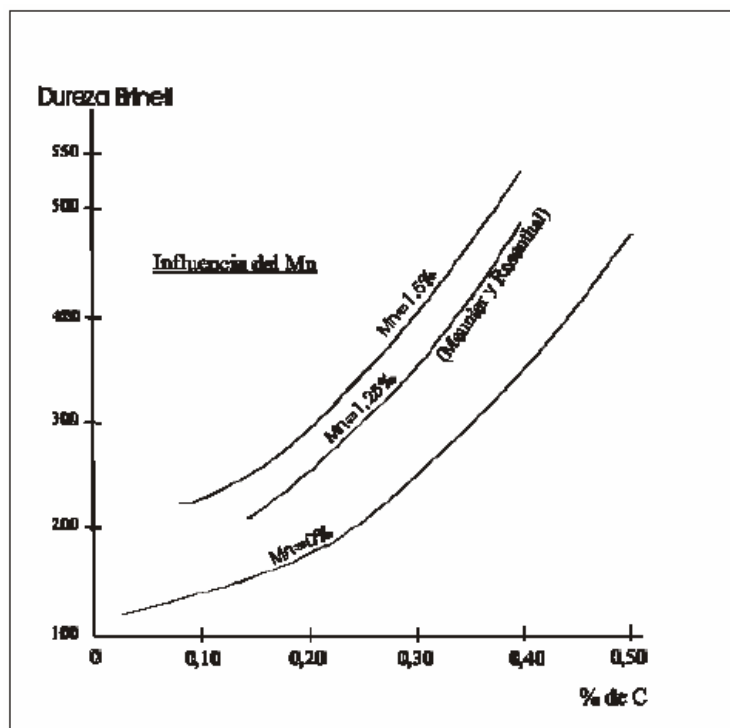


FIGURA. 1.29. INFLUENCIA DEL CONTENIDO DE MANGANESO DEL MATERIAL BASE EN LAS TRANSFORMACIONES DURANTE EL PROCESO DE SOLDADURA POR ARCO, EN FUNCIÓN AL CONTENIDO DE CARBONO.

El manganeso disminuye la velocidad crítica de enfriamiento del acero y aumenta la sensibilidad al sobrecalentamiento y contribuye a la fragilidad en el revenido.

En los aceros tratados térmicamente el manganeso incrementa: la resistencia a la tracción, el límite elástico, la resistencia a la fatiga, la fluencia lenta, la forjabilidad, la resistencia al revenido, la fragilidad en el revenido, la tendencia al crecimiento del grano, la formación de carburos y la dilatación térmica. El manganeso disminuye: la

embutibilidad, la maquinabilidad, la conductividad térmica y eléctrica y la sensibilidad a la fractura frágil.

La curva de la Fig. 1.29, representa la influencia del manganeso en la dureza de la zona de sobrecalentamiento de una soldadura por arco, y en consecuencia en la soldabilidad metalúrgica. Este diagrama muestra como la templabilidad del acero crece muy rápidamente, incluso con pequeñas cantidades de manganeso (de 1.25 a 1.5% Mn), al aumentar el contenido de carbono.

No obstante, es necesario señalar, que las curvas corresponden a los aceros con contenidos elevados de manganeso y permanecen sensiblemente paralelas a la curva del acero con carbono solamente. De ello se deduce que la influencia del manganeso es más acentuada que la del carbono; existiendo un aumento de la dureza sin bajar notablemente la soldabilidad del acero.

Algunos autores atribuyen al manganeso un poder de temple que está relacionado con el carbono:

$$C_{(s)} = \frac{Mn_{(s)}}{4}$$

#### **1.4.1. Comportamiento físico-químico de los elementos de aleación en la zona fundida.**

En el estudio de la evolución de la composición química de la zona fundida es importante analizar el comportamiento Físico-Químico de los elementos de aleación de la zona fundida, la absorción de gases por el metal fundido y la escoria en la soldadura.

##### Pérdida de elementos por oxidación.

Los elementos químicos que forman parte de la zona fundida en cualquier proceso de soldadura, pueden perderse por volatilización. Los fenómenos de volatilización son importantes a medida que la temperatura del baño y el tiempo de permanencia sea mayor.

El  $\text{Fe}_3\text{O}_4$ , constituye el componente más importante de los gases emitidos en el proceso de soldadura por arco eléctrico, dado que el vapor del hierro se oxida inmediatamente en contacto con el oxígeno del aire; del mismo modo tienen lugar pérdidas de manganeso.

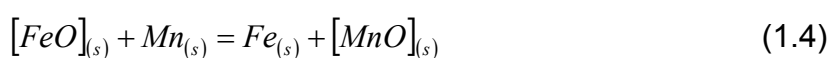
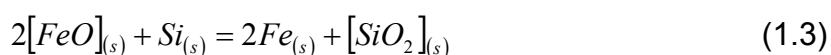
El cromo es uno de los elementos de aleación de los aceros más sensibles a la volatilización, de tal modo que la pérdida de cromo resultante debe compensarse en los revestimientos o en la composición química de los electrodos.

#### Reacciones químicas en el metal fundido.

Exactamente igual a lo que ocurre en la elaboración del acero, en el baño líquido de un proceso de soldadura tienen lugar reacciones químicas. La composición química es mayormente de hierro y carbono, con una cierta proporción de óxido de hierro (FeO), disuelta en la fase líquida en equilibrio con el carbono.

La presencia de una atmósfera que rodea al metal fundido ocasiona reacciones a consecuencia de la reducción del óxido de hierro por los elementos que componen el acero.

Los elementos oxidantes como el silicio, manganeso y carbono, actúan sobre el óxido de hierro (FeO), generando reacciones clásicas como:





Las reacciones (1.3) y (1.4) producen silicatos complejos de manganeso y de hierro que se eliminan fácilmente por decantación a través del metal líquido, mientras que la reacción (1.5) que da óxido de carbono puede, según las circunstancias favorecer la formación de sopladuras o provocar el defecto de poros superficiales.

#### **1.4.2. Absorción de gases por el metal fundido.**

Desde que se descubrió la soldadura por arco eléctrico, no ha cesado la búsqueda de métodos eficientes para la protección, en forma de desprendimientos gaseosos y de una escoria líquida. Sin embargo, por más que se esmere en la protección muchas veces resulta inevitable la absorción de gases desde la atmósfera (Nitrógeno y Oxígeno) y de Hidrógeno debido a la presencia de humedad, ejerciendo una influencia desfavorable sobre las propiedades mecánicas.

### Absorción de oxígeno.

En el estudio sistema Fe-O, el hierro puro disuelve poco oxígeno incluso a elevadas temperatura: 0.05% a 700 °C y 0.10% a 1400 °C. Pero en estado líquido, la cantidad de oxígeno absorbida es mucho mayor y está regulada por las fórmulas de equilibrio (1.3) y (1.5).

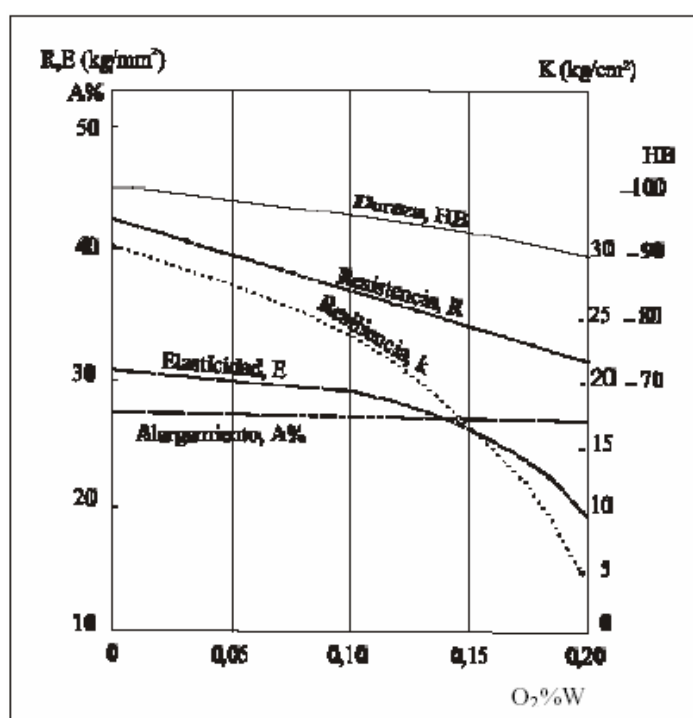


FIGURA. 1.30 INFLUENCIA DEL OXÍGENO EN LAS PROPIEDADES MECÁNICAS DEL ACERO DULCE.

En una unión soldada, el metal base no absorbe oxígeno y en las proximidades de la zona fundida el porcentaje de absorción teóricamente es 0.10% a 1400 °C. Sin embargo esta concentración no se alcanza nunca debido a la rapidez del

calentamiento y enfriamiento que están lejos de las condiciones de equilibrio.

En la zona fundida, las concentraciones de oxígeno pueden ser mayores. La cantidad de oxígeno absorbido dependerá de los siguientes factores:

- Procedimiento de soldadura oxiacetilénico o eléctrico por arco.
- Naturaleza del metal de aportación o del alma del electrodo.
- Naturaleza del revestimiento y su espesor.
- Los gases que rodean a la zona fundida.

En lo que respecta a las propiedades mecánicas disminuyen casi todas a excepción de la elongación y la resistencia que caen sensiblemente a cero, cuando el electrodo no tiene revestimiento.

La influencia del oxígeno sobre las propiedades mecánicas del acero dulce la podemos apreciar en la Fig. 1.30.

### Absorción del nitrógeno.

En este caso, el nitrógeno forma con el hierro el compuesto  $\text{Fe}_4\text{N}$ , que se presenta bajo la forma de cristales aplastados dando la apariencia de agujas.

La cantidad de nitrógeno absorbido dependerá esencialmente de las condiciones de ejecución de la soldadura. Los factores más importantes que influyen en la absorción de nitrógeno son los siguientes:

- Procedimiento de soldadura: En la fusión por arco eléctrico, la absorción de nitrógeno puede alcanzar de 0.15 a 0.20% para los electrodos sin revestimiento ni protección de gas.
- Naturaleza del metal base: Una soldadura por arco aplicada en hierro Armco con electrodo sin revestimiento absorbe:
  - 0.15% de nitrógeno con un arco de 2mm.
  - 0.20% de nitrógeno con un arco de 6 a 8 mm.

Los elementos adicionales del acero influyen en la absorción del nitrógeno de distinta forma según su naturaleza:

- El C, Mn y Si: Tienden a disminuir la absorción.
  - El Al, V y U aumentan ligeramente la absorción de nitrógeno.
  - El Cr, Mo y Zr: Influyen más energicamente.
  - El Ti tiende a disminuir la fijación del nitrógeno.
- 
- Naturaleza de la atmósfera que rodea al metal fundido:  
Muchos investigadores ha realizado numerosos ensayos fundiendo el hierro en distintos medios: Aire, nitrógeno, amoníaco e hidrógeno. Los resultados del análisis químico y los exámenes metalográficos muestran que la concentración de nitrógeno influye de la siguiente manera:
    - Aumenta en las atmósferas de nitrógeno puro o de amoníaco.
    - Disminuye en las atmósferas reductoras de hidrógeno o de óxido de carbono.Esta es la razón del porque se emplean electrodos con elementos que desprendan gases reductores durante la fusión.
- 
- Naturaleza y diámetro del revestimiento del electrodo.

- Naturaleza y longitud del arco: Asumiendo que todos los factores anteriores sean constantes, el aumento de la longitud del arco que corresponde a una elevada tensión, conduce a un aumento en el contenido de nitrógeno.

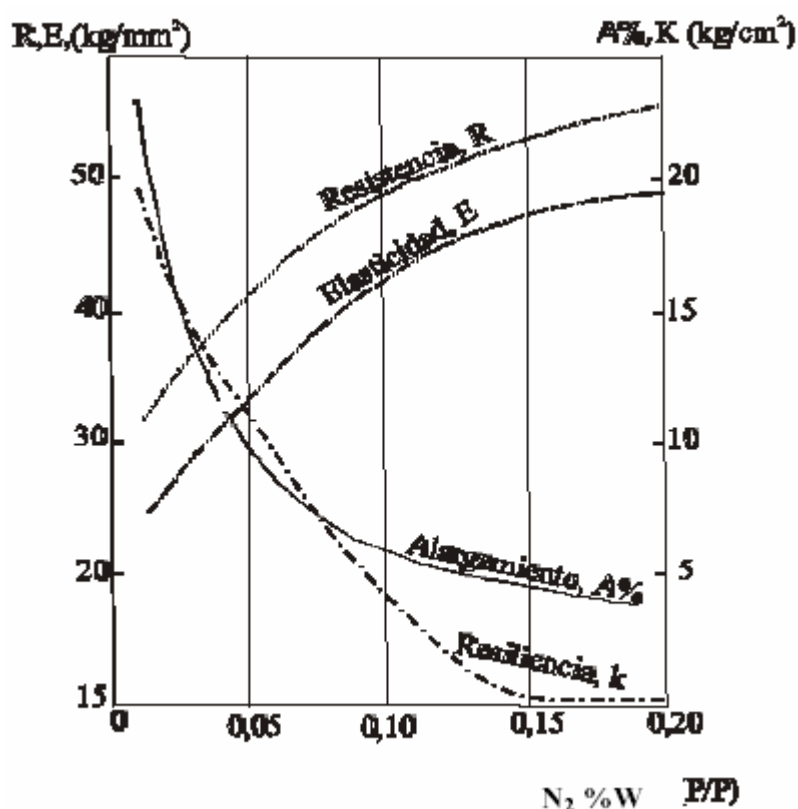


FIGURA. 1.31 INFLUENCIA DEL NITRÓGENO EN LAS PROPIEDADES MECÁNICAS DEL ACERO DULCE.

La absorción del nitrógeno durante el proceso de la soldadura por arco con electrodo sin revestir y arco largo de 5 a 8 mm. es de 0.20% [2]; en estas condiciones:

- Aumentan la resistencia , la elasticidad y la dureza;
- Disminuye la elongación y la resiliencia.

Al igual que el oxígeno, el nitrógeno se concentra en los límites de grano como impurezas que afectan notablemente a las propiedades mecánicas del acero dulce como lo podemos apreciar en la Fig. 1.31.

En el procedimiento por arco, la absorción de nitrógeno es una de las más importantes y varía según la naturaleza, espesor del revestimiento y las condiciones del arco:

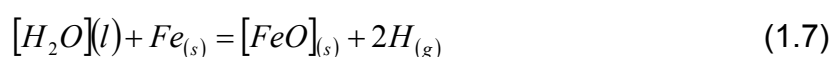
- En las peores condiciones como puede ser un electrodo sin revestimiento y un arco muy largo se obtiene 0.30% de nitrógeno.
- En las mejores condiciones:
  - Con un electrodo a base de hidrógeno la absorción es de 0.03% de nitrógeno.
  - Soldando con electrodo que tiene revestimiento básico la absorción es de 0.015% de nitrógeno.

### Absorción de hidrógeno.

Además del oxígeno y nitrógeno, el metal fundido por arco puede absorber una cantidad importante de hidrógeno; las posibles fuentes que abastecen de hidrógeno pueden ser:

- El material base que contiene herrumbre hidratado en su superficie.
- La atmósfera húmeda.
- El revestimiento del electrodo.

Para llegar a liberarse el hidrógeno presente en los medios anteriores, son necesarias las reacciones (1.6) y (1.7):



El hidrógeno y el hierro no forman hidruros, pero si se disuelve en el hierro.

En la Tabla 2 se muestra la absorción del hidrógeno en la fusión por arco de los electrodos con diferente composición, las concentraciones de hidrógeno se dan en centímetros cúbicos por cada 100 g. de metal.

TABLA 2

Absorción del hidrógeno en la fusión por arco de los electrodos con diferente composición.

| Muestra                                 | % C  | % Mn | % Si | % O <sub>2</sub> | % N <sub>2</sub> | H <sub>2</sub> cm <sup>3</sup> /100g de metal |
|-----------------------------------------|------|------|------|------------------|------------------|-----------------------------------------------|
| Electrodo sin revestimiento             | 0,04 | 0,07 | 0,02 | 0,22             | 0,12             | 1,35                                          |
| Revestimiento muy delgado               | 0,04 | 0,27 | 0,03 | 0,17             | 0,11             | 2,25                                          |
| Revestimiento grueso Tipo A             | 0,10 | 0,48 | 0,05 | 0,09             | 0,016            | 6 a 8                                         |
| Tipo B                                  | 0,08 | 0,56 | 0,06 | 0,08             | 0,015            | 8 a 10                                        |
| Tipo C                                  | 0,11 | 0,65 | 0,56 | 0,09             | 0,015            | 22 a 25 (*)                                   |
| Tipo D                                  | 0,13 | 1,12 | 1,15 | 0,06             | 0,022            | 31 a 32 (*)                                   |
| Tipo E                                  | 0,12 | 0,60 | 0,22 | 0,09             | 0,008            | 17,9 (*)                                      |
| (*) Numerosas manchas en forma de copos |      |      |      |                  |                  |                                               |

El electrodo sin revestimiento contiene 1.35 cm<sup>3</sup> de H<sub>2</sub>/100g de metal. En los electrodos con revestimiento tipo A y B fija una gran cantidad de hidrógeno, 6 a 10 cm<sup>3</sup> de hidrógeno por cada 100 g de metal fundido, proviniendo principalmente de las sustancias orgánicas que sirven de aglutinante y del agua químicamente combinada con el silicato.

Para los electrodos de tipo volátil C y D , es decir que desprenden gas protector, los contenidos de hidrógeno son

todavía más elevados. Según W. Spraragen y H. Claussen, que han estudiado la atmósfera que rodea la zona fundida de una soldadura por arco, han encontrado, para un electrodo celulósico, 85.4 cm<sup>3</sup> de hidrógeno.

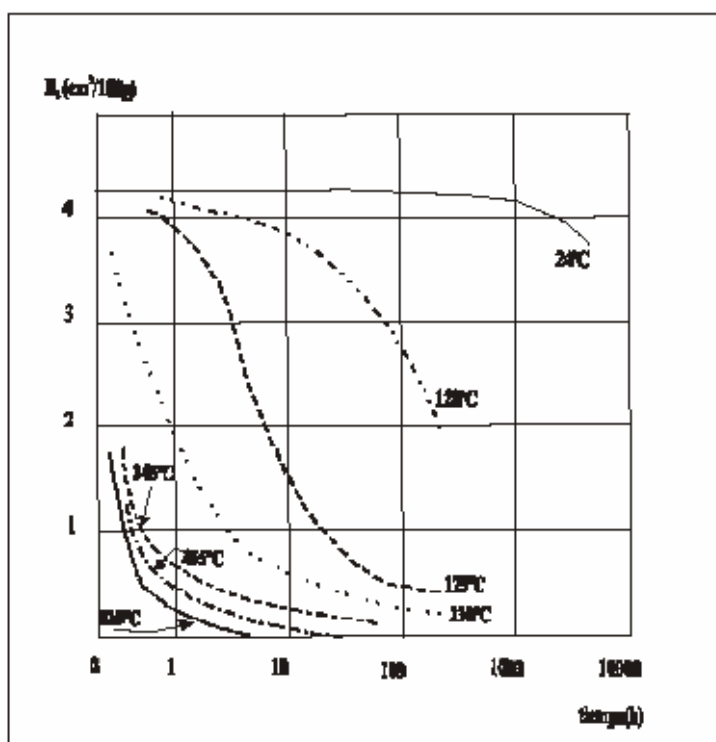


FIGURA 1.32. EFECTO DEL TRATAMIENTO POSTERIOR SOBRE EL CONTENIDO DE H<sub>2</sub> DEL METAL APORTADO EN LA SOLDADURA POR ARCO.

La presencia del hidrógeno en el acero se manifiesta, bajo ciertas condiciones, por manchas claras en las roturas, presentando una estructura de granos, mientras que la rotura en la parte del metal es fibrosa y de color gris oscuro. Estas

manchas pueden existir en toda la región de la rotura o en forma aislada.

La concentración de hidrógeno tiende a disminuir las propiedades mecánicas de resistencia a la deformación. La velocidad durante el proceso de la soldadura tiene una enorme influencia en el contenido de hidrógeno de la soldadura.

La determinación del hidrógeno en las soldaduras por arco se hace difícil por el cambio de concentración de este gas en función al tiempo. En efecto, el hidrógeno se desprende durante todo el proceso de solidificación a la temperatura ordinaria y alcanza el equilibrio al cabo de un tiempo bastante largo. Dado que la difusión del hidrógeno es más lenta en la medida de que la temperatura sea mas baja.

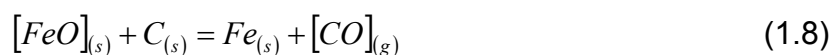
Según Séférian Fig. 1.32 la cantidad de hidrógeno desprendida por un depósito obtenido a partir de electrodos básicos una vez alcanzado el equilibrio a la temperatura ordinaria, es función de la temperatura del tratamiento térmico.

Puede verse que el desprendimiento a 20 °C es relativamente lento y necesita 4000 horas para desprender el 20% de hidrógeno residual. Por el contrario, a 620 °C el desprendimiento se produce en menos de 2 horas.

El hidrógeno presente en el depósito de soldadura puede ocasionar los siguientes defectos macroscópicos:

- Proyecciones de metal: La diferencia entre las capacidades de absorción del hidrógeno por el metal en estado líquido y en estado sólido provoca un desprendimiento efervescente de gas, que genera pérdidas importantes de metal por proyección. Esta pérdida no sólo se debe al hidrógeno, sino también a la presencia del oxígeno.
- Formación de poros por el hidrógeno: Está demostrado que la sobresaturación de gases en el metal en estado líquido, o una solidificación demasiado rápida, generan sopladuras importantes que retienen gases a presión. Sin embargo en la mayoría de los casos tales gases son compuestos oxigenados de carbono, compuestos de hidrógeno y de nitrógeno:  $H_2O$ ,  $H_2S$ ,  $CH_4$ .

La presencia del CO se explica por la reducción del oxígeno de hierro por el carbono de acuerdo a la ecuación de equilibrio (1.8):



Un acero con alto porcentaje de carbono tenderá a generar mayor cantidad de sopladuras. Por otro lado, se sabe que un electrodo húmedo origina con mayor facilidad sopladuras que uno seco; esta tendencia es más pronunciada en los electrodos básicos, que contienen poco hidrógeno; en efecto, basta una cantidad de humedad de 0.35% en peso del revestimiento básico para que aparezcan poros en la soldadura.

Herres, propuso la ecuación (1.9) para explicar otra causa de la formación de poros es la reducción del óxido de hierro por el hidrógeno:



Herres y Voldrich plantearon la hipótesis de que la acción del hidrógeno sobre el azufre generaba sopladuras según la reacción (1.10):



Los aceros que contienen cromo tienen una tendencia marcada a la formación de poros cuando el revestimiento está húmedo. La presencia del metano en los poros se explica por la reacción del hidrógeno con los carburos, en particular sobre los de hierro, manganeso y cromo, reacción (1.11):



Los compuestos carburados de ferromanganeso y el ferrocromo carburados presentes en los revestimientos pueden ser fuentes indirectas de formación de poros por reacción con el hidrógeno.

La influencia del hidrógeno en la formación de poros se manifiesta sobre todo con los revestimientos de elevado “Potencial de hidrógeno”, tales como los celulósicos y los que están húmedos. La atmósfera exterior puede también ser causa de formación de sopladuras en el metal fundido.

- Formación de “Fish-Eyes”: En general, aparecen en las fracturas de las soldaduras en forma de manchas blancas de forma circular de dimensiones muy variables, desde 1 mm de diámetro hasta 1 cm; tienden a formarse alrededor de las inclusiones y con frecuencia van

acompañados de microgrietas, indicando una concentración de tensiones en esa región.

Se ha llegado a la conclusión de que la causa inicial de la formación de fish-eyes en la soldadura por arco es el revestimiento del electrodo y que las soldaduras ejecutadas con varilla sin revestimiento no presentan este defecto.

## **CAPITULO 2**

### **2. SELECCIÓN DEL PROCEDIMIENTO DE SOLDADURA.**

Durante este capitulo se hará uso del Código D 1.4 de la Sociedad Americana de Soldadura, AWS por sus siglas en ingles (American Welding Society), que fue adquirido por la compañía NOVACERO S.A.

Como se vio en el capitulo anterior, queda prohibido por este código, realizar puntos de soldadura que no formen parte de la unión soldada final, sin embargo en la construcción existen ocasiones donde es necesaria una longitud mayor a la que originalmente se distribuye de fabrica (actualmente la mayor longitud es de 12 metros). Digamos por ejemplo que se necesita armar una columna de 18 metros de longitud, para lo cual se deberá realizar un empalme.

## **2.1. Los Códigos en la construcción.**

En un esfuerzo por asegurar la calidad de productos o servicios, la sociedad mantiene la tendencia de estandarizar los procedimientos de manera que exista una repetibilidad en los procesos a ejecutarse. Es así que se crean asociaciones nacionales o internacionales cuyo afán es el de suministrar al gremio que representan información obtenida de la experiencia y/o experimentación.

En el caso de nuestro país es el Instituto Ecuatoriano de Normalización (INEN) el organismo responsable de formular las Normas Técnicas Ecuatorianas que definan las características de materias primas, productos intermedios y productos terminados que se comercialicen en el Ecuador, así como, los métodos de ensayo, inspección, análisis, medida, clasificación y denominación de aquellos materiales o productos.

Estas organizaciones muchas veces sin necesidad de trabajar en conjunto, hacen referencia unas a las otras con el objeto de permitir que cada una se especialice en su campo y así poder complementarse.

Este es el caso de nuestra investigación, donde la necesidad de realizar empalmes soldados de varilla corrugada de acero al carbono, nos dirige al Código Ecuatoriano de la Construcción, el que a su vez delega la responsabilidad completa de los lineamientos que rigen a la uniones soldadas de barras corrugadas de acero al carbono, al Código de Soldadura Estructural – Acero de Refuerzo AWS D1.4/D1.4M:2005 el mismo que en su texto indica que la materia prima del acero de refuerzo debe cumplir con una de las normas listadas, estas pertenecientes a la Sociedad Americana de Ensayos y Materiales ASTM por sus siglas en ingles (American Society for Testing and Materials) siendo en nuestro caso la norma ASTM A615 “Barras lisas y corrugadas para hormigón armado, obtenidas de palanquilla de acero” la que regula la materia prima usada en la fabricación de nuestra varilla corrugada.

## **2.2. Material base.**

Las barras de acero corrugado fabricadas por la empresa NOVACERO S.A. cumplen con los requisitos establecidos por la norma ASTM A615M (Barras lisas y corrugadas para hormigón armado obtenidas de palanquilla de acero), o por su homóloga

nacional que es la NTN INEN 102 (Varillas con resaltes de acero al carbono laminadas en caliente para hormigón armado. Requisitos).

Estas barras son fabricadas en Grado 420 (para la designación según la ASTM A615) o Grado A42 (para la designación de la NTE INEN 102).

Se realizó un ensayo químico al lote suministrado para obtener las muestras a ensayar, obteniéndose los resultados de la TABLA 3.

TABLA 3

PARAMETROS QUIMICOS ANALIZADOS

| %C     | %Mn     | %Si     | %S      | %P      | %Cu     | %Ni    |
|--------|---------|---------|---------|---------|---------|--------|
| 0.4184 | 0.55824 | 0.08843 | 0.03310 | 0.02113 | 0.02496 | 0.0269 |

Las barras usadas tanto en la calificación del soldador, como el proceso de soldadura, es de un diámetro de 28 mm.

### 2.3. Proceso de soldadura.

En vista de que el proceso más usado en el mercado de la construcción es el de electrodo revestido (SMAW Shield Metal Arc Welding), este se convierte en nuestra selección para calificar.

La Soldadura de Arco Manual o MMA es también conocida como Soldadura de Electrodo Cubierto, Soldadura de Varilla o Soldadura de Arco Eléctrico. Es la más antigua y más versátil de todos los diferentes procesos de soldadura de arco.

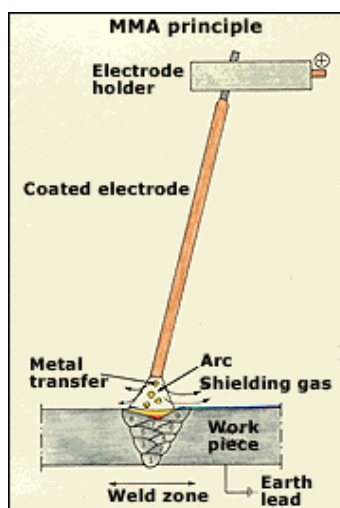


FIGURA. 2.1 PROCESO DE SOLDADURA DE ELECTRODO CUBIERTO

Un Arco Eléctrico es mantenido entre la punta de un electrodo cubierto (Coated Electrode) y la pieza a trabajar. Las gotas de metal derretido son transferidas a través del arco y son convertidas en un cordón de soldadura, un escudo protector de gases es producido de la descomposición del material fundente que cubre el electrodo además, el fundente también puede proveer algunos complementos a la aleación, la escoria derretida se escurre sobre el cordón de soldadura donde protege el metal soldado aislándolo de la atmósfera durante la solidificación, esta escoria también ayuda a darle forma al cordón de soldadura especialmente en soldadura vertical y sobre cabeza. La escoria debe ser removida después de cada procedimiento.

#### **2.4. Tipo de junta.**

Las barras de refuerzo pueden ser soldadas mediante varios tipos de juntas, entre estas se encuentran las uniones: directas a tope, indirectas a tope, a traslape y en T.

TABLA 4  
DIMENSIONES MÁS COMÚNMENTE USADAS EN  
BARRAS DE ACERO DE REFUERZO.

| Numero | Diámetro<br>(mm.) | Area<br>(mm <sup>2</sup> .) | Perímetro<br>(mm.) | Peso<br>(Kg/m) |
|--------|-------------------|-----------------------------|--------------------|----------------|
| 3      | 9,52              | 71                          | 29,9               | 0,560          |
| 4      | 12,70             | 129                         | 39,9               | 0,994          |
| 5      | 15,88             | 199                         | 49,9               | 1,552          |
| 6      | 19,05             | 284                         | 59,8               | 2,235          |
| 7      | 22,22             | 387                         | 69,8               | 3,042          |
| 8      | 25,40             | 510                         | 79,8               | 3,973          |
| 9      | 28,65             | 645                         | 90,0               | 5,060          |
| 10     | 32,26             | 819                         | 101,3              | 6,404          |
| 11     | 35,81             | 1006                        | 112,5              | 7,907          |
| 14     | 43,00             | 1452                        | 135,1              | 11,380         |
| 18     | 57,33             | 2581                        | 180,1              | 20,240         |

En vista de que la mayor utilización que tienen las barras corrugadas de gran longitud (mayor a la provista por el mercado de 12 metros) es usada en la construcción de edificios, donde los diámetros de barra superan los 16 mm, se debe tomar en cuenta que el código en la sección 3.2.2 indica que el uso de uniones en traslape debe estar limitada a las barras No. 6 o mas pequeñas. Esto se debe a la

excentricidad creada por los traslapes, y si bien se decide realizar este empalme, el diseñador de la armadura deberá haber tomado consideración de este detalle constructivo, de manera que no se afecte la integridad estructural del diseño.

Para el efecto de la presente tesis, se han tomado en consideración las dos uniones mas comúnmente usadas en el mercado de la construcción.

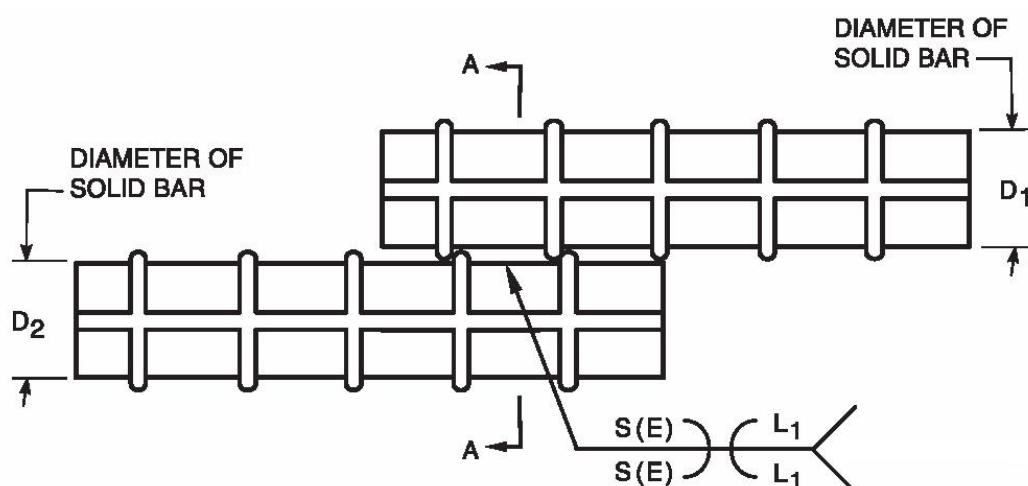


FIGURA. 2.2 UNIÓN DIRECTA A TOPE, BARRAS EN CONTACTO.

Empezando por la unión a traslape, en la que como ya vimos deberá ser considerada la excentricidad debido al traslape, así como la siguiente relación.

$$L_1 = 2D_1(\min): D_1 \leq D_2$$

También se considero la unión a tope directa, la cual debe ser soldada con soldadura de penetración completa según la Fig. 2.3

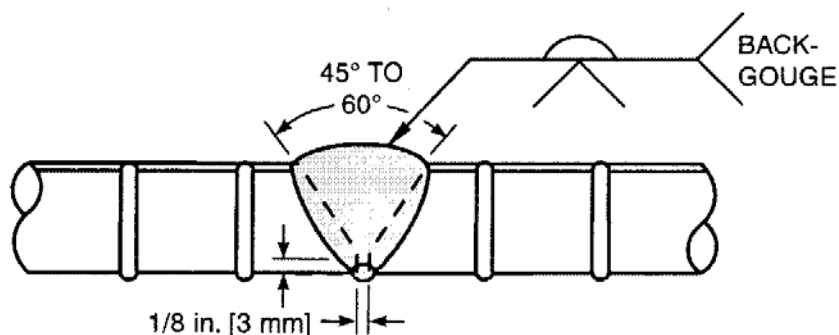


FIG. 2.3 UNIÓN DIRECTA A TOPE, BISELADA EN AMBOS EXTREMOS.

## 2.5. Metal de aporte.

La selección del metal de aporte debe realizarse de acuerdo a la Tabla 5, entonces teniendo en cuenta que las barras de acero a ser soldadas, pertenecen a la clasificación ASTM A615M Grado 420, y habiendo seleccionado un proceso SMAW (Soldadura por arco de electrodo revestido), el tipo de acero recae en el GRUPO III, donde se pueden seleccionar tres tipos de electrodos: E9015-X, E9016-X, E9018-X.

En vista de que no se fabrica a nivel nacional estos tipos de electrodos, se procedió con la importación por medio del departamento de adquisiciones de AGA.

**TABLA 5**  
**REQUERIMIENTOS DEL METAL DE APOORTE Y EL METAL BASE**

| GRUPO | ESPECIFICACION DEL ACERO | Sy<br>MPa | Sut<br>MPa | ESPECIFICACION DE ELECTRODO                                                     | Sy<br>MPa          | Sut<br>MPa     |
|-------|--------------------------|-----------|------------|---------------------------------------------------------------------------------|--------------------|----------------|
| I     | ASTM A615M<br>GRADO 300  | 300       | 500        | SMAW AWS A5.1 y 5.5<br>E7015, E7016, E7018, E7028<br>E7015-X, E7016-X, E7018-X  | 365-496<br>390-415 | 482<br>480-520 |
|       |                          |           |            | GMAW AWS A5.18<br>ER70S-X, E70C-3, E70C-3                                       | 400                | 480            |
|       |                          |           |            | FCAW AWS A5.20 y A5.29<br>E7XT-X<br>E7XTX-X<br>Except. de -2,-3,-10,-13,-14,-GS | 400<br>400         | 480<br>480-620 |
| II    | ASTM A706M<br>GRADO 420  | 420       | 550        | SMAW AWS 5.5<br>E8015-X, E8016-X, E8018-X                                       | 460                | 550            |
|       |                          |           |            | GMAW AWS A5.28<br>ER80S-X, E80C-X, E90C-X                                       | 470                | 550            |
|       |                          |           |            | FCAW AWS A5.29<br>E8XTX-X                                                       | 470                | 550-690        |
| III   | ASTM A615M<br>GRADO 420  | 420       | 600        | SMAW AWS 5.5<br>E9015-X, E9016-X, E9018-X                                       | 530                | 620            |
|       |                          |           |            | GMAW AWS A5.28<br>ER90S-X                                                       | 540                | 620            |
|       |                          |           |            | FCAW AWS A5.29<br>E9XTX-X                                                       | 540                | 620            |
| IV    | ASTM A615M<br>GRADO 520  | 520       | 700        | SMAW AWS 5.5<br>E10015-X, E10016-X, E10018-X<br>E10018-M                        | 600<br>610-690     | 690<br>690     |
|       |                          |           |            | GMAW AWS A5.28<br>ER100S, ER100C-X                                              | 610                | 690            |
|       |                          |           |            | FCAW AWS A5.29<br>E10XTX-X                                                      | 610                | 690-830        |

El electrodo importado pertenece a la familia del E9018, adicionalmente se utilizó un tipo de electrodo que si se fabrica y provee a nivel nacional, el E7018. Esto con el fin de evaluar la factibilidad de usar un electrodo de fabricación nacional, aunque esto no sea el recomendado por el Código D1.4

## **2.6. Determinación de la temperatura de precalentamiento.**

Uno de los objetivos de precalentar el material base, es el de uniformizar la temperatura de este, para evitar que en el momento de la soldadura y aporte del material, existan esfuerzos relacionados con el cambio brusco de temperatura. El objetivo es evitar que el material se temple, o propicie la creación de zonas con formación de estructuras martensíticas, por cuanto endurecerían el material y reducirían su comportamiento elástico, eliminando así la propiedad sismorresistente de la unión soldada.

Como se vio con anterioridad el CE (Carbono Equivalente) es determinante en la templabilidad de un acero, por cuanto se realiza el cálculo del Carbono Equivalente para el material base usando la siguiente fórmula.

$$C.E. = \%C + \frac{\%Mn}{6},$$

donde se toma los datos del reporte de análisis químico (EC-PRO-0039 B), realizado en AGA. Entonces:

$$C.E. = 0,4184\% + \frac{0,55824\%}{6} = 0,51144$$

TABLA 6

TEMPERATURA MINIMA DE PRECALENTAMIENTO

| Rango de C.E.<br>% | Tamaño de la barra<br>mm             | Temperatura mínima<br>°C |
|--------------------|--------------------------------------|--------------------------|
| C.E. ≤ 0,40        | D ≤ 36<br>43 y 57                    | -<br>10                  |
| 0,40 < C.E. ≤ 0,45 | D ≤ 36<br>43 y 57                    | -<br>10                  |
| 0,45 < C.E. ≤ 0,55 | D ≤ 19<br>22 ≤ D ≤ 36<br>43 ≤ D ≤ 57 | -<br>10<br>90            |
| 0,55 < C.E. ≤ 0,65 | D ≤ 19<br>22 ≤ D ≤ 36<br>43 ≤ D ≤ 57 | 40<br>90<br>150          |
| 0,65 < C.E. < 0,75 | D ≤ 19<br>22 ≤ D ≤ 57                | 150<br>200               |
| C.E. > 0,75        | D ≤ 19<br>22 ≤ D ≤ 57                | 150<br>260               |

Usando la tabla 6, este valor recae dentro del intervalo “Sobre 0,45 hasta 0,55 inclusive”, se obtiene que para barras desde 22 a 36 mm se necesita que la barra se encuentre a 10 °C, por lo que haciendo

uso de un medidor láser de temperatura, se verifica que la temperatura de la barra no se encuentra a menos de 2 °C de la temperatura ambiente, que se mantiene en 32 °C.

## **CAPITULO 3**

### **3. CALIFICACION                      BAJO                      CODIGO                      AWS D1.4/D1.4M:2005.**

#### **3.1. Elaboración de las probetas.**

##### **3.1.1. Preparación del metal base.**

Las superficies a ser soldadas deben estar libres de limallas, grietas u otros defectos que pudiesen afectar negativamente la calidad o resistencia de la soldadura. Las superficies a ser soldadas, y las superficies adyacentes a la soldadura, deberán también estar libres de humedad, oxido, grasa, recubrimientos epóxicos u otro material que pudiese afectar la unión soldada o pudiese en el proceso expeler vapores o gases nocivos.

Los extremos de las barras de acero, para una unión directa a tope, deben ser formadas por medio de oxicorte, sierras u otros procedimientos mecánicos (Fig. 3.1).



FIGURA. 3.1 CORTE DEL EXTREMO DE LA BARRA DE ACERO CON DISCO DE SIERRA.

### **3.1.2. Ensamble de las probetas.**

La unión de los elementos debe ser alineada, de manera que se minimicen las excentricidades, las barras de la numeración No. 10 (32 mm) o menores, deben tener una separación menor o igual a 3mm entre los ejes de las dos barras (Fig. 3.2).



FIGURA. 3.2 ALINEACIÓN DE LA UNIÓN A TOPE EN V.

### 3.2. Calificación del soldador y del procedimiento de soldadura.

Debido a que no se encontró un soldador calificado para realizar juntas, de acuerdo a los requerimientos del Código D1.4, NOVACERO S.A. procedió a enviar a un operador del área de Proyectos, con previa experiencia en soldadura bajo otros procesos, para que realice la calificación como soldador acreditado por AGA, según el Código D 1.4 de la AWS.

Las mismas probetas usadas para calificar al soldador, y los resultados de estas, fueron utilizadas para calificar el proceso de soldadura.

### 3.2.1. Calificación del Soldador.

El soldador (Jhon Jairo Bautista) fue calificado en un proceso de soldadura SMAW, o soldadura por electrodo revestido; para un ensamble de junta de penetración completa a tope, tal como se vio en la figura 2.1. La posición de soldadura es la 3G (Fig. 3.3 y Fig. 3.4), con un ángulo de  $60^\circ$  para el bisel, sin usar respaldo.

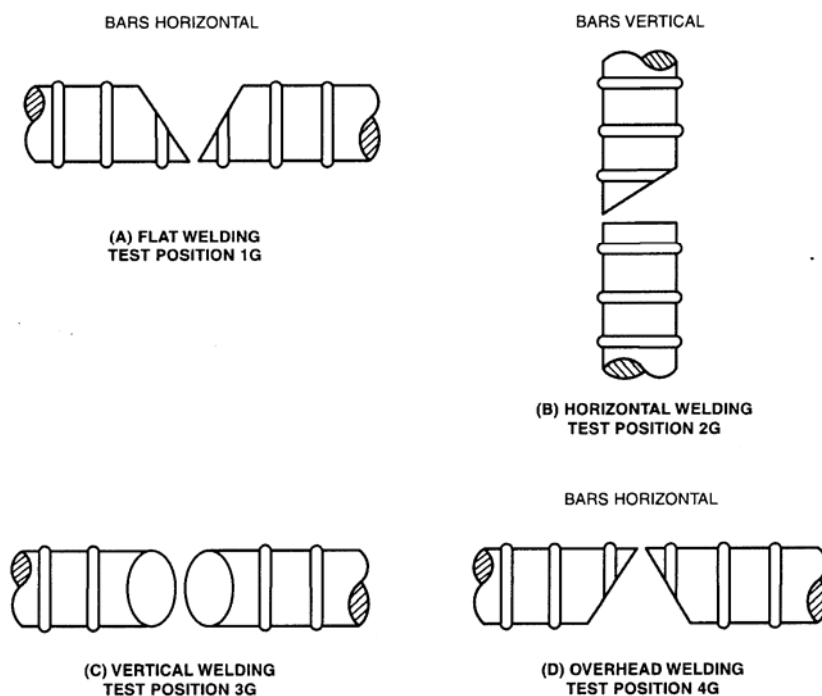


FIGURA. 3.3 POSICIONES DE LAS PROBETAS PARA UNA JUNTA A TOPE.



FIGURA. 3.4 FOTOGRAFÍA DEL OPERADOR SOLDANDO EN POSICIÓN 3G.

### **3.2.2. Parámetros de soldadura.**

#### **3.2.2.1. Probeta 1**

Se utiliza corriente directa con un amperaje en un rango entre 110 y 130 amperios, y un voltaje en un rango de 20 a 28 voltios.

Con barras de acero al carbono tipo ASTM A615M de 28 mm de diámetro, y con un CE de 0,51, se uso un electrodo E9018-G H4R. (TABLA 7).

TABLA 7

**PROCEDURE QUALIFICATION RECORD**

**PQR N° 001**

| Contractor: <b>Rodrigo Corral Franco</b>                                                                                                                       |                     |                                            |                         |                                                                                        |                                                                                                  |                                   |                     |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------|--------------------------------------------|-------------------------|----------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------|-----------------------------------|---------------------|
| Authorized by: <b>NOVACERO</b>                                                                                                                                 |                     |                                            |                         |                                                                                        | Revision No. <b>001</b>                                                                          |                                   |                     |
| Welder: <b>John Bautista Angulo</b>                                                                                                                            |                     |                                            |                         |                                                                                        | Test Date: <b>12-05-2006</b>                                                                     |                                   |                     |
| <b>WELDING PROCESS:</b> <input type="checkbox"/> FCAW-S <input type="checkbox"/> FCAW-G <input type="checkbox"/> GMAW <input checked="" type="checkbox"/> SMAW |                     |                                            |                         |                                                                                        |                                                                                                  |                                   |                     |
| <b>PQR JOINT TYPE:</b> <input checked="" type="checkbox"/> Direct Butt <input type="checkbox"/> Indirect Butt <input type="checkbox"/> T-Joint                 |                     |                                            |                         |                                                                                        |                                                                                                  |                                   |                     |
| <b>Test Assembly:</b> Fig. 2.3 Unión directa a tope, biselada en ambos extremos                                                                                |                     |                                            |                         |                                                                                        |                                                                                                  |                                   |                     |
| Position: <b>1G</b>                                                                                                                                            |                     | Type Groove: <b>A TOPE</b>                 |                         | Single Bevel <input type="checkbox"/> Double Bevel <input checked="" type="checkbox"/> |                                                                                                  |                                   |                     |
| Root Opening: <b>3 mm</b>                                                                                                                                      |                     | Type Root Face: <b>3 mm</b>                |                         | Groove Angle: <b>60°</b>                                                               |                                                                                                  |                                   |                     |
| Backing: <input type="checkbox"/> Yes <input checked="" type="checkbox"/> No                                                                                   |                     |                                            |                         |                                                                                        | Backing Type: <b>N.A.</b>                                                                        |                                   |                     |
| <b>TECHNIQUE:</b> <input type="checkbox"/> Stringers <input checked="" type="checkbox"/> Weave                                                                 |                     |                                            |                         |                                                                                        |                                                                                                  |                                   |                     |
| <b>ELECTRICAL CHARACTERISTICS</b>                                                                                                                              |                     |                                            |                         |                                                                                        |                                                                                                  |                                   |                     |
| Current: <input type="checkbox"/> AC <input checked="" type="checkbox"/> DCEP <input type="checkbox"/> DCEN                                                    |                     |                                            |                         |                                                                                        |                                                                                                  |                                   |                     |
| <b>BASE METAL</b>                                                                                                                                              |                     |                                            |                         |                                                                                        |                                                                                                  |                                   |                     |
|                                                                                                                                                                |                     | Material Specification: <b>ASTM A-615M</b> |                         |                                                                                        | Grade: <b>420</b>                                                                                |                                   |                     |
| Welded to:                                                                                                                                                     |                     | Material Specification: <b>ASTM A-615M</b> |                         |                                                                                        | Grade: <b>420</b>                                                                                |                                   |                     |
| Maximum Carbon Equivalent: <b>0.51 %</b>                                                                                                                       |                     | Bar size: <b>28 mm</b>                     |                         |                                                                                        |                                                                                                  |                                   |                     |
| Coated Bar: <input type="checkbox"/> Yes <input checked="" type="checkbox"/> No                                                                                |                     |                                            |                         |                                                                                        | Type of Coating: <b>N.A.</b>                                                                     |                                   |                     |
| <b>FILLER METAL</b>                                                                                                                                            |                     |                                            |                         |                                                                                        |                                                                                                  |                                   |                     |
| AWS Specification: <b>A 5.5</b>                                                                                                                                |                     |                                            |                         |                                                                                        | AWS Classification: <b>E-9018-G H4R</b>                                                          |                                   |                     |
| <b>PREHEAT/INTERPASS</b>                                                                                                                                       |                     |                                            |                         |                                                                                        |                                                                                                  |                                   |                     |
| Preheat/Interpass Temperature (Min): <b>N.A.</b>                                                                                                               |                     |                                            |                         |                                                                                        | Interpass Temperature (Max): <b>N.A.</b>                                                         |                                   |                     |
| <b>WELDING PARAMETERS</b>                                                                                                                                      |                     |                                            |                         |                                                                                        |                                                                                                  |                                   |                     |
| Pass Number(s)                                                                                                                                                 | Electrode Diameter  | Current                                    |                         |                                                                                        |                                                                                                  | Travel Speed (ipm)                | Joint Detail        |
|                                                                                                                                                                |                     | Type                                       | Amperage                | Volts Range                                                                            | Electrical Stickout                                                                              |                                   |                     |
| <b>1 - n</b>                                                                                                                                                   | <b>E-9018 Ø 1/8</b> | <b>Continua (+)</b>                        | <b>110-130</b>          | <b>20-28</b>                                                                           | <b>-</b>                                                                                         | <b>-</b>                          | <b>Ver Fig. 2.3</b> |
| <b>TEST RESULTS</b>                                                                                                                                            |                     |                                            |                         |                                                                                        |                                                                                                  |                                   |                     |
| <b>VISUAL EXAMINATION</b>                                                                                                                                      |                     |                                            |                         |                                                                                        |                                                                                                  |                                   |                     |
| Test Assembly Number One: Pass <input checked="" type="checkbox"/> Fail <input type="checkbox"/>                                                               |                     |                                            |                         |                                                                                        | Test Assembly Number Two: Pass <input checked="" type="checkbox"/> Fail <input type="checkbox"/> |                                   |                     |
| Comments: -----                                                                                                                                                |                     |                                            |                         |                                                                                        |                                                                                                  |                                   |                     |
| <b>TENSILE TEST</b>                                                                                                                                            |                     |                                            |                         |                                                                                        |                                                                                                  |                                   |                     |
| Test Assembly Number One: Pass <input checked="" type="checkbox"/> Fail <input type="checkbox"/>                                                               |                     |                                            |                         |                                                                                        | Test Assembly Number Two: Pass <input checked="" type="checkbox"/> Fail <input type="checkbox"/> |                                   |                     |
| Specimen No.                                                                                                                                                   | Width               | Diameter (mm)                              | Area (mm <sup>2</sup> ) | Ultimate Tensile Load (Kg)                                                             | Ultimate Unit Stress (Kgf/mm <sup>2</sup> )                                                      | Character of Failure and Location |                     |
| 1                                                                                                                                                              | -                   | 28                                         | 615,44                  | 35,332                                                                                 | 57,41                                                                                            | Material Base                     |                     |
| 1                                                                                                                                                              | -                   | 28                                         | 615,44                  | 35,233                                                                                 | 57,25                                                                                            | Material Base                     |                     |
| <b>MACROETCH TEST</b>                                                                                                                                          |                     |                                            |                         |                                                                                        |                                                                                                  |                                   |                     |
| Test Assembly Number One: Pass <input checked="" type="checkbox"/> Fail <input type="checkbox"/>                                                               |                     |                                            |                         |                                                                                        | Test Assembly Number Two: Pass <input checked="" type="checkbox"/> Fail <input type="checkbox"/> |                                   |                     |
| Specimen No.                                                                                                                                                   | Results             |                                            |                         | Remarks                                                                                |                                                                                                  |                                   |                     |
| 1                                                                                                                                                              | ACEPTADO            |                                            |                         | -                                                                                      |                                                                                                  |                                   |                     |
| 2                                                                                                                                                              | ACEPTADO            |                                            |                         | -                                                                                      |                                                                                                  |                                   |                     |

## 3.2.2.2. Probeta 2

TABLA 8

### PROCEDURE QUALIFICATION RECORD

#### PQR N° 003

| Contractor: <b>Rodrigo Corral Franco</b>                                                                                                                                                                                                          |                     |                                            |                         |                                                                                        |                                             |                                                 |                     |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------|--------------------------------------------|-------------------------|----------------------------------------------------------------------------------------|---------------------------------------------|-------------------------------------------------|---------------------|
| Authorized by: <b>NOVACERO</b>                                                                                                                                                                                                                    |                     |                                            |                         | Revision No. <b>001</b>                                                                |                                             |                                                 |                     |
| Welder: <b>John Bautista Angulo</b>                                                                                                                                                                                                               |                     |                                            |                         | Test Date: <b>12-05-2006</b>                                                           |                                             |                                                 |                     |
| <b>WELDING PROCESS:</b> <input type="checkbox"/> FCAW-S <input type="checkbox"/> FCAW-G <input type="checkbox"/> GMAW <input checked="" type="checkbox"/> SMAW                                                                                    |                     |                                            |                         |                                                                                        |                                             |                                                 |                     |
| <b>PQR JOINT TYPE:</b> <input checked="" type="checkbox"/> Direct Butt <input type="checkbox"/> Indirect Butt <input type="checkbox"/> T-Joint                                                                                                    |                     |                                            |                         |                                                                                        |                                             |                                                 |                     |
| <b>Test Assembly:</b> Fig. 2.3 Unión directa a tope, biselada en ambos extremos                                                                                                                                                                   |                     |                                            |                         |                                                                                        |                                             |                                                 |                     |
| Position: <b>1G</b>                                                                                                                                                                                                                               |                     | Type Groove: <b>A TOPE</b>                 |                         | Single Bevel <input type="checkbox"/> Double Bevel <input checked="" type="checkbox"/> |                                             |                                                 |                     |
| Root Opening: <b>3 mm</b>                                                                                                                                                                                                                         |                     | Type Root Face: <b>3 mm</b>                |                         | Groove Angle: <b>60°</b>                                                               |                                             |                                                 |                     |
| Backing: <input type="checkbox"/> Yes <input checked="" type="checkbox"/> No                                                                                                                                                                      |                     |                                            |                         | Backing Type: <b>N.A.</b>                                                              |                                             |                                                 |                     |
| <b>TECHNIQUE:</b> <input type="checkbox"/> Stringers <input checked="" type="checkbox"/> Weave                                                                                                                                                    |                     |                                            |                         |                                                                                        |                                             |                                                 |                     |
| <b>ELECTRICAL CHARACTERISTICS</b>                                                                                                                                                                                                                 |                     |                                            |                         |                                                                                        |                                             |                                                 |                     |
| Current: <input type="checkbox"/> AC <input checked="" type="checkbox"/> DCEP <input type="checkbox"/> DCEN                                                                                                                                       |                     |                                            |                         |                                                                                        |                                             |                                                 |                     |
| <b>BASE METAL</b>                                                                                                                                                                                                                                 |                     |                                            |                         |                                                                                        |                                             |                                                 |                     |
|                                                                                                                                                                                                                                                   |                     | Material Specification: <b>ASTM A-615M</b> |                         |                                                                                        | Grade: <b>420</b>                           |                                                 |                     |
| Welded to:                                                                                                                                                                                                                                        |                     | Material Specification: <b>ASTM A-615M</b> |                         |                                                                                        | Grade: <b>420</b>                           |                                                 |                     |
| Maximum Carbon Equivalent: <b>0.51 %</b>                                                                                                                                                                                                          |                     |                                            |                         | Bar size: <b>28 mm</b>                                                                 |                                             |                                                 |                     |
| Coated Bar: <input type="checkbox"/> Yes <input checked="" type="checkbox"/> No                                                                                                                                                                   |                     |                                            |                         | Type of Coating: <b>N.A.</b>                                                           |                                             |                                                 |                     |
| <b>FILLER METAL</b>                                                                                                                                                                                                                               |                     |                                            |                         |                                                                                        |                                             |                                                 |                     |
| AWS Specification: <b>A 5.1</b>                                                                                                                                                                                                                   |                     |                                            |                         | AWS Classification: <b>E-7018</b>                                                      |                                             |                                                 |                     |
| <b>PREHEAT/INTERPASS</b>                                                                                                                                                                                                                          |                     |                                            |                         |                                                                                        |                                             |                                                 |                     |
| Preheat/Interpass Temperature (Min): <b>N.A.</b>                                                                                                                                                                                                  |                     |                                            |                         | Interpass Temperature (Max): <b>N.A.</b>                                               |                                             |                                                 |                     |
| <b>WELDING PARAMETERS</b>                                                                                                                                                                                                                         |                     |                                            |                         |                                                                                        |                                             |                                                 |                     |
| Pass Number(s)                                                                                                                                                                                                                                    | Electrode Diameter  | Current                                    |                         |                                                                                        |                                             | Travel Speed (ipm)                              | Joint Detail        |
|                                                                                                                                                                                                                                                   |                     | Type                                       | Amperage                | Volts Range                                                                            | Electrical Stickout                         |                                                 |                     |
| <b>1 - n</b>                                                                                                                                                                                                                                      | <b>E-9018 Ø 1/8</b> | <b>Continua (+)</b>                        | <b>130-150</b>          | <b>22-30</b>                                                                           | <b>-</b>                                    | <b>-</b>                                        | <b>Ver Fig. 2.3</b> |
| <b>TEST RESULTS</b>                                                                                                                                                                                                                               |                     |                                            |                         |                                                                                        |                                             |                                                 |                     |
| <b>VISUAL EXAMINATION</b><br>Test Assembly Number One: Pass <input checked="" type="checkbox"/> Fail <input type="checkbox"/> Test Assembly Number Two: Pass <input checked="" type="checkbox"/> Fail <input type="checkbox"/><br>Comments: ----- |                     |                                            |                         |                                                                                        |                                             |                                                 |                     |
| <b>TENSILE TEST</b><br>Test Assembly Number One: Pass <input checked="" type="checkbox"/> Fail <input type="checkbox"/> Test Assembly Number Two: Pass <input type="checkbox"/> Fail <input type="checkbox"/>                                     |                     |                                            |                         |                                                                                        |                                             |                                                 |                     |
| Specimen No.                                                                                                                                                                                                                                      | Width               | Diameter (mm)                              | Area (mm <sup>2</sup> ) | Ultimate Tensile Load (Kg)                                                             | Ultimate Unit Stress (Kgf/mm <sup>2</sup> ) | Character of Failure and Location Material Base |                     |
| 3                                                                                                                                                                                                                                                 | -                   | 28                                         | 615,44                  | 35,381                                                                                 | 57,49                                       |                                                 |                     |
| <b>MACROETCH TEST</b><br>Test Assembly Number One: Pass <input checked="" type="checkbox"/> Fail <input type="checkbox"/> Test Assembly Number Two: Pass <input type="checkbox"/> Fail <input type="checkbox"/>                                   |                     |                                            |                         |                                                                                        |                                             |                                                 |                     |
| Specimen No.                                                                                                                                                                                                                                      |                     | Results                                    |                         |                                                                                        | Remarks                                     |                                                 |                     |
| 3                                                                                                                                                                                                                                                 |                     | ACEPTADO                                   |                         |                                                                                        | -                                           |                                                 |                     |

Se utiliza corriente directa con un amperaje en un rango entre 130 y 150 amperios, y un voltaje en un rango de 22 a 30 voltios.

Con barras de acero al carbono tipo ASTM A615M de 28 mm de diámetro, y con un CE de 0,51, se uso un electrodo E7018. (TABLA 8).

### **3.2.3. Calificación del Procedimiento de Soldadura.**

El Proceso de soldadura se califica al mismo tiempo que los ensayos realizados sobre las probetas cumplan satisfactoriamente los requisitos del código D1.4 para la calificación del soldador.

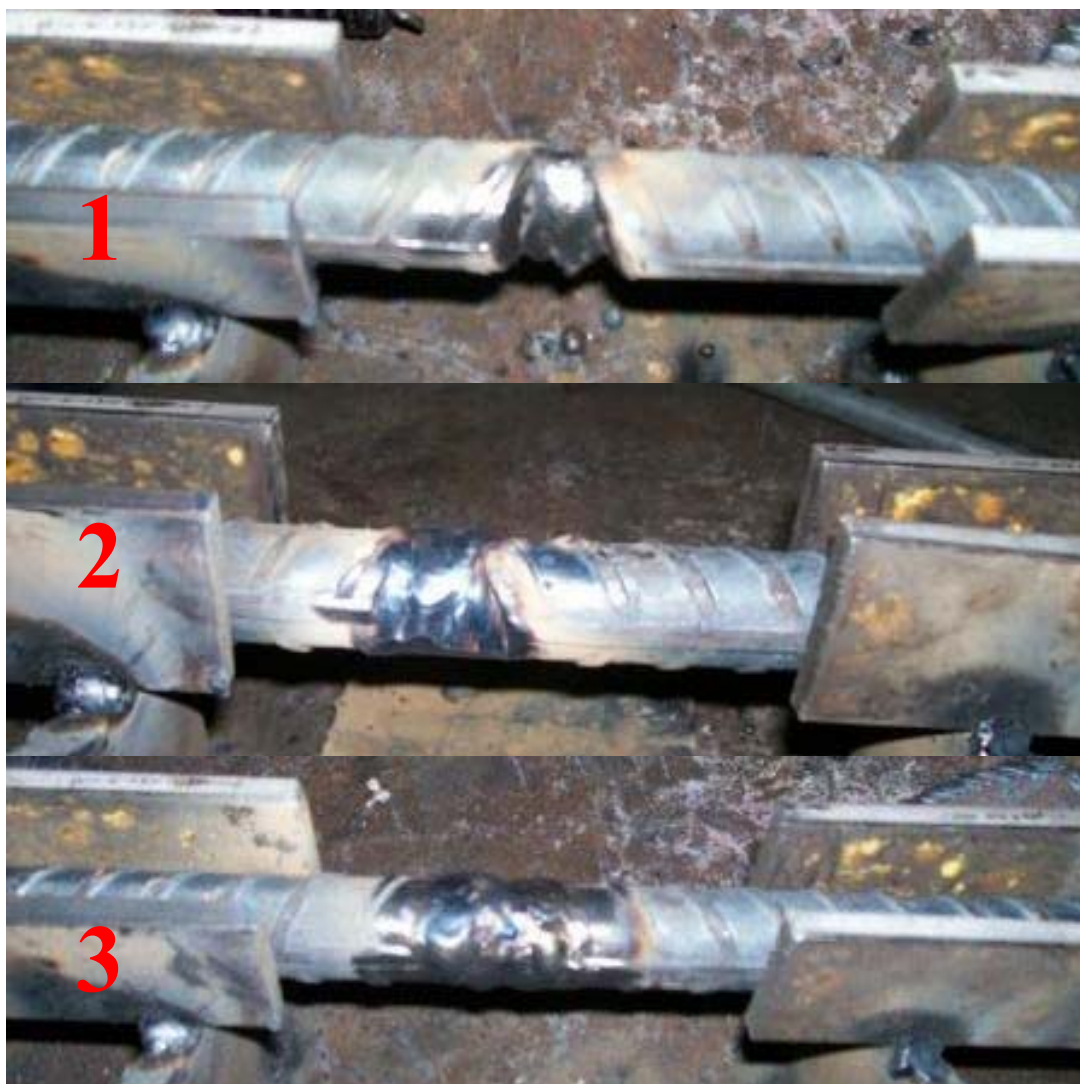


FIGURA. 3.5 SECUENCIA DE SOLDADURA.

La unión soldada se realizó tal como se muestra en la secuencia de fotos (Fig. 3.5)

| <b>TABLA 9</b><br><b>WELDING PROCEDURE SPECIFICATION</b><br><b>WPS N° 001</b>                                                                                  |                       |                                            |                        |              |                                          |                          |                     |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------|--------------------------------------------|------------------------|--------------|------------------------------------------|--------------------------|---------------------|
| Contractor: <b>Rodrigo X. Corral F.</b>                                                                                                                        |                       |                                            |                        |              |                                          |                          |                     |
| Authorized by: <b>NOVACERO</b>                                                                                                                                 |                       |                                            |                        |              | Revision No. <b>001</b>                  |                          |                     |
| Supporting PQR Identification: <b>001</b>                                                                                                                      |                       |                                            |                        |              | Test Date: <b>12-05-2006</b>             |                          |                     |
| <b>WELDING PROCESS:</b> <input type="checkbox"/> FCAW-S <input type="checkbox"/> FCAW-G <input type="checkbox"/> GMAW <input checked="" type="checkbox"/> SMAW |                       |                                            |                        |              |                                          |                          |                     |
| <b>WELD TYPE:</b> <input checked="" type="checkbox"/> Groove <input type="checkbox"/> Fillet                                                                   |                       |                                            |                        |              |                                          |                          |                     |
| <b>JOINT TYPE:</b> <input checked="" type="checkbox"/> Direct Butt <input type="checkbox"/> Indirect Butt <input type="checkbox"/> T-Joint                     |                       |                                            |                        |              |                                          |                          |                     |
| Joint(s) Qualified : <b>Fig. 2.3 Unión directa a tope, biselada en ambos extremos</b>                                                                          |                       |                                            |                        |              |                                          |                          |                     |
| Position: <b>3G</b>                                                                                                                                            |                       |                                            |                        |              | Type Groove: <b>A TOPE</b>               |                          |                     |
| Root Opening: <b>3 mm</b>                                                                                                                                      |                       |                                            | Root Face: <b>3 mm</b> |              |                                          | Groove Angle: <b>60°</b> |                     |
| Backing: <input type="checkbox"/> Yes <input checked="" type="checkbox"/> No                                                                                   |                       |                                            |                        |              | Backing Type:                            |                          |                     |
| Backgouging: <input checked="" type="checkbox"/> Yes <input type="checkbox"/> No                                                                               |                       |                                            |                        |              | Backgouging Method: <b>ESMERILADO</b>    |                          |                     |
| <b>TECHNIQUE:</b> <input type="checkbox"/> Stringers <input checked="" type="checkbox"/> Weave                                                                 |                       |                                            |                        |              |                                          |                          |                     |
| <b>ELECTRICAL CHARACTERISTICS</b>                                                                                                                              |                       |                                            |                        |              |                                          |                          |                     |
| Current: <input type="checkbox"/> AC <input checked="" type="checkbox"/> DCEP <input type="checkbox"/> DCEN                                                    |                       |                                            |                        |              |                                          |                          |                     |
| Transfer Mode (GMAW): <input type="checkbox"/> Short-circuiting <input type="checkbox"/> Globular <input type="checkbox"/> Spray                               |                       |                                            |                        |              |                                          |                          |                     |
| <b>BASE METAL</b>                                                                                                                                              |                       |                                            |                        |              |                                          |                          |                     |
|                                                                                                                                                                |                       | Material Specification: <b>ASTM A-615M</b> |                        |              |                                          | Grade: <b>420</b>        |                     |
| Welded to:                                                                                                                                                     |                       | Material Specification: <b>ASTM A-615M</b> |                        |              |                                          | Grade: <b>420</b>        |                     |
| Maximum Carbon Equivalent: <b>0.51 %</b>                                                                                                                       |                       |                                            | Bar size: <b>28 mm</b> |              |                                          | Plate Thickness:         |                     |
| Coated Bar: <input type="checkbox"/> Yes <input checked="" type="checkbox"/> No                                                                                |                       |                                            |                        |              | Type of Coating: <b>N.A.</b>             |                          |                     |
| <b>FILLER METAL</b>                                                                                                                                            |                       |                                            |                        |              |                                          |                          |                     |
| AWS Specification: <b>A 5.5</b>                                                                                                                                |                       |                                            |                        |              | AWS Classification: <b>E-9018-G H4R</b>  |                          |                     |
| <b>PREHEAT/INTERPASS</b>                                                                                                                                       |                       |                                            |                        |              |                                          |                          |                     |
| Preheat/Interpass Temperature (Min): <b>N.A.</b>                                                                                                               |                       |                                            |                        |              | Interpass Temperature (Max): <b>N.A.</b> |                          |                     |
| <b>WELDING PARAMETERS</b>                                                                                                                                      |                       |                                            |                        |              |                                          |                          |                     |
| Pass Number(s)                                                                                                                                                 | Electrode Diameter    | Current                                    |                        |              |                                          | Travel Speed (ipm)       | Joint Detail        |
|                                                                                                                                                                |                       | Type                                       | Amperage Range         | Volts Range  | Electrical Stickout                      |                          |                     |
| <b>1 - n</b>                                                                                                                                                   | <b>E-9018-G Ø 1/8</b> | <b>Continua (+)</b>                        | <b>110-130</b>         | <b>20-28</b> | <b>---</b>                               | <b>---</b>               | <b>Ver Fig. 2.3</b> |

| <b>TABLA 10</b><br><b>WELDING PROCEDURE SPECIFICATION</b><br><b>WPS N° 003</b>        |                     |                                                                              |                                          |                                  |                                          |                    |                     |
|---------------------------------------------------------------------------------------|---------------------|------------------------------------------------------------------------------|------------------------------------------|----------------------------------|------------------------------------------|--------------------|---------------------|
| Contractor: <b>Rodrigo X. Corral F.</b>                                               |                     |                                                                              |                                          |                                  |                                          |                    |                     |
| Authorized by: <b>NOVACERO</b>                                                        |                     |                                                                              |                                          |                                  | Revision No. <b>001</b>                  |                    |                     |
| Supporting PQR Identification: <b>003</b>                                             |                     |                                                                              |                                          |                                  | Test Date: <b>12-05-2006</b>             |                    |                     |
| <b>WELDING PROCESS:</b>                                                               |                     | <input type="checkbox"/> FCAW-S                                              | <input type="checkbox"/> FCAW-G          | <input type="checkbox"/> GMAW    | <input checked="" type="checkbox"/> SMAW |                    |                     |
| <b>WELD TYPE:</b>                                                                     |                     | <input checked="" type="checkbox"/> Groove                                   | <input type="checkbox"/> Fillet          |                                  |                                          |                    |                     |
| <b>JOINT TYPE:</b>                                                                    |                     | <input checked="" type="checkbox"/> Direct Butt                              | <input type="checkbox"/> Indirect Butt   | <input type="checkbox"/> T-Joint |                                          |                    |                     |
| Joint(s) Qualified : <b>Fig. 2.3 Unión directa a tope, biselada en ambos extremos</b> |                     |                                                                              |                                          |                                  |                                          |                    |                     |
| Position: <b>3G</b>                                                                   |                     |                                                                              |                                          |                                  | Type Groove: <b>A TOPE</b>               |                    |                     |
| Root Opening: <b>3 mm</b>                                                             |                     | Root Face: <b>3 mm</b>                                                       |                                          |                                  | Groove Angle: <b>60°</b>                 |                    |                     |
| Backing: <input type="checkbox"/> Yes <input checked="" type="checkbox"/> No          |                     | Backing Type:                                                                |                                          |                                  |                                          |                    |                     |
| Backgouging: <input checked="" type="checkbox"/> Yes <input type="checkbox"/> No      |                     | Backgouging Method: <b>ESMERILADO</b>                                        |                                          |                                  |                                          |                    |                     |
| <b>TECHNIQUE:</b>                                                                     |                     | <input type="checkbox"/> Stringers <input checked="" type="checkbox"/> Weave |                                          |                                  |                                          |                    |                     |
| <b>ELECTRICAL CHARACTERISTICS</b>                                                     |                     |                                                                              |                                          |                                  |                                          |                    |                     |
| Current:                                                                              |                     | <input type="checkbox"/> AC                                                  | <input checked="" type="checkbox"/> DCEP | <input type="checkbox"/> DCEN    |                                          |                    |                     |
| Transfer Mode (GMAW):                                                                 |                     | <input type="checkbox"/> Short-circuiting                                    | <input type="checkbox"/> Globular        | <input type="checkbox"/> Spray   |                                          |                    |                     |
| <b>BASE METAL</b>                                                                     |                     |                                                                              |                                          |                                  |                                          |                    |                     |
|                                                                                       |                     | Material Specification: <b>ASTM A-615M</b>                                   |                                          |                                  |                                          | Grade: <b>420</b>  |                     |
| Welded to:                                                                            |                     | Material Specification: <b>ASTM A-615M</b>                                   |                                          |                                  |                                          | Grade: <b>420</b>  |                     |
| Maximum Carbon Equivalent: <b>0.51 %</b>                                              |                     | Bar size: <b>28 mm</b>                                                       |                                          |                                  | Plate Thickness:                         |                    |                     |
| Coated Bar: <input type="checkbox"/> Yes <input checked="" type="checkbox"/> No       |                     | Type of Coating: <b>N.A.</b>                                                 |                                          |                                  |                                          |                    |                     |
| <b>FILLER METAL</b>                                                                   |                     |                                                                              |                                          |                                  |                                          |                    |                     |
| AWS Specification: <b>A 5.1</b>                                                       |                     |                                                                              |                                          |                                  | AWS Classification: <b>E-7018</b>        |                    |                     |
| <b>PREHEAT/INTERPASS</b>                                                              |                     |                                                                              |                                          |                                  |                                          |                    |                     |
| Preheat/Interpass Temperature (Min): <b>N.A.</b>                                      |                     |                                                                              |                                          |                                  | Interpass Temperature (Max): <b>N.A.</b> |                    |                     |
| <b>WELDING PARAMETERS</b>                                                             |                     |                                                                              |                                          |                                  |                                          |                    |                     |
| Pass Number(s)                                                                        | Electrode Diameter  | Current                                                                      |                                          |                                  |                                          | Travel Speed (ipm) | Joint Detail        |
|                                                                                       |                     | Type                                                                         | Amperage Range                           | Volts Range                      | Electrical Stickout                      |                    |                     |
| <b>1 - n</b>                                                                          | <b>E-7018 Ø 1/8</b> | <b>Continua (+)</b>                                                          | <b>130-150</b>                           | <b>22-30</b>                     | <b>---</b>                               | <b>---</b>         | <b>Ver Fig. 2.3</b> |

### 3.3. Ensayos y análisis de las probetas.

Siguiendo las especificaciones de la tabla 6.3 del código D1.4, esta especifica el número y tipo de ensayos necesarios para calificar un soldador, así también indica que posiciones quedan calificadas o habilitadas, según la posición que se uso para la realización de la probeta.

Para una unión directa a tope (Fig. 3.6) son requeridas dos probetas, las cuales deberán ser inspeccionadas por radiografía.

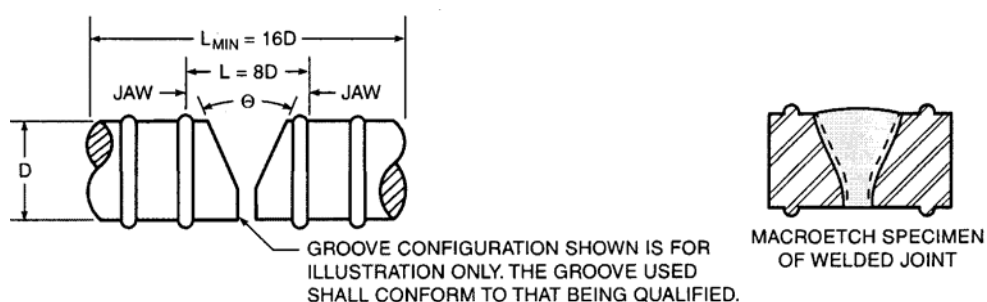


FIGURA. 3.6 SECCIÓN A REALIZAR ENSAYO DE TRACCIÓN Y MICROSCOPIA PARA CALIFICACIÓN DE SOLDADOR Y PROCESO DE SOLDADURA.

Si no se desea realizar el ensayo radiográfico, se puede realizar un ensayo de tensión que cumpla con por lo menos el 125% de la resistencia a la fluencia del tipo de barra a ser ensayada, mas una macroscopia.

Siendo esta la selección de ensayos a realizarse, con fines didácticos, sin embargo para futuras certificaciones de soldadores o procesos de soldadura, así como también para certificaciones de uniones soldadas en obra, es suficiente realizar los ensayos radiográficos, tal como lo explica el código D1.4 en la sección 7.9.



FIGURA. 3.7 PROBETAS PARA ENSAYOS.

Para esto se realizaron 4 probetas, dos usando electrodo E7018 y dos usando electrodo E9018 (Fig. 3.7)

### 3.3.1. Macroscopia.

Para las probetas a las que se realizara un ensayo macroscópico, la unión soldada deberá ser cortada mecánicamente transversalmente a la dirección de la soldadura,

el corte debe mostrar la sección transversal de la soldadura, la raíz y cualquier refuerzo que se haya usado (Fig. 3.6 y Fig. 3.8)



FIGURA. 3.8 PROBETAS PARA MACROSCOPIA.

Se examinó la probeta reportando que no se encontró discontinuidades, tales como grietas en el material aportado por el electrodo o la zona afectada por el calor (ZAC). Se inspecciono ambas probetas certificando que existe fusión entre

el metal base y el metal de aporte y entre los pasos sucesivos usados en la unión soldada.

### **3.3.2. Ensayo de tracción.**

Para las probetas a las que se realizara un ensayo de tracción, la distancia mínima entre las muelas de la maquina de ensayos debe ser igual a por lo menos 8 veces el diámetro de la barra a ser ensayada. Este debe ser roto bajo una carga de tensión y la carga máxima deberá ser determinada. La resistencia a la tracción deberá ser obtenida dividiendo la carga máxima para el diámetro nominal de la sección transversal de la barra.



FIGURA. 3.9 PROBETA 1, CON ELECTRODO E9018.



FIGURA. 3.10 PROBETA 2, CON ELECTRODO E7018.

Las probetas fueron ensayadas en el laboratorio del INEN en la ciudad de Quito, al ser la única que posee una máquina de ensayos de tracción capaz de romper varillas de hasta 44 mm de diámetro.

El código especifica que se debe alcanzar por lo menos el 125% del valor de la resistencia para la varilla tipo A42 (o grado 420), donde el 125% de 420 MPa, es 525 MPa.

La Probeta No. 1 (Fig. 3.9) presento un  $S_{ut} = 562$  MPa, fracturándose en la barra y no en la unión soldada.

La Probeta No. 2 (Fig. 3.10) presento un  $S_{ut} = 563$  MPa, fracturándose en la barra y no en la unión soldada.

De las probetas con la junta a traslape, no se pudieron obtener resultados satisfactorios, ya que luego de varios intentos no pudieron ser fijadas en la maquina de ensayos, ya que al momento del ensayo existía deslizamiento entre las muelas y la barra aplicando la carga sobre la probeta en un ángulo entre 5 y 10 grados de inclinación, lo que cargaba directamente sobre la soldadura, por lo que no se incluyen resultados sobre este tipo de junta.

# **CAPITULO 4**

## **4. CONCLUSIONES Y RECOMENDACIONES.**

### **4.1. Conclusiones.**

- Las barras corrugadas de acero al carbono de un porcentaje de 0,51 de Carbono Equivalente son soldables usando los WPS aquí desarrollados.
- Siguiendo las indicaciones el electrodo ideal para este empalme es el E9018, sin embargo al no encontrarse disponible en el mercado se realizo un procedimiento de soldadura para el electrodo comercial E7018, cumpliendo este con los requisitos del Código AWS D1.4
- Cualquier cambio en las variables esenciales indicadas a continuación requerirá una recalificación del procedimiento para estos nuevos parámetros.

- Cambio en el diámetro o resistencia del electrodo, o del recubrimiento,
- cambio en el rango de amperaje o voltaje,
- cambio en la preparación de la junta que signifique un exceso de 5° en el ángulo del bisel, cambio en la raíz por  $\pm 1.6$  mm.
- La única forma de reemplazar un empalme o unión de una armadura de acero corrugado para hormigón armado por medio de soldadura es usando un procedimiento calificado.

#### **4.2.Recomendaciones.**

- En la difusión del producto en el mercado, realizar campañas de educación a los clientes en lo referente a las propiedades del producto y la soldabilidad de este.
- Al tratarse del lanzamiento de un producto para una empresa nueva en el mercado, este debería representar un soporte en el desarrollo de procedimientos de soldadura de acuerdo a las necesidades del mercado para la utilización de barras corrugadas de acero al carbono no termotratado.
- Abrir canales de comunicación o colaboración entre los colegios de ingenieros ya que los mayores usuarios de barras corrugadas

de acero al carbono son los ingenieros civiles, generalmente ajenos a las uniones soldadas.

- Desarrollar en conjunto con el INEN procedimientos de soldadura para las diferentes barras de acero al carbono que se encuentran en el mercado, tratando de usar los parámetros económicamente mas asequibles y suministrar esta información al mercado de los constructores.

APENDICE A

Standard Specification for

Deformed and Plain Billet-Steel Bars for Concrete

Reinforcement<sup>1</sup>

Designation: A 615/A615M - 01



Designation: A 615/A 615M – 01

American Association State Highway and  
Transportation Officials Standard  
AASHTO No.: M 31

## Standard Specification for Deformed and Plain Billet-Steel Bars for Concrete Reinforcement<sup>1</sup>

This standard is issued under the fixed designation A 615/A 615M; 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 specification covers deformed and plain billet-steel bars for concrete reinforcement in cut lengths and coils. The standard sizes and dimensions of deformed bars and their number designations are given in Table 1. The text of this specification references notes and footnotes which provide explanatory material. These notes and footnotes (excluding those in tables and figures) shall not be considered as requirements of the specification.

1.2 Bars are of three minimum yield levels: namely, 40 000 [300 MPa], 60 000 [420 MPa], and 75 000 psi [520 MPa], designated as Grade 40 [300], Grade 60 [420], and Grade 75 [520], respectively.

1.3 Hot-rolled plain rounds, in sizes up to and including 2 in. [50.8 mm] in diameter in coils or cut lengths, when specified for dowels, spirals and structural ties or supports shall be furnished under this specification in Grade 40 [300], Grade 60 [420], and Grade 75 [520]. For ductility properties (elongation and bending), test provisions of the nearest smaller nominal diameter deformed bar size shall apply. Requirements providing for deformations and marking shall not be applicable.

NOTE 1—Welding of the material in this specification should be approached with caution since no specific provisions have been included to enhance its weldability. When steel is to be welded, a welding procedure suitable for the chemical composition and intended use or service should be used. The use of the latest edition of ANSI/AWS D 1.4 is recommended. This document describes the proper selection of the filler metals, preheat/interpass temperatures, as well as, performance and procedure qualification requirements.

1.4 This specification is applicable for orders in either inch-pound units (as Specification A 615) or in SI units (as Specification A 615M).

1.5 The values stated in either inch-pound units or SI units are to be regarded 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 must be used inde-

pendently of the other. Combining values from the two systems may result in nonconformance with the specification.

### 2. Referenced Documents

#### 2.1 ASTM Standards:

A 6/A 6M Specification for General Requirements for Rolled Structural Steel Bars, Plates, Shapes, and Sheet Piling<sup>2</sup>

A 370 Test Methods and Definitions for Mechanical Testing of Steel Products<sup>3</sup>

A 510 Specification for General Requirements for Wire Rods and Coarse Round Wire, Carbon Steel<sup>3</sup>

A 510M Specification for General Requirements for Wire Rods and Coarse Round Wire, Carbon Steel (Metric)<sup>3</sup>

A 700 Practices for Packaging, Marking, and Loading Methods for Steel Products for Domestic Shipment<sup>4</sup>

A 706/A 706M Specification for Low-Alloy Steel Deformed and Plain Bars for Concrete Reinforcement<sup>2</sup>

E 29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications<sup>5</sup>

#### 2.2 AWS Standard:

ANSI/AWS D 1.4 Structural Welding Code—Reinforcing Steel<sup>6</sup>

#### 2.3 U.S. Military Standards:

MIL-STD-129 Marking for Shipment and Storage<sup>7</sup>

MIL-STD-163 Steel Mill Products Preparation for Shipment and Storage<sup>7</sup>

#### 2.4 U.S. Federal Standard:

Fed. Std. No. 123 Marking for Shipment (Civil Agencies)<sup>7</sup>

### 3. Terminology

#### 3.1 Definitions of Terms Specific to This Standard:

3.1.1 *deformed bar, n*—steel bar with protrusions; a bar that is intended for use as reinforcement in reinforced concrete construction.

<sup>2</sup> Annual Book of ASTM Standards, Vol 01.04.

<sup>3</sup> Annual Book of ASTM Standards, Vol 01.03.

<sup>4</sup> Annual Book of ASTM Standards, Vol 01.05.

<sup>5</sup> Annual Book of ASTM Standards, Vol 14.02.

<sup>6</sup> Available from American Welding Society, 550 N.W. LeJeune Road, P.O. Box 351040, Miami, FL 33135.

<sup>7</sup> Available from Standardization Documents Order Desk, Bldg. 4 Section D, 700 Robbins Ave., Philadelphia, PA 19111-5094, Attn: NPODS.

<sup>1</sup> This specification is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel, and Related Alloys and is the direct responsibility of Subcommittee A01.05 on Steel Reinforcement.

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 A 615/A 615M
**TABLE 1 Deformed Bar Designation Numbers, Nominal Weights [Masses], Nominal Dimensions, and Deformation Requirements**

| Bar Designation No. <sup>A</sup> | Nominal Weight, lb/ft [Nominal Mass, kg/m] | Nominal Dimensions <sup>B</sup> |                                                           |                     | Deformation Requirements, in. [mm] |                        |                                                    |
|----------------------------------|--------------------------------------------|---------------------------------|-----------------------------------------------------------|---------------------|------------------------------------|------------------------|----------------------------------------------------|
|                                  |                                            | Diameter, in. [mm]              | Cross-Sectional Area, in. <sup>2</sup> [mm <sup>2</sup> ] | Perimeter, in. [mm] | Maximum Average Spacing            | Minimum Average Height | Maximum Gap (Chord of 12.5 % of Nominal Perimeter) |
| 3 [10]                           | 0.376 [0.560]                              | 0.375 [9.5]                     | 0.11 [71]                                                 | 1.178 [29.9]        | 0.262 [6.7]                        | 0.015 [0.38]           | 0.143 [3.6]                                        |
| 4 [13]                           | 0.668 [0.994]                              | 0.500 [12.7]                    | 0.20 [129]                                                | 1.571 [39.9]        | 0.350 [8.9]                        | 0.020 [0.51]           | 0.191 [4.9]                                        |
| 5 [16]                           | 1.043 [1.552]                              | 0.625 [15.9]                    | 0.31 [199]                                                | 1.963 [49.9]        | 0.437 [11.1]                       | 0.028 [0.71]           | 0.239 [6.1]                                        |
| 6 [19]                           | 1.502 [2.235]                              | 0.750 [19.1]                    | 0.44 [284]                                                | 2.356 [59.8]        | 0.525 [13.3]                       | 0.038 [0.97]           | 0.286 [7.3]                                        |
| 7 [22]                           | 2.044 [3.042]                              | 0.875 [22.2]                    | 0.60 [387]                                                | 2.749 [69.8]        | 0.612 [15.5]                       | 0.044 [1.12]           | 0.334 [8.5]                                        |
| 8 [25]                           | 2.670 [3.973]                              | 1.000 [25.4]                    | 0.79 [510]                                                | 3.142 [79.8]        | 0.700 [17.8]                       | 0.050 [1.27]           | 0.383 [9.7]                                        |
| 9 [29]                           | 3.400 [5.060]                              | 1.128 [28.7]                    | 1.00 [645]                                                | 3.544 [90.0]        | 0.790 [20.1]                       | 0.056 [1.42]           | 0.431 [10.9]                                       |
| 10 [32]                          | 4.303 [6.404]                              | 1.270 [32.3]                    | 1.27 [819]                                                | 3.990 [101.3]       | 0.889 [22.6]                       | 0.064 [1.63]           | 0.487 [12.4]                                       |
| 11 [36]                          | 5.313 [7.907]                              | 1.410 [35.8]                    | 1.56 [1006]                                               | 4.430 [112.5]       | 0.987 [25.1]                       | 0.071 [1.80]           | 0.540 [13.7]                                       |
| 14 [43]                          | 7.65 [11.38]                               | 1.693 [43.0]                    | 2.25 [1452]                                               | 5.32 [135.1]        | 1.185 [30.1]                       | 0.085 [2.16]           | 0.648 [16.5]                                       |
| 18 [57]                          | 13.60 [20.24]                              | 2.257 [57.3]                    | 4.00 [2581]                                               | 7.09 [180.1]        | 1.58 [40.1]                        | 0.102 [2.59]           | 0.864 [21.9]                                       |

<sup>A</sup>Bar numbers are based on the number of eighths of an inch included in the nominal diameter of the bars [bar numbers approximate the number of millimetres of the nominal diameter of the bar].

<sup>B</sup>The nominal dimensions of a deformed bar are equivalent to those of a plain round bar having the same weight [mass] per foot [metre] as the deformed bar.

3.1.1.1 *Discussion*—The surface of the bar is provided with lugs or protrusions that inhibit longitudinal movement of the bar relative to the concrete surrounding the bar in such construction. The lugs or protrusions conform to the provisions of this specification.

3.1.2 *deformations, n*—protrusions on a deformed bar.

3.1.3 *plain bar, n*—steel bar without protrusions.

3.1.4 *rib, n*—longitudinal protrusion on a deformed bar.

#### 4. Ordering Information

4.1 It shall be the responsibility of the purchaser to specify all requirements that are necessary for material ordered to this specification. Such requirements shall include but are not limited to the following:

4.1.1 Quantity (weight) [mass],

4.1.2 Name of material (deformed and plain billet-steel bars for concrete reinforcement),

4.1.3 Size,

4.1.4 Cut lengths or coils,

4.1.5 Deformed or plain,

4.1.6 Grade,

4.1.7 Packaging (see Section 21),

4.1.8 ASTM designation and year of issue, and

4.1.9 Certified mill test reports (if desired). (See Section 16.)

NOTE 2—A typical ordering description is as follows: 20 tons, deformed and plain billet-steel bars for concrete reinforcement, No. 8, 60 ft 0 in. long, deformed, Grade 60, in secured lifts, to ASTM A 615 — . Certified mill test reports are required.

[19 tons, deformed and plain billet-steel bars for concrete reinforcement, No. 25, 18.3-m long, deformed, Grade 420, in secured lifts to ASTM A 615M — . Certified mill test reports are required.]

#### 5. Material and Manufacture

5.1 The bars shall be rolled from properly identified heats of mold cast or strand cast steel using the open-hearth, basic-oxygen, or electric-furnace process.

#### 6. Chemical Composition

6.1 An analysis of each heat of steel shall be made by the manufacturer from test samples taken preferably during the pouring of the heats. The percentages of carbon, manganese,

phosphorus, and sulfur, shall be determined. The phosphorus content thus determined shall not exceed 0.06 %.

6.2 An analysis may be made by the purchaser from finished bars. The phosphorus content thus determined shall not exceed that specified in 6.1 by more than 25 %.

#### 7. Requirements for Deformations

7.1 Deformations shall be spaced along the bar at substantially uniform distances. The deformations on opposite sides of the bar shall be similar in size, shape, and pattern.

7.2 The deformations shall be placed with respect to the axis of the bar so that the included angle is not less than 45°. Where the line of deformations forms an included angle with the axis of the bar from 45 to 70° inclusive, the deformations shall alternately reverse in direction on each side, or those on one side shall be reversed in direction from those on the opposite side. Where the line of deformations is over 70°, a reversal in direction shall not be required.

7.3 The average spacing or distance between deformations on each side of the bar shall not exceed seven tenths of the nominal diameter of the bar.

7.4 The overall length of deformations shall be such that the gap between the ends of the deformations on opposite sides of the bar shall not exceed 12½ % of the nominal perimeter of the bar. Where the ends terminate in a longitudinal rib, the width of the longitudinal rib shall be considered the gap. Where more than two longitudinal ribs are involved, the total width of all longitudinal ribs shall not exceed 25 % of the nominal perimeter of the bar; furthermore, the summation of gaps shall not exceed 25 % of the nominal perimeter of the bar. The nominal perimeter of the bar shall be 3.14 times the nominal diameter.

7.5 The spacing, height, and gap of deformations shall conform to the requirements prescribed in Table 1.

#### 8. Measurements of Deformations

8.1 The average spacing of deformations shall be determined by measuring the length of a minimum of 10 spaces and dividing that length by the number of spaces included in the measurement. The measurement shall begin from a point on a deformation at the beginning of the first space to a corresponding point on a deformation after the last included space. Spacing measurements shall not be made over a bar area

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containing bar marking symbols involving letters or numbers.

8.2 The average height of deformations shall be determined from measurements made on not less than two typical deformations. Determinations shall be based on three measurements per deformation, one at the center of the overall length and the other two at the quarter points of the overall length.

8.3 Insufficient height, insufficient circumferential coverage, or excessive spacing of deformations shall not constitute cause for rejection unless it has been clearly established by determinations on each lot (Note 3) tested that typical deformation height, gap, or spacing do not conform to the minimum requirements prescribed in Section 7. No rejection shall be made on the basis of measurements if fewer than ten adjacent deformations on each side of the bar are measured.

NOTE 3—As used within the intent of 8.3, the term “lot” shall mean all the bars of one bar size and pattern of deformations contained in an individual shipping release or shipping order.

## 9. Tensile Requirements

9.1 The material, as represented by the test specimens, shall conform to the requirements for tensile properties prescribed in Table 2.

9.2 The yield point or yield strength shall be determined by one of the following methods:

9.2.1 The yield point shall be determined by drop of the beam or halt in the gage of the testing machine.

9.2.2 Where the steel tested does not have a well-defined yield point, the yield strength shall be determined by reading the stress corresponding to the prescribed strain using an autographic diagram method or an extensometer as described in Test Methods and Definitions A 370. The strain shall be 0.5 % of gage length for Grade 40 [300] and Grade 60 [420] and shall be 0.35 % of gage length for Grade 75 [520]. When material is furnished in coils, the test sample shall be straightened prior to placing it in the jaws of the tensile machine. Straightening shall be done carefully to avoid formation of local sharp bends and to minimize cold work. Insufficient straightening prior to attaching the extensometer can result in lower-than-actual yield strength readings.

9.3 The percentage of elongation shall be as prescribed in Table 2.

## 10. Bending Requirements

10.1 The bend-test specimen shall withstand being bent

**TABLE 2 Tensile Requirements**

|                                            | Grade 40<br>[300] <sup>A</sup> | Grade 60<br>[420] | Grade 75<br>[520] <sup>B</sup> |
|--------------------------------------------|--------------------------------|-------------------|--------------------------------|
| Tensile strength, min, psi<br>[MPa]        | 70 000 [500]                   | 90 000 [620]      | 100 000 [690]                  |
| Yield strength, min, psi<br>[MPa]          | 40 000 [300]                   | 60 000 [420]      | 75 000 [520]                   |
| Elongation in 8 in. [203.2<br>mm], min, %: |                                |                   |                                |
| Bar Designation No.                        |                                |                   |                                |
| 3 [10]                                     | 11                             | 9                 | ...                            |
| 4, 5 [13, 16]                              | 12                             | 9                 | ...                            |
| 6 [19]                                     | 12                             | 9                 | 7                              |
| 7, 8 [22, 25]                              | ...                            | 8                 | 7                              |
| 9, 10, 11 [29, 32, 36]                     | ...                            | 7                 | 6                              |
| 14, 18 [43, 57]                            | ...                            | 7                 | 6                              |

<sup>A</sup>Grade 40 [300] bars are furnished only in sizes 3 through 6 [10 through 19].

<sup>B</sup>Grade 75 [520] bars are furnished only in sizes 6 through 18 [19 through 57].

around a pin without cracking on the outside radius of the bent portion. The requirements for degree of bending and sizes of pins are prescribed in Table 3. When material is furnished in coils, the test sample shall be straightened prior to placing it in the bend tester.

10.2 The bend test shall be made on specimens of sufficient length to ensure free bending and with apparatus which provides:

10.2.1 Continuous and uniform application of force throughout the duration of the bending operation.

10.2.2 Unrestricted movement of the specimen at points of contact with the apparatus and bending around a pin free to rotate.

10.2.3 Close wrapping of the specimen around the pin during the bending operation.

10.3 Other acceptable more severe methods of bend testing, such as placing a specimen across two pins free to rotate and applying the bending force with a fixed pin, may be used. When failures occur under more severe methods, retests shall be permitted under the bend-test method prescribed in 10.2.

## 11. Permissible Variation in Weight [Mass]

11.1 Deformed reinforcing bars shall be evaluated on the basis of nominal weight [mass]. The weight [mass] determined using the measured weight [mass] of the test specimen and rounding in accordance with Practice E 29, shall be at least 94 % of the applicable weight [mass] per unit length prescribed in Table 1. In no case shall overweight [excess mass] of any deformed bar be the cause for rejection. Weight [mass] variation for plain rounds shall be computed on the basis of permissible variation in diameter. For plain bars smaller than 3/8 in. [9.5 mm], use Specification A 510 [Specification A 510M]. For larger bars up to and including 2 in. [50.8 mm], use Specification A 6/A 6M.

## 12. Finish

12.1 The bars shall be free of detrimental surface imperfections.

12.2 Rust, seams, surface irregularities, or mill scale shall not be cause for rejection, provided the weight, dimensions, cross-sectional area, and tensile properties of a hand wire brushed test specimen are not less than the requirements of this specification.

12.3 Surface imperfections or flaws other than those specified in 12.2 shall be considered detrimental when specimens containing such imperfections fail to conform to either tensile or bending requirements. Examples include, but are not limited to, laps, seams, scabs, slivers, cooling or casting cracks, and mill or guide marks.

**TABLE 3 Bend Test Requirements**

| Bar Designation No.    | Pin Diameter for Bend Tests <sup>A</sup> |                |                |
|------------------------|------------------------------------------|----------------|----------------|
|                        | Grade 40 [300]                           | Grade 60 [420] | Grade 75 [520] |
| 3, 4, 5 [10, 13, 16]   | 3 1/2 d <sup>B</sup>                     | 3 1/2 d        | ...            |
| 6 [19]                 | 5 d                                      | 5 d            | 5 d            |
| 7, 8 [22, 25]          | ...                                      | 5 d            | 5 d            |
| 9, 10, 11 [29, 32, 36] | ...                                      | 7 d            | 7 d            |
| 14, 18 [43, 57] (90°)  | ...                                      | 9 d            | 9 d            |

<sup>A</sup>Test bends 180° unless noted otherwise.

<sup>B</sup>d = nominal diameter of specimen.

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**NOTE 4**—Reinforcing bar intended for epoxy coating applications should have surfaces with a minimum of sharp edges to achieve proper cover. Particular attention should be given to bar marks and deformations where coating difficulties are prone to occur.

**NOTE 5**—Deformed bars destined to be mechanically-spliced or butt-welded may require a certain degree of roundness in order for the splices to adequately achieve strength requirements.

### 13. Number of Tests

13.1 For bar sizes No. 3 to 11 [10 to 36], inclusive, one tension test and one bend test shall be made of the largest size rolled from each heat. If, however, material from one heat differs by three or more designation numbers, one tension and one bend test shall be made from both the highest and lowest designation number of the deformed bars rolled.

13.2 For bar sizes Nos. 14 and 18 [43 and 57], one tension test and one bend test shall be made of each size rolled from each heat.

### 14. Retests

14.1 If any tensile property of any tension test specimen is less than that specified, and any part of the fracture is outside the middle third of the gage length, as indicated by scribe scratches marked on the specimen before testing, a retest shall be allowed.

14.2 If the results of an original tension specimen fail to meet the specified minimum requirements and are within 2000 psi [14 MPa] of the required tensile strength, within 1000 psi [7 MPa] of the required yield point, or within two percentage units of the required elongation, a retest shall be permitted on two random specimens for each original tension specimen failure from the lot. Both retest specimens shall meet the requirements of this specification.

14.3 If a bend test fails for reasons other than mechanical reasons or flaws in the specimen as described in 14.5 and 14.6, a retest shall be permitted on two random specimens from the same lot. Both retest specimens shall meet the requirements of this specification. The retest shall be performed on test specimens that are at air temperature but not less than 60°F [16°C].

14.4 If a weight [mass] test fails for reasons other than flaws in the specimen as described in 14.6, a retest shall be permitted on two random specimens from the same lot. Both retest specimens shall meet the requirements of this specification.

14.5 If any test specimen fails because of mechanical reasons such as failure of testing equipment or improper specimen preparation, it may be discarded and another specimen taken.

14.6 If flaws are detected in a test specimen, either before or during the performance of the test, it may be discarded and another specimen of the same size bar from the same heat substituted.

### 15. Test Specimens

15.1 All mechanical tests shall be conducted in accordance with Test Methods and Definitions A 370 including Annex A9.

15.2 Tension test specimens shall be the full section of the bar as rolled. The unit stress determination shall be based on the nominal bar area.

15.3 The bend-test specimens shall be the full section of the bar as rolled.

### 16. Test Reports

16.1 When specified in the purchase order, report the following information, on a per heat basis. Additional items may be reported as requested or desired.

16.1.1 Chemical analysis including carbon, manganese, phosphorus, and sulfur.

16.1.2 Tensile properties.

16.1.3 Bend test.

### 17. Inspection

17.1 The inspector representing the purchaser shall have free entry, at all times while work on the contract of the purchaser is being performed, to all parts of the manufacturer's works that concern the manufacture of the material ordered. The manufacturer shall afford the inspector all reasonable facilities to satisfy him that the material is being furnished in accordance with this specification. All tests (except product analysis) and inspection, shall be made at the place of manufacture prior to shipment, unless otherwise specified, and shall be so conducted as not to interfere unnecessarily with the operation of the works.

17.2 *For Government Procurement Only*— Except as otherwise specified in the contract, the contractor is responsible for the performance of all inspection and test requirements specified herein and may use his own or any other suitable facilities for the performance of the inspection and test requirements specified herein, unless disapproved by the purchaser at the time of purchase. The purchaser shall have the right to perform any of the inspections and tests at the same frequency as set forth in this specification, where such inspections are deemed necessary to ensure that material conforms to prescribed requirements.

### 18. Rejection

18.1 Unless otherwise specified, any rejection based on tests made in accordance with 6.2, shall be reported to the manufacturer within five working days from the receipt of samples by the purchaser.

18.2 Material that shows injurious defects subsequent to its acceptance at the manufacturer's works will be rejected, and the manufacturer shall be notified.

### 19. Rehearing

19.1 Samples tested in accordance with 6.2 that represent rejected material shall be preserved for two weeks from the date rejection is reported to the manufacturer. In case of dissatisfaction with the results of the tests, the manufacturer may make claim for a rehearing within that time.

### 20. Marking

20.1 When loaded for mill shipment, bars shall be properly separated and tagged with the manufacturer's heat or test identification number.

20.2 Each producer shall identify the symbols of his marking system.

20.3 All bars produced to this specification, except plain round bars which shall be tagged for grade, shall be identified by a distinguishing set of marks legibly rolled onto the surface of one side of the bar to denote in the following order:

 **A 615/A 615M**

20.3.1 *Point of Origin*—Letter or symbol established as the producer's mill designation.

20.3.2 *Size Designation*—Arabic number corresponding to bar designation number of Table 1.

20.3.3 *Type of Steel*—Letter *S* indicating that the bar was produced to this specification, or for Grade 60 [420] bars only, letters *S* and *W* indicating that the bar was produced to meet both Specifications A 615/A 615M and A 706/A 706M.

20.3.4 *Minimum Yield Designation*—For Grade 60 [420] bars, either the number 60 [4] or a single continuous longitudinal line through at least five spaces offset from the center of the bar side. For Grade 75 [520] bars, either the number 75 [5] or two continuous longitudinal lines through at least five spaces offset each direction from the center of the bar. (No marking designation for Grade 40 [300] bars.)

20.3.5 It shall be permissible to substitute: a metric size bar of Grade 300 for the corresponding inch-pound size bar of Grade 40, a metric size bar of Grade 420 for the corresponding

inch-pound size bar of Grade 60, and a metric size bar of Grade 520 for the corresponding inch-pound size bar of Grade 75.

## 21. Packaging

21.1 When specified in the purchase order, packaging shall be in accordance with the procedures in Practices A 700.

21.2 *For Government Procurement Only*— When specified in the contract or order, and for direct procurement by or direct shipment to the U.S. government, material shall be preserved, packaged, and packed in accordance with the requirements of MIL-STD-163. The applicable levels shall be as specified in the contract. Marking for shipment of such material shall be in accordance with Fed. Std. No. 123 for civil agencies and MIL-STD-129 for military agencies.

## 22. Keywords

22.1 concrete reinforcement; deformations (protrusions); steel bars

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APENDICE B

Structural Welding Code—

Reinforcing Steel

Designation: AWS D1.4/D1.4M:2005

**AWS D1.4/D1.4M:2005**  
**An American National Standard**



# **Structural Welding Code— Reinforcing Steel**



**American Welding Society**



**Key Words** —Allowable stress, inspection,  
qualification, reinforcing steel,  
structural details, welded joint details

**AWS D1.4/D1.4M:2005**  
**An American National Standard**

Approved by the  
American National Standards Institute  
July 8, 2005

## **Structural Welding Code— Reinforcing Steel**

Including  
Metal Inserts and Connections  
in Reinforced Concrete  
Construction

Sixth Edition

**Supersedes ANSI/AWS D1.4-98**

Prepared by the  
American Welding Society (AWS) D1 Structural Welding Committee

Under the Direction of the  
AWS Technical Activities Committee

Approved by the  
AWS Board of Directors

### **Abstract**

This code covers the requirements for welding reinforcing steel in most reinforced concrete applications. It contains a body of rules for the regulations of welding reinforcing steel and provides suitable acceptance criteria for such welds.

550 N.W. LeJeune Road, Miami, FL 33126

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This standard is subject to revision at any time by the AWS D1 Committee on Structural Welding. It must be reviewed every five years, and if not revised, it must be either reaffirmed or withdrawn. Comments (recommendations, additions, or deletions) and any pertinent data that may be of use in improving this standard are required and should be addressed to AWS Headquarters. Such comments will receive careful consideration by the AWS D1 Committee on Structural Welding and the author of the comments will be informed of the Committee's response to the comments. Guests are invited to attend all meetings of the AWS D1 Committee on Structural Welding to express their comments verbally. Procedures for appeal of an adverse decision concerning all such comments are provided in the Rules of Operation of the Technical Activities Committee. A copy of these Rules can be obtained from the American Welding Society, 550 N.W. LeJeune Road, Miami, FL 33126.

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## Foreword

This foreword is not a part of AWS D1.4/D1.4M:2005, *Structural Welding Code—Reinforcing Steel*, but is included for informational purposes only.

In 1961, the American Welding Society published its first reinforcing steel welding standard, AWS D12.1-61, *Recommended Practices for Welding Reinforcing Steel, Metal Inserts and Connections in Reinforced Concrete Construction*. The D12 Committee was disbanded some time after publication of the 1961 code and before publication of the 1975 edition.

The 1961 document was replaced with a greatly revised version, AWS D12.1-75, *Reinforcing Steel Welding Code*, with the format patterned after the AWS D1.1-72, *Structural Welding Code*. The 1975 code was produced by the AWS Structural Welding Committee but was not renumbered to reflect this committee change. As with ANSI/AWS D1.1, AWS D12.1-75 was designed as a self-contained code, including within it the qualification of welders and procedures, and requirements for workmanship, quality, and inspection.

The listings of materials and welding processes were revised in the D12.1-75 code. Items newly introduced were the carbon equivalent method for determining preheat, the parenthetical inclusion of metric (SI) conversions, and the two different methods of joint strength determination.

The AWS D12.1-75 document was revised and the title changed to ANSI/AWS D1.4-79, *Structural Welding Code—Reinforcing Steel*. Since the 1979 edition of ANSI/AWS D1.4, *Structural Welding Code—Reinforcing Steel*, was issued, further use by designers, engineers, and fabricators has necessitated a number of changes to the requirements; the 1992 and 1998 editions reflected these changes. This edition, AWS D1.4/D1.4M:2005, has additional revisions.

The following is a summary of the significant technical revisions in this edition:

Subsection 1.3.1—Deleted ASTM specifications from listed steels: ASTM A 184, A 185, A 497, A 616, and A 617.

Table 5.2—Addresses bar sizes up to and including #6 [19] for C.E. over 0.75.

Section 5.4—New section added on weld cleaning.

Subsections to Section 6.3—Several subsections added to address welder qualification requirements and testing for fillet welds.

Subsection 7.7.3 and Section 7.9—Comprehensive approach for radiographic testing of reinforcing steel was added.

Annex A—Sample welding, testing, and inspection forms were updated.

**Changes in Code Requirements.** Technical and editorial changes in the text are indicated by underlining; changes to tables and figures are indicated by a single vertical line in the adjacent margin. Tables and figures have been revised, and two tables and one figure have been added.

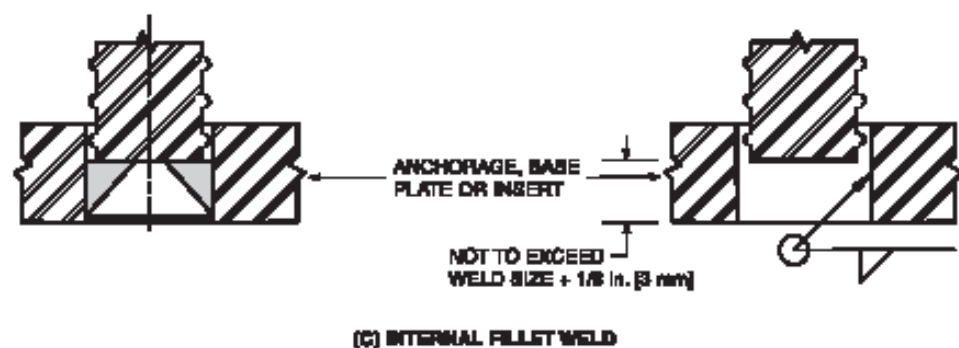
**Errata.** It is the Structural Welding Committee's Policy that all errata should be made available to users of the code. Therefore, in the Society News Section of the *AWS Welding Journal*, any errata (major changes) that have been noted will be published in the July and November issues of the *Welding Journal* and posted on the AWS website at: <http://www.aws.org/technical/d1/>.

**Suggestions.** Your comments for improving the *Structural Welding Code—Reinforcing Steel* are welcome. Submit comments to the Managing Director, Technical Services Division, American Welding Society, 550 N.W. LeJeune Road, Miami, FL 33126; telephone (305) 443-9353; fax (305) 443-5951; e-mail [info@aws.org](mailto:info@aws.org); or via the AWS web site <<http://www.aws.org>>.

## Errata

The following Errata have been identified and incorporated into the current reprint of this document.

Page 14—Figure 3.5, Detail C: figure on right side, upper dimension line for “NOT TO EXCEED WELD SIZE + 1/8 in. [3 mm]” moved down parallel to the bottom of the reinforcing bar.



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# Structural Welding Code— Reinforcing Steel

## 1. General Provisions

### 1.1 Scope

The code shall apply to the welding of:

1. Reinforcing steel to reinforcing steel, and
2. Reinforcing steel to carbon or low-alloy structural steel.

When the code is stipulated in contract documents, conformance with all provisions shall be required, except for those provisions that the Engineer or contract documents specifically modifies or exempts.

### 1.2 Application

**1.2.1** This code shall be used in conjunction with the prescribed general building code requirements and is applicable to all welding of reinforcing steel, using the processes listed in 1.4, and performed as a part of reinforced concrete construction.

**1.2.2** The weldments specified in this code shall not be used where impact properties are a requirement of the general specification. Impact testing requirements of welded reinforcing bars are not included in this code.

**1.2.3** All references to the need for approval shall be interpreted to mean approval by the Engineer.

### 1.3 Reinforcing Steel Base Metal

**1.3.1** Reinforcing steel base metal in this code shall conform to the requirements of the latest edition of one of the ASTM specifications listed within this paragraph. Combinations of any of these reinforcing steel base metals, when welded, shall use a WPS (welding procedure specification) qualified in conformance with Section 6.

1. ASTM A 82/A 82M
2. ASTM A 496/A 496M
3. ASTM A 615/A 615M
4. ASTM A 706/A 706M
5. ASTM A 767/A 767M
6. ASTM A 775/A 775M
7. ASTM A 934/A 934M

Manufacturing and testing requirements for mats and fabric are covered by the respective ASTM specification. For joining the ASTM A 82/A 82M and A 496/A 496M to other reinforcing wires, reinforcing bars, or structural steels, the Engineer shall specify filler metal and the provisions of this code shall apply.

**1.3.2** When a reinforcing steel not listed in 1.3.1 is approved under the provisions of the general building code or by the Engineer, its chemical composition and carbon equivalent shall be provided and its weldability established by qualification in accordance with the requirements of 6.2 and all other requirements prescribed by the Engineer.

**1.3.3** Base metal, other than those previously listed, shall be one of the structural steels listed in the latest edition of AWS D1.1, *Structural Welding Code—Steel*, or any steel stipulated in the contract documents or approved by the Engineer.

**1.3.4** The carbon equivalent of reinforcing steel bars shall be calculated as shown in 1.3.4.1 or 1.3.4.2, as applicable.

**1.3.4.1** For all steel bars, except those designated as ASTM A 706, the carbon equivalent shall be calculated using the chemical composition, as shown in the mill test report, by the following formula:

$$C.E. = \%C + \%Mn/6 \quad (Eq. 1)$$

**1.3.4.2** For steel bars designated ASTM A 706/A 706M, the carbon equivalent shall be calculated using the chemical composition, as shown in the mill test report, by the following formula:

$$\text{C.E.} = \%C + \%Mn/6 + \%Cu/40 + \%Ni/20 + \%Cr/10 - \%Mo/50 - \%V/10 \quad (\text{Eq. 2})$$

The carbon equivalent shall not exceed 0.55%.

**1.3.4.3** If mill test reports are not available, chemical analysis may be made on bars representative of the bars to be welded. If the chemical composition is not known or obtained:

1. For bars number 6 [19] or less, use a minimum preheat of 300°F [150°C].
2. For bars number 7 [22] or larger, use a minimum preheat of 500°F [260°C].
3. For all ASTM A 706/A 706M bar sizes, use Table 5.2 C.E. values of "over 0.45% to 0.55% inclusive."

## 1.4 Welding Processes

**1.4.1** Welding shall be performed with shielded metal arc welding (SMAW), gas metal arc welding (GMAW), or flux cored arc welding (FCAW).

**1.4.2** Other welding processes may be used when approved by the Engineer, provided that any special qualification test requirements not covered here are met to ensure that welds satisfactory for the intended application will be obtained.

## 1.5 Definitions

The welding terms used in this code shall be interpreted in accordance with the definitions given in the latest edition of AWS A3.0, *Standard Welding Terms and Definitions*.

## 1.6 Welding Symbols

Welding symbols shall be those designated to the latest edition of AWS A2.4, *Standard Symbols for Welding, Brazing, and Nondestructive Examination*. Special conditions shall be fully explained by additional notes or details.

## 1.7 Safety Precautions

This technical document does not address all welding and health hazards. However, pertinent information can be found in the following documents:

1. ANSI Z49.1, Safety in Welding, Cutting, and Allied Processes
2. Manufacturer's safety literature on equipment and materials
3. Other pertinent documents as appropriate.

These documents shall be referred to and followed as required (also see Annex D, Safe Practices).

Note: This code may involve hazardous materials, operations, and equipment. The code does not purport to address all of the safety problems associated with its use. It is the responsibility of the user to establish appropriate safety and health practices. The user should determine the applicability of any regulatory limitations prior to use.

## 1.8 Standard Units of Measurement

This standard makes use of both U.S. Customary Units and the International System of Units (SI). The measurements may not be exact equivalents; therefore, each system shall be used independently of the other without combining in any way. The standard with the designation D1.4:2005 uses U.S. Customary Units. The standard designation D1.4M:2005 uses SI Units. The latter are shown within brackets [ ].

## 1.9 Reference Documents

The following standards contain provisions which, through reference in this text, constitute provisions of this AWS standard. For undated references, the latest edition of the referenced standard in use at the date of the contract bid submission shall apply. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply.

### ASNT Standards<sup>1</sup>

1. ASNT Recommended Practice No. SNT-TC-1A, Personnel Qualification and Certification in Nondestructive Testing

<sup>1</sup> ASNT standards are published by the American Society for Nondestructive Testing, 1711 Arlington Lane, Columbus, OH 43228-0518.

**ASME Standards<sup>2</sup>**

1. ASME B46.1, *Surface Texture*
2. ASME Boiler and Pressure Vessel Code

**ASTM Standards<sup>3</sup>**

1. ASTM A 82/A 82M, *Specification for Steel Wire, Plain, for Concrete Reinforcement*
2. ASTM A 496/A 496M, *Specification for Steel Wire, Deformed, for Concrete Reinforcement*
3. ASTM A 615/A 615M, *Specification for Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement*
4. ASTM A 706/A 706M, *Specification for Low-Alloy Steel Deformed and Plain Bars for Concrete Reinforcement*
5. ASTM A 767/A 767M, *Specification for Zinc-Coated (Galvanized) Steel Bars for Concrete Reinforcement*
6. ASTM A 775/A 775M, *Specification for Epoxy-Coated Steel Reinforcing Bars*
7. ASTM A 934/A 934M, *Specification for Epoxy-Coated Prefabricated Steel Reinforcing Bars*
8. ASTM E 94, *Standard Guide for Radiographic Examination*
9. ASTM E 165, *Standard Test Method for Liquid Penetrant Examination*
10. ASTM E 709, *Standard Guide for Magnetic Particle Examination*
11. ASTM E 1032, *Standard Test Method for Radiographic Examination of Weldments*

<sup>2</sup> ASME standards are published by the American Society of Mechanical Engineers, 3 Park Avenue, New York, NY 10017.

<sup>3</sup> ASTM standards are published by the American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959.

**AWS Standards<sup>4</sup>**

1. ANSI Z49.1:1999, *Safety in Welding, Cutting, and Allied Processes*
2. AWS A2.4-98, *Standard Symbols for Welding, Brazing, and Nondestructive Examination*
3. AWS A3.0:2001, *Standard Welding Terms and Definitions*
4. AWS A5.1:2004, *Specification for Carbon Steel Electrodes for Shielded Metal Arc Welding Electrodes*
5. AWS A5.5-96, *Specification for Low-Alloy Steel Electrodes for Shielded Metal Arc Welding Electrodes*
6. AWS A5.18:2001, *Specification for Carbon Steel Electrodes and Rods for Gas Shielded Arc Welding*
7. AWS A5.20:2005, *Specification for Carbon Steel Electrodes for Flux Cored Arc Welding*
8. AWS A5.28-96, *Specification for Low Alloy Steel Filler Metals for Gas Shielded Arc Welding*
9. AWS A5.29:1998, *Specification for Low Alloy Steel Electrodes for Flux Cored Arc Welding*
10. AWS D1.1:2004, *Structural Welding Code—Steel*
11. AWS D12.1-75, *Reinforcing Steel Welding Code* (obsolete, superseded by D1.4-79)
12. AWS QC1-96, *Standard for AWS Certification of Welding Inspectors*

**CSA Standards<sup>5</sup>**

1. CSA Standard W178.2, *Certification of Welding Inspectors*

<sup>4</sup> AWS standards are published by the American Welding Society, 550 N.W. LeJeune Road, Miami, FL 33126.

<sup>5</sup> CSA standards are published by the Canadian Standards Association, 178 Rexdale Boulevard, Toronto, Ontario, Canada, M9W 1R3.

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## 2. Allowable Stresses

### 2.1 Base-Metal Stresses

The allowable base-metal stresses shall be those specified in the applicable code or general specification for reinforced concrete construction.

### 2.2 Allowable Stresses in Welds

**2.2.1** Except as modified by Table 2.1, the allowable stresses for complete joint penetration bevel and V-groove welds in direct butt joints subject to tension or compression shall be the same as the corresponding allowable stresses for the reinforcing steel base metal, provided the filler metal used has a strength classification at least equal to the tensile strength of the base metal being welded.

**2.2.2** The allowable stresses for fillet welds, flare-bevel, and flare-V-groove welds shall be in accordance with Table 2.1.

### 2.3 Effective Weld Areas, Lengths, Throats, and Sizes

**2.3.1 Complete Joint Penetration Groove Welds in Direct Butt Joints.** The effective weld area shall be the nominal cross-sectional area of the bar being welded (see Figure 3.2). If different size bars are being welded, the weld area shall be based on the smaller bar.

**2.3.2 Flare-Bevel- and Flare-V-Groove Welds.** The effective weld area shall be the effective weld length multiplied by the effective weld size (see Figure 2.1).

**2.3.2.1** The effective weld length shall be the weld length of the specified weld size.

**2.3.2.2** The minimum effective weld length shall not be less than two times the bar diameter for equal size bars or two times the smaller bar diameter for two unequal size bars.

**2.3.2.3** The effective weld size, when filled flush to the solid section of the reinforcing steel bar, shall be 0.4 of the bar radius for flare-bevel-groove welds and 0.6 of the bar radius for flare-V-groove welds. Larger effective weld sizes may be used to determine allowable stresses provided, the WPS qualifies the larger weld size. When bars of unequal diameter are being joined, the effective weld size shall be based on the radius of the smaller bar. See 6.2.6.2 for macroetch test requirements for determining weld size.

**2.3.3 Fillet Welds.** The effective weld area shall be the effective weld length multiplied by the effective throat. (Stress in a fillet weld shall be considered as applied to this effective weld area, for any direction of applied load.)

**2.3.3.1** The effective weld length of a curved fillet weld shall be measured along the weld axis.

**2.3.3.2** The effective throat shall be calculated as the minimum distance from the weld root to the face of the fillet weld, minus convexity.

**Table 2.1**  
**Allowable Stresses in Welds (see 2.2.1)**

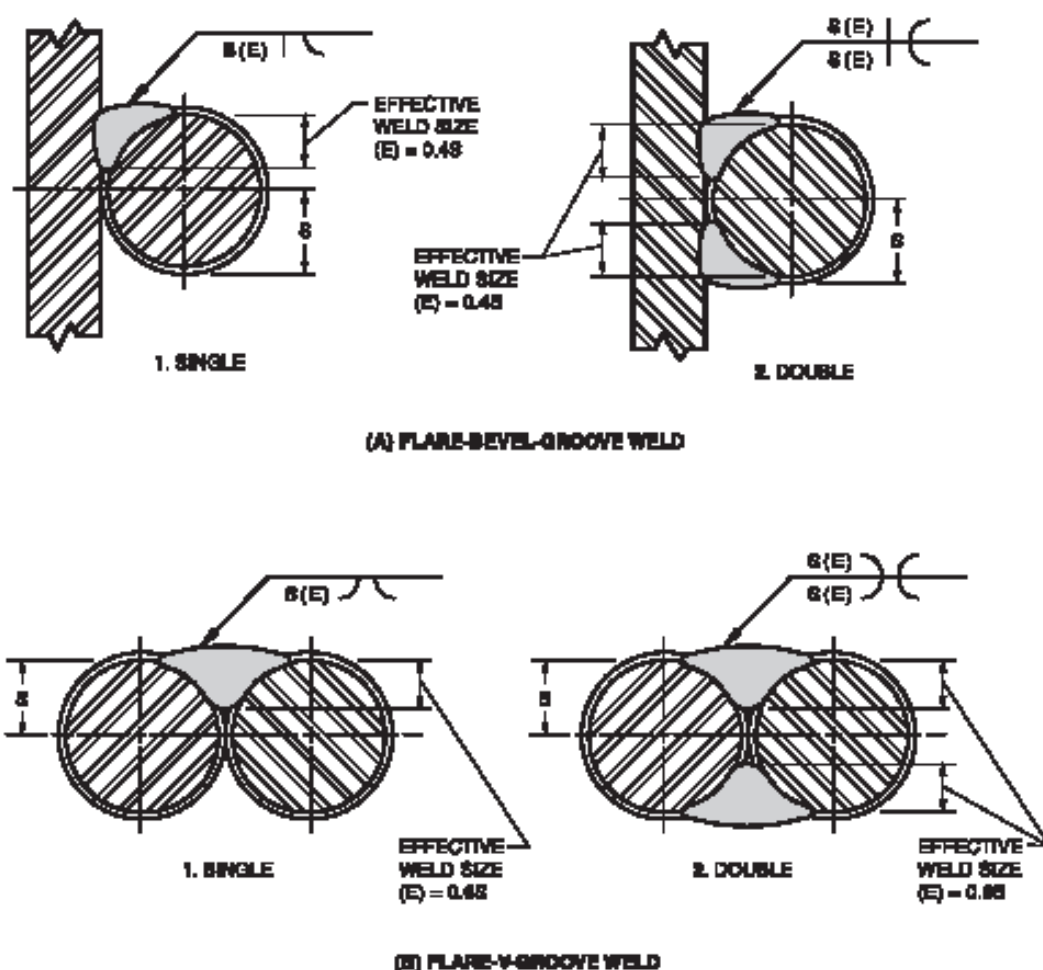
| Type of Weld                            | Stress in Weld <sup>a</sup>              |                            | Allowable Stress <sup>b, c</sup>                                                                                                                        | Required Filler Metal Strength Level <sup>d</sup>                                                                               |
|-----------------------------------------|------------------------------------------|----------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------|
| Complete joint penetration groove welds | Tension normal to the effective area     |                            | Same as base metal                                                                                                                                      | Matching filler metal shall be used. See Table 5.1                                                                              |
|                                         | Compression normal to the effective area |                            | Same as base metal                                                                                                                                      | Filler metal with a strength level equal to or one classification (10 ksi [70 MPa]) less than matching filler metal may be used |
|                                         | Shear on the effective areas             |                            | $0.30 \times$ nominal tensile strength of filler metal, except shear stress on base metal shall not exceed $0.40 \times$ yield strength of base metal   | Filler metal with a strength level equal to or less than matching filler metal may be used                                      |
| Flare-bevel and flare-V-groove welds    | Compression normal to effective area     | Joint not designed to bear | $0.50 \times$ nominal tensile strength of filler metal, except stress on base metal shall not exceed $0.60 \times$ yield strength of base metal         | Filler metal with a strength level equal to or less than matching filler metal may be used                                      |
|                                         |                                          | Joint designed to bear     | Same as base metal                                                                                                                                      |                                                                                                                                 |
|                                         | Shear on the effective area              |                            | $0.30 \times$ nominal tensile strength of filler metal, except shear stress on base metal shall not exceed $0.40 \times$ yield strength of base metal   |                                                                                                                                 |
|                                         | Tension normal to the effective area     |                            | $0.30 \times$ nominal tensile strength of filler metal, except tensile stress on base metal shall not exceed $0.60 \times$ yield strength of base metal |                                                                                                                                 |
| Fillet welds                            | Shear on the effective area              |                            | $0.30 \times$ nominal tensile strength of filler metal                                                                                                  | Filler metal with a strength level equal to or less than matching filler metal may be used                                      |

<sup>a</sup> For definition of effective area, see 2.3.1, 2.3.2, and 2.3.3.

<sup>b</sup> For fatigue or dynamic loading refer to the applicable construction code or specification for allowable stress values.

<sup>c</sup> The Engineer should be aware that the strength of cold drawn wire may be reduced when welded.

<sup>d</sup> For matching filler metal, see Table 5.1.



## Notes:

1. Radius of reinforcing bar =  $S$ .
2. These are sectional views. Bar deformations are shown only for illustrative purposes.

Figure 2.1—Effective Weld Sizes for Flare-Groove Welds (see 2.3.2)

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## 3. Structural Details

### 3.1 Transition in Bar Size

Direct butt joints in tension in axially aligned bars of different size shall be made as shown in Figure 3.1 (see Annex B for bar sizes).

### 3.2 Eccentricity

**3.2.1** Where welded lap or indirect butt joints are used (Figures 3.3 and 3.4, respectively), the concrete surrounding the joint in the finished structure shall be sufficiently strengthened with transverse reinforcement (splice plate) to prevent splitting of the concrete caused by the tendency of the joint to flex during eccentric loading.

**3.2.2** Welded lap joints shall be limited to bar size No. 6 [19] and smaller.

### 3.3 Joint Types

Reinforcing bars may be welded with direct or indirect butt joints, lap joints, or T-joints (Figures 3.2, 3.3, 3.4, and 3.5); however, direct butt joints are preferable for bars greater than No. 6 [19].

### 3.4 Direct Butt Joints

Direct butt joints shall be welded with complete joint penetration groove welds. Table 3.1 and Figure 3.2 describe the type of welded joints required.

### 3.5 Indirect Butt Joints

An indirect butt joint shall be made with either single- or double-flare-groove welds between the bars and the splice member. See Figure 3.3.

### 3.6 Lap Joints

**3.6.1** A lap joint shall be made with double-flare-V-groove welds [see Figure 3.4(A)], except that single-flare-V-groove welds may be used when the joint is accessible from only one side, and approved by the Engineer.

**3.6.2** An indirect lap joint shall be made with single-flare-bevel groove welds between the bars and the splice plate, with the bars being separated [see Figure 3.4(B)].

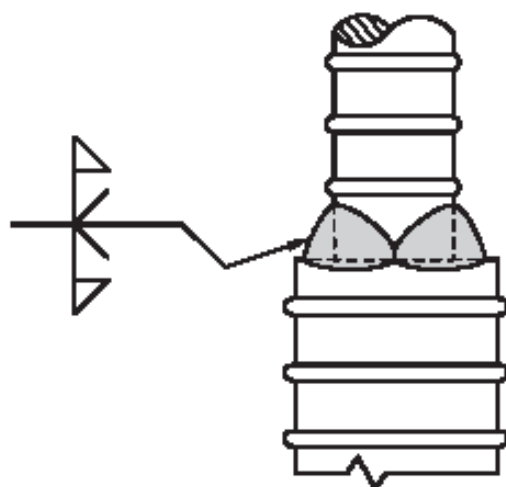
### 3.7 Interconnection of Precast Members

Precast members may be interconnected by welding reinforcing bars that project through the ends of the precast members or by welding together insert plates which have been cast into the precast members. The welding of reinforcing steel for precast concrete structures shall conform to the requirements of this code.

**Table 3.1**  
**CJP Groove Weld Requirements for Direct Butt Joints (see 3.4)**

| Bar Axis Orientation | Optional Types of CJP Groove Weld    | Optional Figure 3.2 Detail |
|----------------------|--------------------------------------|----------------------------|
| Horizontal           | Single-V                             | A                          |
|                      | Double-V                             | B                          |
|                      | Single-V with Split Pipe Backing     | C <sup>a</sup>             |
| Vertical             | Single-Bevel                         | D                          |
|                      | Double-Bevel                         | E                          |
|                      | Single-Bevel with Split Pipe Backing | C <sup>a</sup>             |

<sup>a</sup> Bars shall be of equal diameter.



**Figure 3.1—Direct Butt Joint Showing  
 Transition Between Bars of Different Sizes  
 (see 3.1)**

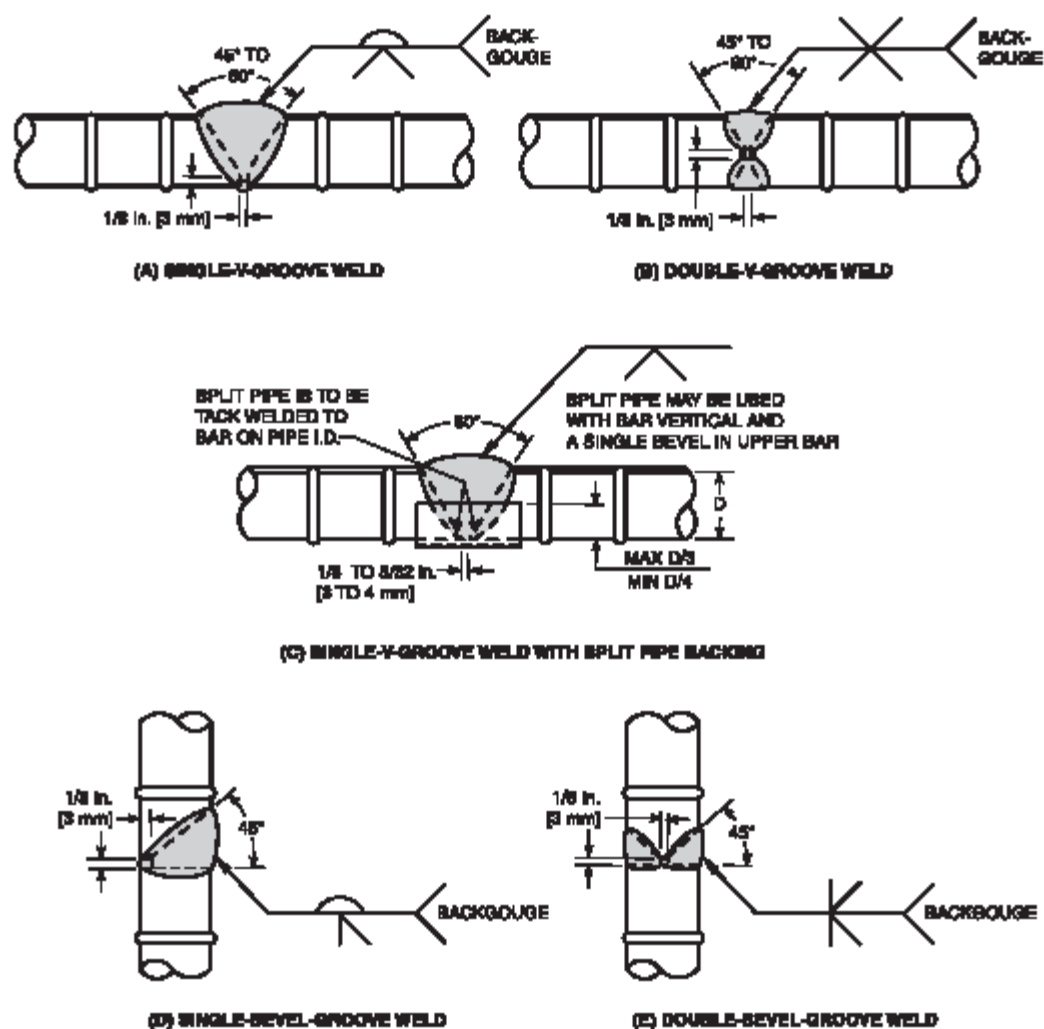
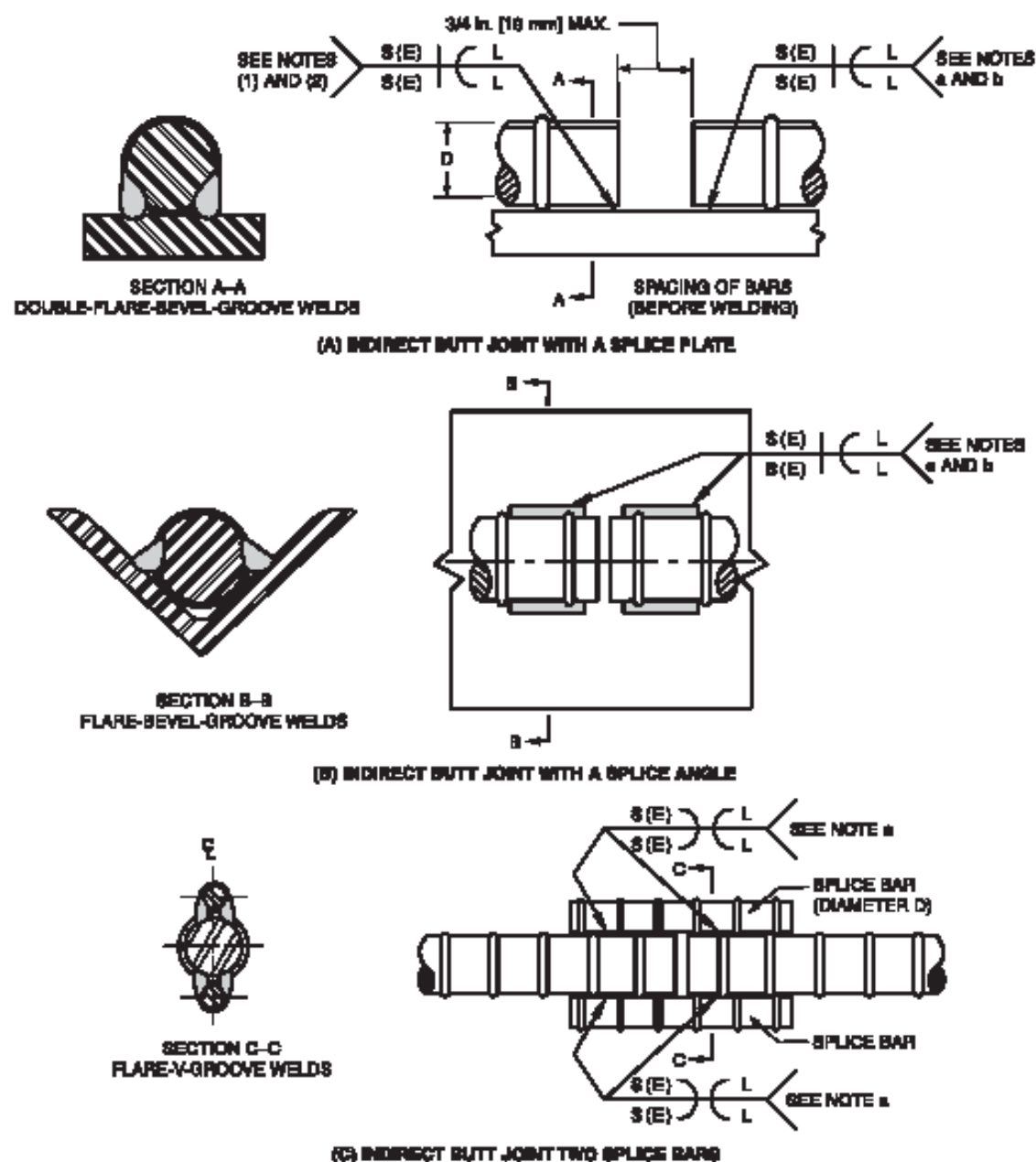


Figure 3.2—Direct Butt Joints (see Table 3.1)



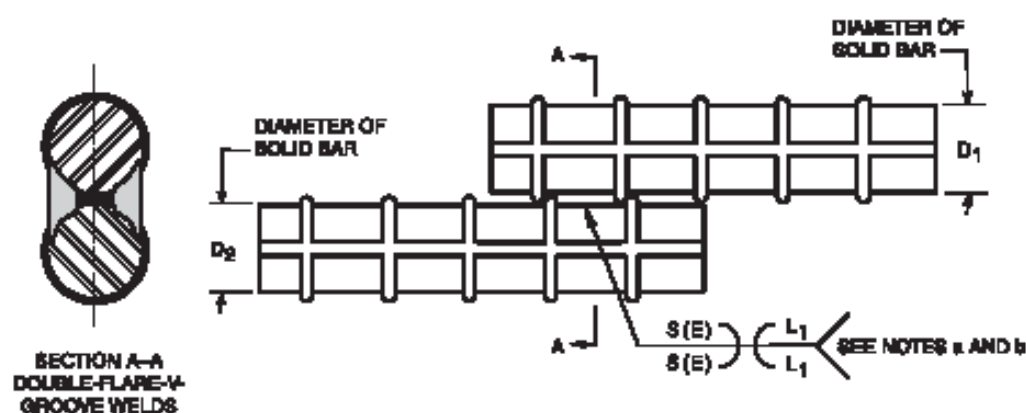
<sup>a</sup>  $L = 2D$  (min.)

<sup>b</sup> Variation of this weld using single flare-V welds is permitted provided eccentricity is considered or restraint provided in the design of the joint.

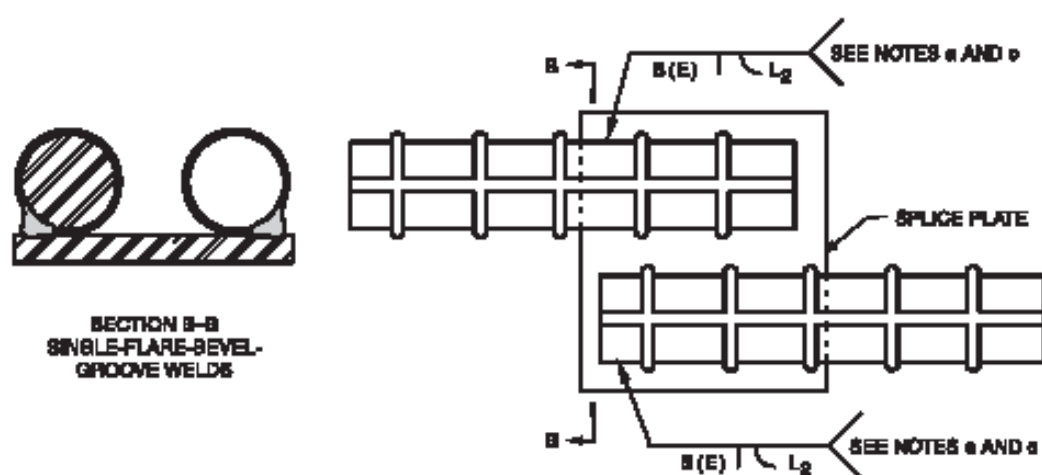
Notes:

1. Gaps between bars and plate will vary depending on height of deformations.
2. Deformations shown on sectional views are for illustrative purposes only.

Figure 3.3—Indirect Butt Joints (see 3.5)



(A) DIRECT LAP JOINT WITH BARS IN CONTACT



(B) INDIRECT LAP JOINTS WITH BARS SEPARATED

<sup>a</sup> The effects of eccentricity shall be considered or restraint provided in the design of the joint.

<sup>b</sup>  $L_1 = 2 D_1$  (min);  $D_1 \leq D_2$ .

<sup>c</sup>  $L_2 = 2 \times$  diameter of bar (min.).

Note: Gaps between bars and plate will vary depending on height of deformations.

Figure 3.4—Lap Joints (see 3.2.1)

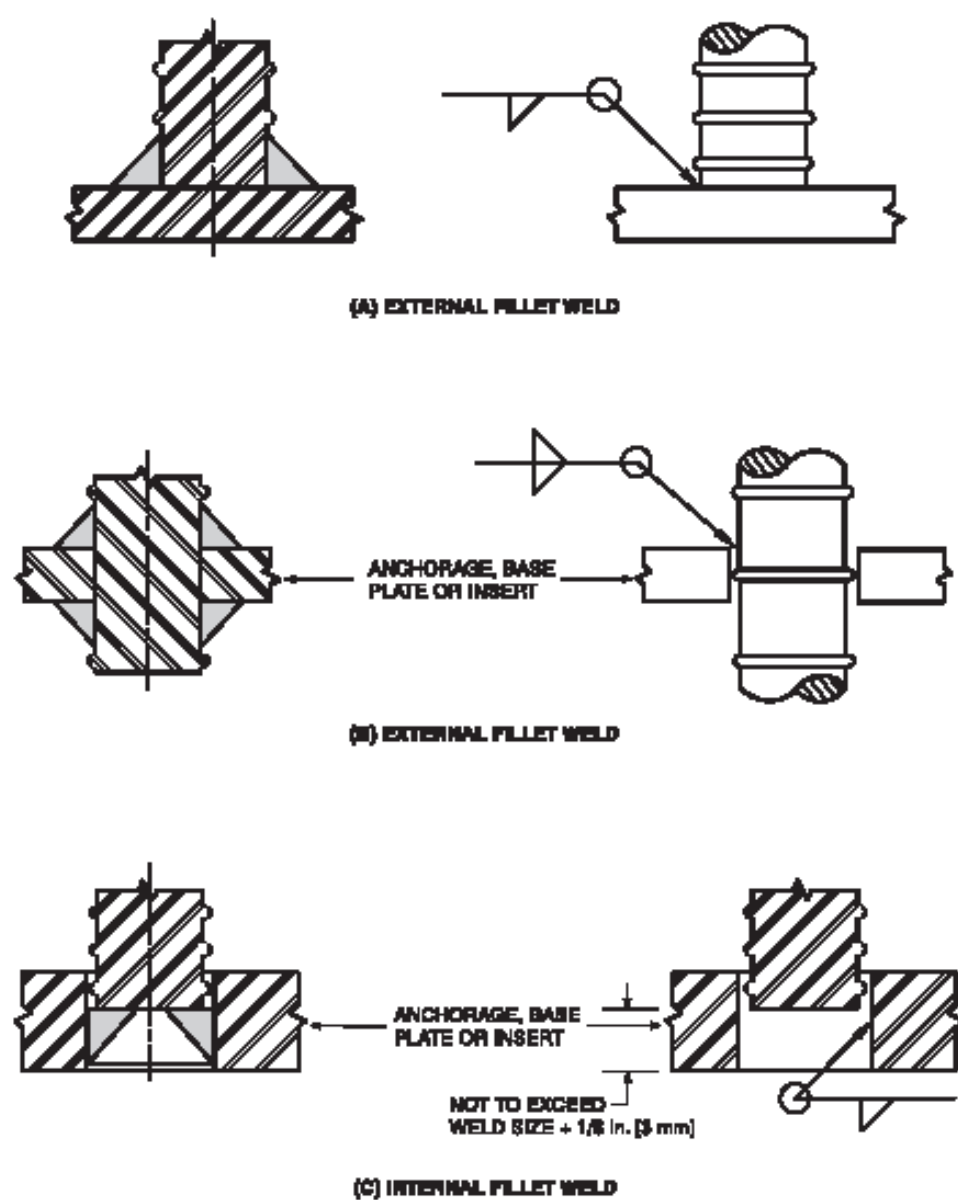
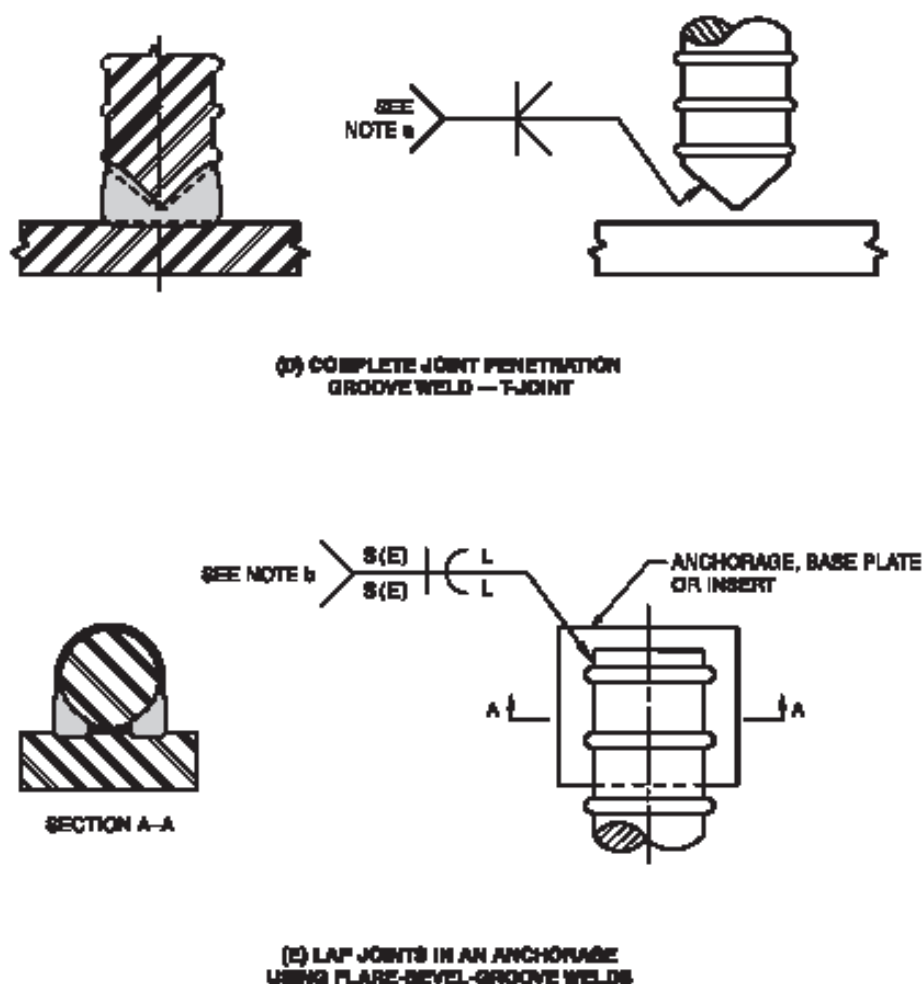


Figure 3.5—Details of Joints of Anchorages, Base Plates, and Inserts (see 3.3)



<sup>a</sup> Backgouge to sound metal before welding other side. For bar sizes 8 [25] or smaller, the single-bevel weld with backgouging and back welding is recommended.

<sup>b</sup>  $L = 2 \times$  bar diameter (min.).

Figure 3.5 (Continued)—Details of Joints of Anchorages, Base Plates, and Inserts (see 3.3)

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## 4. Workmanship

### 4.1 Preparation of Base Metal

**4.1.1** Surfaces to be welded shall be free from fins, tears, cracks, or other defects that would adversely affect the quality or strength of weld. Surfaces to be welded, and surfaces adjacent to a weld, shall also be free from loose or thick scale, slag, rust, moisture, grease, epoxy coating, or other foreign material that would prevent proper welding or produce objectionable fumes. Mill scale that withstands vigorous wire brushing, a thin rust inhibitive coating, or antisplatter compound may remain.

**4.1.2** The ends of reinforcing bars in direct butt joints shall be shaped to form the weld groove by oxygen cutting, air carbon arc cutting, sawing, or other mechanical means. Roughness of oxygen cut surfaces shall be no greater than the 2000  $\mu\text{in.}$  [50  $\mu\text{m}$ ] limit defined in ANSI/ASME B46.1, *Surface Texture*. Roughness exceeding this value and occasional notches or gouges not more than 3/16 in. [5 mm] deep, on otherwise satisfactory surfaces, shall be removed by machining or grinding. Bars for direct butt joints that have sheared ends shall be trimmed back beyond the area deformed by shearing.

### 4.2 Assembly

**4.2.1** The joint members shall be aligned so as to minimize eccentricities. Welded direct butt joints shall not be offset at the joint by more than the following:

|                                             |                 |
|---------------------------------------------|-----------------|
| Bar sizes No. 10 [32] or smaller .....      | 1/8 in. [3 mm]  |
| Bar sizes No. 11 [36] and No. 14 [43] ..... | 3/16 in. [5 mm] |
| Bar size No. 18 [57] .....                  | 1/4 in. [6 mm]  |

**4.2.2** For indirect butt joints with splice plates, the maximum joint clearance between the bars shall not be more than 3/4 in. [19 mm]. See Figure 3.3(A).

**4.2.3** For direct lap joints, if the bar deviates by more than one-half of the bar diameter, or by no more than 1/4 in. [6 mm] from each other while the bars remain in approximately the same plane, the joint shall be made

through a splice bar or plate, and the requirements for an indirect lap joint shall apply (see 3.6.2).

**4.2.4** For indirect lap joints [see Figure 3.4(B)], the maximum separation between the bar and the splice plate shall be no more than one-quarter of the bar diameter, but not more than 3/16 in. [5 mm].

**4.2.5** Welding of bars which cross shall not be permitted unless authorized by the Engineer.

**4.2.6** Welds made on the unbent portion of cold bent reinforcing steel shall be terminated or initiated at a minimum distance of two bar diameters from the points of tangency for the radius created by cold bending. See Figure 4.2.

### 4.3 Control of Distortion, Shrinkage, and Heat

**4.3.1** In assembling and joining parts of a structure or precast member, the procedure and sequence followed shall minimize distortion and shrinkage.

**4.3.2** When welding is performed on bars or other structural components that are already embedded in concrete, allowance shall be made for thermal expansion of the steel to prevent spalling or cracking of the concrete or significant destruction of the bond between the concrete and the steel. The heat of welding may cause localized damage to the concrete.

### 4.4 Quality of Welds

Welds that do not meet the quality requirements of 4.4.1 through 4.4.8, inclusive, shall be repaired by removal of unacceptable portions or by rewelding, whichever is applicable.

**4.4.1** The fillet weld faces shall be slightly convex or slightly concave as shown in Figures 4.1(A) and 4.1(B) or flat, and with none of the unacceptable profiles exhibited in Figure 4.1(C). Groove weld profiles shall conform to Figure 4.1(D).

**4.4.2** Welds shall have no cracks in either the weld metal or heat-affected zone (HAZ).

**4.4.3** There shall be complete fusion between weld metal and base metal and between successive passes in the weld.

**4.4.4** All weld craters shall be filled to a cross section that meets the minimum specified weld size.

**4.4.5** Welds shall be free from overlap.

**4.4.6** Undercut depth greater than 1/32 in. [1 mm] in the solid section of the bar or structural member shall not be allowed.

**4.4.7** The sum of diameters of piping porosity in flare-groove welds and fillet welds shall not exceed 3/8 in. [10 mm] in any linear inch [25 mm] of weld and shall not exceed 9/16 in. [14 mm] in any 6 in. [150 mm] length of weld.

**4.4.8** When radiographic inspection of direct butt joints is required, the maximum dimension of any single porosity or fusion-type discontinuity, or the sum of the maximum dimensions of all porosity or fusion-type discontinuities, shall not exceed the limits given in Table 4.1. For radiographic inspection, see 7.7.3.

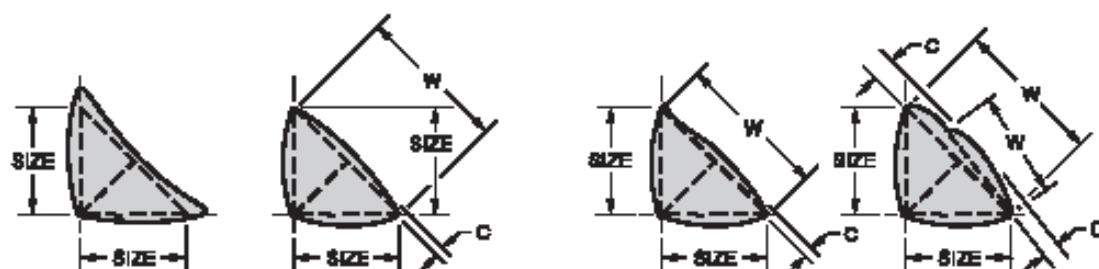
**4.4.9** Repairs to welds made with the shielded metal arc welding (SMAW), gas metal arc welding (GMAW), or flux cored arc welding (FCAW) processes shall be made in accordance with a qualified WPS approved by the Engineer applicable to these processes.

**4.4.10** The weld size shall be equal to or greater than the weld size specified. The length of weld containing this weld size shall be equal to or greater than the weld length specified. Any portion of the length, including starts or stops, that contain a smaller weld size shall not be measured in the weld length.

**Table 4.1**  
**Radiographic Acceptance Criteria<sup>a</sup> (see 4.4.8)**

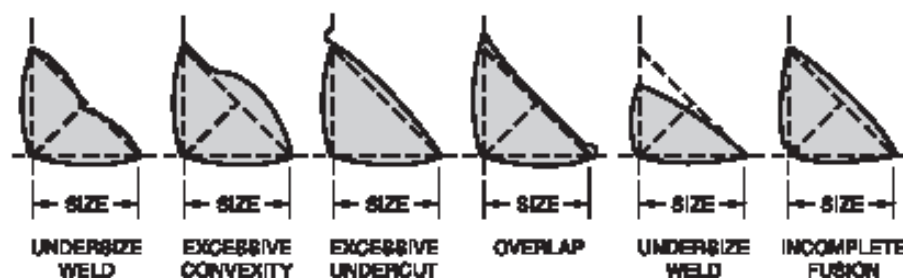
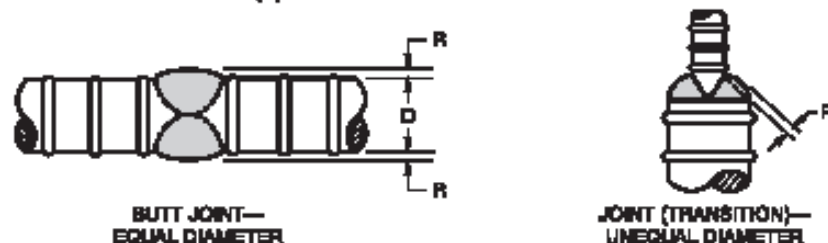
| Bar Size | Sum of Discontinuity Dimensions |    | Single Discontinuity Dimension |    |
|----------|---------------------------------|----|--------------------------------|----|
|          | in.                             | mm | in.                            | mm |
| 8 [25]   | 3/16                            | 5  | 1/8                            | 3  |
| 9 [29]   | 3/16                            | 5  | 1/8                            | 3  |
| 10 [32]  | 1/4                             | 6  | 1/8                            | 3  |
| 11 [36]  | 1/4                             | 6  | 3/16                           | 5  |
| 14 [43]  | 5/16                            | 8  | 3/16                           | 5  |
| 18 [57]  | 7/16                            | 11 | 1/4                            | 6  |

<sup>a</sup> Acceptance criteria for bar sizes less than No. 8 [25] shall be established by the Engineer.

**(A) DESIRABLE FILLET WELD PROFILES****(B) ACCEPTABLE FILLET WELD PROFILES**

Note: Convexity,  $C$ , of a weld or individual surface bead with dimension  $W$  shall not exceed the value of the following table:

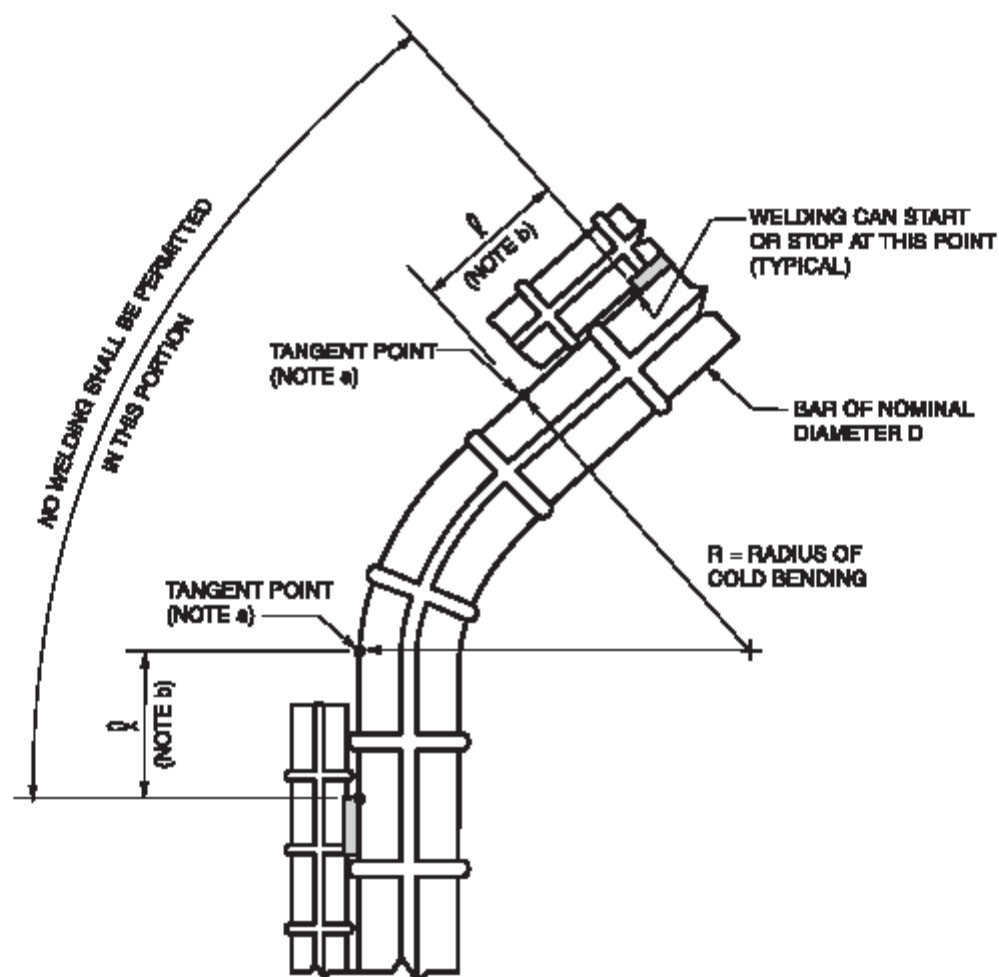
| WIDTH OF WELD FACE OR<br>INDIVIDUAL SURFACE BEAD, $W$ | MAX CONVEXITY, $C$ |
|-------------------------------------------------------|--------------------|
| $W \leq 5/16$ in. [8 mm]                              | 1/16 in. [2 mm]    |
| $W > 5/16$ in. [8 mm] TO $W < 1$ in. [25 mm]          | 1/8 in. [3 mm]     |
| $W \geq 1$ in. [25 mm]                                | 3/16 in. [5 mm]    |

**(C) UNACCEPTABLE FILLET WELD PROFILES**

Note: Reinforcement  $R$  shall not exceed 1/8 in. [3 mm].

**(D) ACCEPTABLE GROOVE WELD PROFILE IN BUTT JOINT****(E) UNACCEPTABLE GROOVE WELD PROFILES IN BUTT JOINTS**

Figure 4.1—Acceptable and Unacceptable Weld Profiles (see 4.4.1)



<sup>a</sup> For welding on inside radius, use tangent points on inside radius.

<sup>b</sup>  $l \geq 2D$ .

Note: This figure is for illustration only.

Figure 4.2—Minimum Distance to Cold Bending Radius Tangent Points<sup>1</sup> (see 4.2.6)

## 5. Technique

### 5.1 Filler Metal Requirements

**5.1.1** For any connections welded to this code, the base metal–filler metal strength relationship below shall be used in conjunction with Table 5.1 to determine whether matching or undermatching filler metals are required.

| Relationship   | Base Metal                                                                                                              | Filler Metal Strength Required                                                                                      |
|----------------|-------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------|
| Matching       | Any reinforcing steel to itself or any reinforcing steel to any other steel with a comparable minimum tensile strength. | Any filler metal listed in the same Table 5.1 strength group.                                                       |
|                | Any reinforcing steel in one group to any reinforcing steel or other steel with a lower minimum tensile strength.       | Any filler metal listed for the same Table 5.1 strength group as the steel with the lower minimum tensile strength. |
| Under-matching | Any reinforcing steel to a reinforcing steel or other steel with a comparable minimum tensile strength.                 | Any filler metal listed for the next lower Table 5.1 strength group.                                                |

Note: See Table 2.1 to determine the filler metal strength requirements to match or undermatch base metal strength.

**5.1.2** When joining different grades of steels, the filler metal shall be selected for the lower tensile strength base metal.

### 5.2 Minimum Preheat and Interpass Temperature Requirements

**5.2.1** Minimum preheat and interpass temperatures shall be in accordance with Table 5.2 using the highest carbon equivalent number of the base metal as determined in accordance with 1.3.4.

**5.2.2** Welding shall not be done when ambient temperature is lower than 0°F [−18°C], or when surfaces to be welded are exposed to rain or snow. For the GMAW and FCAW-G processes, welding shall not be performed when wind velocities exceed 5 mph [8 km/h].

### 5.3 Arc Strikes

Arc strikes outside the area of permanent welds shall be avoided, especially on reinforcing bars.

### 5.4 Weld Cleaning

**5.4.1 In-Process Cleaning.** Before welding over previously deposited metal, all slag shall be removed and the weld and adjacent base metal shall be brushed clean. This requirement shall apply not only to successive layers but also to successive beads and to the crater area when welding is resumed after any interruption.

**5.4.2 Cleaning of Completed Welds.** Slag shall be removed from all completed welds, and the weld and adjacent base metal shall be cleaned by brushing or other suitable means. Tightly adherent spatter remaining after the cleaning operation is acceptable, unless its removal is required for the purpose of NDT. Welded joints shall not be painted until after welding has been completed and the weld accepted.

### 5.5 Tack Welds

Tack welds that do not become a part of permanent welds shall be prohibited unless authorized by the Engineer. Tack welds shall be subject to the welding requirements of the code, including preheat, electrode selection, and discontinuity acceptance criteria.

## 5.6 Progression of Welding

Welds made in the vertical position [Figure 6.1(C), Position 3G or Figure 6.2(C), Position 3G], shall use uphill progression.

## 5.7 Welding of Coated Base Metal

**5.7.1** Preparation for welding on coated base metal shall preferably be made after coating. After welding to a qualified WPS, suitable coating protection shall be applied to the finished joint to restore the corrosion-resistant properties of the coated bars.

**5.7.2** When welding galvanized base metal, one of the following options shall be met:

**5.7.2.1 Option 1.** Welding of galvanized base metal, without prior removal of the coating, shall be performed in accordance with a WPS qualified to the requirements of this code. Note that the WPS will normally involve larger root openings in joints, electrodes with lower silicon content, and slower welding speeds.

**5.7.2.2 Option 2.** Welding of galvanized base metal may be done after removing all coating from within 2 in. [50 mm] of the weld joint. In this option, the welding shall be performed using a WPS for uncoated reinforcing bar qualified in accordance with this code. The galvanized coating may be removed with oxyfuel gas flame, abrasive shot blasting, or other suitable means.

**5.7.3** When welding galvanized surfaces, suitable ventilation shall be provided to prevent the concentration of fumes. See ANSI Z49.1 and Annex D.

**5.7.4** When welding or preheating epoxy coated base metal, the epoxy coating shall be removed from the surfaces to be heated.

## 5.8 SMAW Electrodes

Electrodes for SMAW shall conform to the requirements of the latest edition of AWS A5.1, *Specification for Carbon Steel Electrodes for Shielded Metal Arc Welding Electrodes*, or to the requirements of AWS A5.5, *Specification for Low-Alloy Steel Electrodes for Shielded Metal Arc Welding*.

**5.8.1 Low-Hydrogen Electrode Storage Conditions.** All electrodes having low-hydrogen coverings conforming to AWS A5.1 and AWS A5.5 shall be purchased in hermetically sealed containers or shall be rebaked prior to use. Immediately after opening the hermetically sealed container, electrodes shall be stored in ovens held at a temperature of at least 250°F [120°C].

**5.8.2 Approved Atmospheric Time Periods.** After hermetically sealed containers are opened or after electrodes are removed from baking or storage ovens, the electrode exposure to the atmosphere shall not exceed the values shown in column A, Table 5.3, for the specific electrode classification with optional supplemental designators, where applicable. Electrodes exposed to the atmosphere for periods less than those permitted by column A, Table 5.3 may be returned to a holding oven maintained at 250°F [120°C] min; after a minimum hold period of four hours at 250°F [120°C] min., the electrodes may be reissued. Electrodes that have been wet shall not be used.

**5.8.3 Alternative Atmospheric Exposure Time Periods Established by Tests.** The alternative exposure time values shown in column B in Table 5.3 may be used, provided testing establishes the maximum allowable time. The testing shall be performed in conformance with AWS A5.5, subsection 3.10, for each electrode classification and each electrode manufacturer. Such tests shall establish that the maximum moisture-content values of AWS A5.5 (Table 9) are not exceeded. Additionally, E70XX or E70XX-X (AWS A5.1 or A5.5) low-hydrogen electrode coverings shall be limited to a maximum moisture content not exceeding 0.4% by weight. These electrodes shall not be used at relative humidity-temperature combinations that exceed either the relative humidity or moisture content in the air that prevailed during the testing program.

For proper application to this provision, see Annex E for the temperature-moisture content chart and its examples. The chart shown in Annex E, or any standard psychrometric chart, shall be used in the determination of temperature-relative humidity limits.

**5.8.4 Rebaking Electrodes.** Electrodes exposed to the atmosphere for periods greater than those permitted in Table 5.3 shall be rebaked as follows:

1. All electrodes having low-hydrogen coverings conforming to AWS A5.1 shall be baked for at least two hours between 500°F [260°C] and 800°F [430°C], or
2. All electrodes having low-hydrogen coverings conforming to AWS A5.5 shall be baked for at least one hour at temperatures between 700°F [370°C] and 800°F [430°C].

Electrode shall be rebaked no more than once.

**5.8.5 Electrode Restrictions for ASTM A 514 or A 517 Steels.** When used for welding ASTM A 514 or A 517 steels, electrodes of any classification lower than E100XX-X, except for E7018M and E70XXH4R, shall be baked at least one hour at temperatures between 700 and 800°F [370 and 430°C] before being used, whether furnished in hermetically sealed containers or otherwise.

## 5.9 Electrodes and Shielding Gas for Gas Metal Arc Welding (GMAW) and Flux Cored Arc Welding (FCAW)

The electrodes and shielding for gas metal arc welding (GMAW) or flux cored arc welding (FCAW) for producing weld metal with minimum specified yield strengths of 60 000 psi [420 MPa] or less, shall conform to the requirements of the latest edition of AWS A5.18, *Specification for Carbon Steel Electrodes and Rods for Gas Shielded Arc Welding*, or AWS A5.20, *Specification for Carbon Steel Electrodes for Flux Cored Arc Welding*, as applicable.

**5.9.1 Low-Alloy Electrodes for GMAW.** The electrodes and shielding for GMAW for producing weld

metal with a minimum specified yield strength greater than 60 000 psi [420 MPa] shall conform with the latest edition of AWS A5.28, *Specification for Low-Alloy Steel Electrodes and Rods for Gas Shielded Arc Welding*.

**5.9.2 Low-Alloy Electrodes for FCAW.** The electrodes and shielding gas for FCAW for producing weld metal with a minimum specified yield strength greater than 60 000 psi [415 MPa] shall conform to the latest edition of AWS A5.29, *Specification for Low-Alloy Steel Electrodes for Flux Cored Arc Welding*.

**5.9.3 Shielding Gas.** When a gas or gas mixture is used for shielding in GMAW or FCAW, it shall be of a welding grade having a dew point of  $-40^{\circ}\text{F}$  [ $-40^{\circ}\text{C}$ ] or lower. When requested by the Engineer, the gas manufacturer shall furnish certification that the gas or gas mixture will meet the dew point requirement.

**Table 5.1**  
**Matching Filler Metal Requirements (see 5.1)**

| Group                 | Steel Specification Requirements |                              |          |                          | Filler Metal Requirements            |                                   |                |                               |
|-----------------------|----------------------------------|------------------------------|----------|--------------------------|--------------------------------------|-----------------------------------|----------------|-------------------------------|
|                       | Steel Specification              | Minimum Yield Point/Strength |          | Minimum Tensile Strength | Electrode Specification <sup>a</sup> | Yield Point/Strength <sup>b</sup> |                | Tensile Strength <sup>b</sup> |
|                       |                                  | ksi                          | MPa      |                          |                                      | ksi                               | MPa            |                               |
| I                     | ASTM A615<br>ASTM A615M          | Grade 40<br>Grade 300        | —<br>300 | 70<br>—<br>500           | SMAW AWS A5.1 and A5.5               | 53–72<br>365–496                  | 70<br>—<br>482 |                               |
|                       |                                  |                              |          |                          | E7015, E7016, E7018, E7028           |                                   |                |                               |
|                       |                                  |                              |          |                          | E7015-X, E7016-X, E7018-X            |                                   |                |                               |
|                       |                                  |                              |          |                          | GMAW AWS A5.18                       |                                   |                |                               |
|                       |                                  |                              |          |                          | ER70S-X, E70C-3, E70C-6              |                                   |                |                               |
|                       |                                  |                              |          |                          | FCAW AWS A5.20 and A5.29             | 58<br>400                         | 70<br>—<br>480 |                               |
|                       |                                  |                              |          |                          | E7XT-X                               |                                   |                |                               |
|                       |                                  |                              |          |                          | E7XTX-X                              |                                   |                |                               |
|                       |                                  |                              |          |                          | (Except -2, -3, -10, -13, -14, -GS)  |                                   |                |                               |
|                       |                                  |                              |          |                          | SMAW AWS A5.5                        |                                   |                |                               |
| II                    | ASTM A706<br>ASTM A706M          | Grade 60<br>Grade 420        | —<br>420 | 80<br>—<br>550           | E8015-X, E8016-X, E8018-X            | 67<br>460                         | 80<br>—<br>550 |                               |
|                       |                                  |                              |          |                          | GMAW AWS A5.28                       |                                   |                |                               |
|                       |                                  |                              |          |                          | ER80S-X, E80C-X, E90C-X              |                                   |                |                               |
|                       |                                  |                              |          |                          | FCAW AWS A5.29                       |                                   |                |                               |
|                       |                                  |                              |          |                          | E8XTX-X                              |                                   |                |                               |
| III                   | ASTM A615<br>ASTM A615M          | Grade 60<br>Grade 420        | —<br>420 | 90<br>—<br>600           | SMAW AWS A5.5                        | 77<br>530                         | 90<br>—<br>620 |                               |
|                       |                                  |                              |          |                          | E9015-X, E9016-X, E9018-X            |                                   |                |                               |
|                       |                                  |                              |          |                          | GMAW AWS A5.28                       |                                   |                |                               |
|                       |                                  |                              |          |                          | ER90S-X                              |                                   |                |                               |
|                       |                                  |                              |          |                          | FCAW AWS A5.29                       |                                   |                |                               |
| E9XTX-X               |                                  |                              |          |                          |                                      |                                   |                |                               |
| 78 540 90–110 620–760 |                                  |                              |          |                          |                                      |                                   |                |                               |

**Table 5.1 (Continued)**  
**Matching Filler Metal Requirements (see 5.1)**

| Group | Steel Specification Requirements |                              |     |                          | Filler Metal Requirements            |                                   |         |                               |
|-------|----------------------------------|------------------------------|-----|--------------------------|--------------------------------------|-----------------------------------|---------|-------------------------------|
|       | Steel Specification              | Minimum Yield Point/Strength |     | Minimum Tensile Strength | Electrode Specification <sup>a</sup> | Yield Point/Strength <sup>b</sup> |         | Tensile Strength <sup>b</sup> |
|       |                                  | ksi                          | MPa |                          |                                      | ksi                               | MPa     |                               |
| IV    | ASTM A615                        | Grade 75 <sup>c</sup>        | —   | —                        | SMAW AWS A5.5                        | —                                 | —       | —                             |
|       | ASTM A615M                       | Grade 520 <sup>d</sup>       | —   | —                        | E10015-X, E10016-X,<br>E10018-X      | 87                                | 600     | 100 690                       |
|       |                                  |                              |     |                          | E10018-M                             | 88–100                            | 610–690 | 100 690                       |
|       |                                  |                              |     |                          | GMAW AWS A5.28                       | —                                 | —       | —                             |
|       |                                  |                              |     |                          | ER100S-X, E100C-X                    | 88                                | 610     | 100 690                       |
|       |                                  |                              |     |                          | FCAW AWS A5.29                       | —                                 | —       | —                             |
|       |                                  |                              |     |                          | E10XTX-X                             | 88                                | 610     | 100–120 690–830               |

<sup>a</sup> Filler metals of alloy group B3, B3L, B4L, B5, B5L, B6, B6L, B7, B7L, B8, B8L, or B9 in AWS A5.5, A5.28, or A5.29 may be used when given prior approval by the Engineer. Consideration shall be made of the differences in tensile strength, ductility, and hardness between the PWHT versus as-welded conditions.

<sup>b</sup> This table is based on filler metal as-welded properties. Single values are minimums. Hyphenated values indicate minima and maxima.

<sup>c</sup> Applicable to bar sizes Nos. 6 through 18.

<sup>d</sup> Applicable to bar sizes Nos. 19 through 57.

**Table 5.2**  
**Minimum Preheat and Interpass Temperatures<sup>a, b</sup> (see 5.2.1)**

| Carbon Equivalent (C.E.) Range, % <sup>c, d</sup> | Size of Reinforcing Bar      | SMAW with Low-Hydrogen Electrodes,<br>GMAW, or FCAW |                   |
|---------------------------------------------------|------------------------------|-----------------------------------------------------|-------------------|
|                                                   |                              | Minimum Temperature                                 |                   |
|                                                   |                              | °F                                                  | °C                |
| Up to 0.40                                        | Up to 11 [36] inclusive      | none <sup>e</sup>                                   | none <sup>e</sup> |
|                                                   | 14 and 18 [43 and 57]        | 50                                                  | 10                |
| Over 0.40 to 0.45 inclusive                       | Up to 11 [36] inclusive      | none <sup>e</sup>                                   | none <sup>e</sup> |
|                                                   | 14 and 18 [43 and 57]        | 50                                                  | 10                |
| Over 0.45 to 0.55 inclusive                       | Up to 6 [19] inclusive       | none <sup>e</sup>                                   | none <sup>e</sup> |
|                                                   | 7 to 11 [22 to 36]           | 50                                                  | 10                |
|                                                   | 14 to 18 [43 to 57]          | 200                                                 | 90                |
| Over 0.55 to 0.65 inclusive                       | Up to 6 [19] inclusive       | 100                                                 | 40                |
|                                                   | 7 to 11 [22 to 36]           | 200                                                 | 90                |
|                                                   | 14 to 18 [43 to 57]          | 300                                                 | 150               |
| Over 0.65 to 0.75                                 | Up to 6 [19] inclusive       | 300                                                 | 150               |
|                                                   | 7 to 18 [22 to 57] inclusive | 400                                                 | 200               |
| Over 0.75                                         | Up to 6 [19] inclusive       | 300                                                 | 150               |
|                                                   | 7 to 18 [22 to 57] inclusive | 500                                                 | 260               |

<sup>a</sup> When reinforcing steel is to be welded to main carbon steel, the preheat requirements of the structural steel shall also be considered (see AWS D1.1, table titled "Prequalified Minimum Preheat and Interpass Temperature.") The minimum preheat requirement to apply in this situation shall be the higher requirement of the two tables. However, extreme caution shall be exercised in the case of welding reinforcing steel to quenched and tempered steels, and such measures shall be taken as to satisfy the preheat requirements for both. If not possible, welding shall not be used to join the two base metals.

<sup>b</sup> Welding shall not be done when the ambient temperature is lower than 0°F [–18°C]. When the base metal is below the temperature listed for the welding process being used and the size and carbon equivalent range of the bar being welded, it shall be preheated (except as otherwise provided) in such a manner that the cross section of the bar for not less than 6 in. [150 mm] on each side of the joint shall be at or above the specified minimum temperature. Preheat and interpass temperatures shall be sufficient to prevent crack formation.

<sup>c</sup> After welding is complete, bars shall be allowed to cool naturally to ambient temperature. Accelerated cooling is prohibited.

<sup>d</sup> Where it is impractical to obtain chemical analysis, the carbon equivalent shall be assumed to be above 0.75%. See also 1.3.4.3.

<sup>e</sup> When the base metal is below 32°F [0°C], the base metal shall be preheated to at least 70°F [20°C], or above, and maintained at this minimum temperature during welding.

**Table 5.3**  
**Permissible Atmospheric Exposure of Low-Hydrogen Electrodes (see 5.7.2 and 5.7.3)**

| Electrode | Column A (hours) | Column B (hours)  |
|-----------|------------------|-------------------|
| A5.1      |                  |                   |
| E70XX     | 4 max            |                   |
| E70XXR    | 9 max            | Over 4 to 10 max  |
| E70XXHZR  | 9 max            |                   |
| E7018M    | 9 max            |                   |
| A5.5      |                  |                   |
| E70XX-X   | 4 max            | Over 4 to 10 max  |
| E80XX-X   | 2 max            | Over 2 to 10 max  |
| E90XX-X   | 1 max            | Over 1 to 5 max   |
| E100XX-X  | 1/2 max          | Over 1/2 to 4 max |
| E110XX-X  | 1/2 max          | Over 1/2 to 4 max |

## Notes:

1. Column A: Electrodes exposed to atmosphere for longer periods than shown shall be redried before use.
2. Column B: Electrodes exposed to atmosphere for longer periods than those established by testing shall be redried before use.
3. Entire table: Electrodes shall be issued and held in quivers, or other small open containers. Heated containers are not mandatory.
4. The optional supplemental designator, R, designates a low-hydrogen electrode, which has been tested for covering moisture content after exposure to a moist environment for 9 hours and has met the maximum level permitted in AWS A5.1, *Specification for Carbon Steel Electrodes for Shielded Metal Arc Welding*.

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## 6. Qualification

### 6.1 General

#### 6.1.1 Responsibility

**6.1.1.1** All welding performed to contracts involving AWS D1.4 shall utilize written WPSs that meet the requirements of this code.

**6.1.1.2** Each contractor shall conduct the test required by Section 6 to qualify the WPSs and the welders who will apply these WPSs.

**6.1.1.3** At the Engineer's discretion, evidence of previous qualification of the WPSs and welders to be employed may be accepted.

#### 6.1.2 Welding Procedures

**6.1.2.1** WPS qualification by testing in conformance with 6.2 shall be required for all joint types (see 3.3), except that WPSs for fillet welds shall be considered prequalified and exempt from testing.

**6.1.2.2** Subject to the approval of the Engineer, WPSs meeting the requirements of this code may be used for work being performed under the provisions of previous editions of this code and AWS D12.1.

**6.1.2.3** Each WPS shall be prepared by the contractor. This written WPS shall include, as a minimum, the applicable essential variables of 6.2 and shall be available to those authorized to examine them. A suggested form showing the information required in the WPS specification is given in Annex A.

**6.1.2.4** WPS qualifications performed prior to publication of this edition of the code may be updated to the requirements of this code, provided the variables required by this edition of the code were previously recorded.

#### 6.1.3 Welders

**6.1.3.1** Welders who perform code work shall be qualified in conformance with 6.3 prior to production welding.

**6.1.3.2** Welders who successfully complete a WPS qualification for either complete joint penetration groove

welds or flare-groove welds shall be considered qualified for welding the type of weld joint used in the WPS qualification and other joint types as permitted in 6.3.3.1. The position of welding may be changed to the extent permitted by 6.3.4.

**6.1.3.3** Subject to the approval of the Engineer, welders who qualify to the requirements of this edition of the code may be used for work being performed under provisions of previous editions of this code.

### 6.2 WPS Qualification

#### 6.2.1 Limitation of Variables

**6.2.1.1** The largest bar size to be production welded shall be used for qualification. Qualification for each specification and grade of reinforcing bar is not required.

**6.2.1.2** WPS qualification shall be performed using a steel that has a carbon equivalent (C.E.) at least equal to the highest C.E. to be encountered in production. The WPS is then qualified for the highest C.E. value qualified and all lower values.

**6.2.1.3** A change from uncoated bars or steel to coated bars or steel where the coating lies within 2 in. [50 mm] of weld joint preparation, or any greater distance required to prevent coating from melting and contaminating the weld metal shall require requalification. (The 2 in. limit should keep any coating from melting and contaminating the weld where the bars are in the vertical plane.)

**6.2.1.4** Any changes beyond the essential variable limitations of Table 6.1 shall require WPS requalification.

**6.2.2 Types of Tests and Their Purposes.** The following tests are to determine the tensile strength and degree of soundness of welded joints made under a given WPS specification:

1. Full section tension test (for tensile strength)
2. Macroetch test (for soundness)

### 6.2.3 Position of Test Welds

The position of production welds may be determined from Figure 6.3 (groove) and Figure 6.4 (fillet.) The test positions are defined in Figures 6.1 and 6.2. A WPS shall be required for each production welding position.

### 6.2.4 Test Assemblies Number, Type, and Preparation

**6.2.4.1 Number and Type of Test Assemblies.** The number and type of assemblies that shall be tested to qualify a WPS are shown in Table 6.2.

**6.2.4.2 Test assemblies for groove welds in T-joints** may be either direct butt joints having the same groove configuration as the T-joint to be used in construction, or the T-joint assembly shown in Figure 6.5(B).

**6.2.4.3 Tension Test Assemblies.** The size and length of tension test assemblies shall be as follows:

1. *Direct Butt Joint and T-Joint.* Unless a greater length is required for testing, welded test assemblies for direct butt joints shall have a minimum length of at least 16 times the diameter of the bar, with the weld located centrally [see Figures 6.5(A) and 6.5(B), as appropriate].

2. *Indirect Butt Joint.* For indirect butt joint welded test assemblies, the minimum length in No. 1 above shall be increased by the length of the joint [see Figures 6.5(C) and 6.5 (D)]. The length of the connecting welds shall be such that the total shear capacity is equal to 0.6 times the minimum specified tensile strength times the nominal area of the solid bar. Note that for two bars of unequal tensile strengths, the lesser of the two values shall be used.

**6.2.4.4 Macroetch Specimens.** Macroetch test specimens shall be prepared as follows:

1. *Direct Butt Joints and T-Joints.* The test assembly shall be mechanically cut at one location transverse to the direction of welding. The test specimen shall show the full longitudinal cross section of the weld, the root of the weld, and any reinforcement. [See Figures 6.5(A) or 6.5(B).]

2. *Indirect Butt Joints.* Each test assembly shall be mechanically cut at one location to provide a transverse cross section of each welded assembly. [See Figures 6.5(C) and 6.5(D).]

### 6.2.5 Method of Testing Specimens

**6.2.5.1 Full Section Tension Test.** The minimum distance between the jaws of the testing machine shall be equal to the following:

- At least eight times the diameter of the bars for direct butt joints
- At least eight times the diameter of the bar, plus the length of the joint, for indirect butt joints

The test specimen shall be ruptured under tension load, and the maximum load shall be determined. The

tensile strength shall be obtained by dividing the maximum load by the nominal cross-sectional area of the bar.

**6.2.5.2 Macroetch Test.** All cross sections shall be polished and etched with a suitable solution to give a clear definition of the weld.

### 6.2.6 Test Results Required

**6.2.6.1 Full Section Tension Test.** The tensile strength shall be no less than 125% of the minimum specified yield strength of the type and grade of bars to be joined, unless otherwise stipulated by the general specification.

**6.2.6.2 Macroetch Test.** The specimen shall be examined for discontinuities, and any that have discontinuities prohibited by 4.4 shall be considered as failed. The etched cross sections shall have complete penetration with the base metal for single-V- or double-V-groove welds. For flare-bevel- and flare-V-groove welds, the designated weld size shall be obtained.

## 6.3 Welder Qualification

**6.3.1** The qualification test described here are especially devised to determine the welder's ability to produce sound welds. It is not intended that the qualification tests be used as a guide for welding during actual construction. The latter shall be performed in accordance with the requirements of the WPS.

### 6.3.2 Limitation of Variables

**6.3.2.1 Qualification with a particular process and with any of the steels permitted by this code** shall be considered as qualification to weld any of the other approved steels with that process except that qualification for galvanized steel shall be performed using galvanized steel.

**6.3.2.2 Qualified Bar Sizes.** The smallest bar size used in qualification shall qualify the welder for welding that bar size and any larger size.

**6.3.2.3 Base Metal.** The base metal used shall comply with 1.3.1 or the WPS. The base metal may be uncoated or galvanized, as required by 6.3.2.1.

**6.3.2.4** A welder qualified with an approved electrode and shielding medium combination shall be considered qualified to weld with any other approved electrode and shielding medium combination (see Table 5.1) for the process used in the qualification test.

**6.3.2.5** A change in the position of welding to one for which the welder is not qualified requires qualification in that position.

### 6.3.3 Qualification Tests Required

**6.3.3.1** Qualification tests for welders shall be as follows:

1. Direct butt joint groove weld test made using SMAW, GMAW, or FCAW processes qualifies for complete joint penetration groove welds and for fillet welds.

2. Indirect butt joint flare-groove weld test made using SMAW, GMAW, or FCAW processes. This test qualifies welders for welding indirect butt joints, lap joints, and for fillet welds.

3. Complete joint penetration groove weld T-joint made using SMAW, GMAW, or FCAW processes qualifies welders for welding complete joint penetration groove welds (both direct butt joints and T-joints) and fillet welds.

4. Fillet weld tests made using SMAW, GMAW, or FCAW processes qualifies for external fillet welds as shown in Figure 3.5(A) and Figure 3.5(B).

**6.3.3.2** The qualification test assembly shall have joint details as follows:

1. The direct butt joint groove weld test assembly shall be a complete joint penetration groove weld made by SMAW, GMAW, or FCAW processes. See Figure 6.6(A). The smallest bar size to be fabricated shall be used.

2. The indirect butt joint flare-groove weld test shall be an indirect butt joint made by SMAW, GMAW, or FCAW processes using a double-flare-bevel-groove and flat bar, as shown in Figure 6.6(B).

3. The complete joint penetration T-joint made by SMAW, GMAW, or FCAW processes shall be as shown in Figure 6.6(C).

4. The fillet weld bend test shall be a bar welded to a plate, see Figure 6.6(D). The welder shall be qualified with the smallest bar size to be used in construction. The bar shall be welded to a plate with the minimum size single pass fillet weld to be used in construction.

## **6.3.4 Position of Test Welds and Related Validity of Qualification**

### **6.3.4.1 Direct Butt Joint Groove Weld Test**

1. Qualification in the 1G (flat) position qualifies for direct butt joints in the 1G flat position, and for fillet welds in the 1F (flat) and 2F (horizontal) positions (see Figure 6.1).

2. Qualification in the 2G (horizontal) position qualifies for direct butt joints in the 1G (flat) and 2G (horizontal) positions and for fillet welds in 1F (flat) and 2F (horizontal) positions (see Figure 6.1).

3. Qualification in the 3G (vertical) position qualifies for direct butt joints in the 1G (flat), 2G (horizontal), and 3G (vertical) positions; and for fillet welds in the 1F (flat), 2F (horizontal), and 3F (vertical) positions (see Figure 6.1).

4. Qualification in the 4G (overhead) position qualifies for direct butt joints in the 1G (flat) and 4G (over-

head) positions and for fillet welds in 1F (flat), 2F (horizontal), and 4F (overhead) positions (see Figure 6.1).

### **6.3.4.2 Indirect Butt Joint Flare-Groove Weld Test**

1. Qualification in the 1G (flat) position qualifies for indirect butt joints and lap joints in the 1G (flat) position, and for fillet welds in 1F (flat), and 2F (horizontal) positions (see Figure 6.2).

2. Qualification in the 2G (horizontal) position qualifies for indirect butt joints and lap joints in the 1G (flat) and 2G (horizontal) positions and for fillet welds in 1F (flat), and 2F (horizontal) positions (see Figure 6.2).

3. Qualification in the 3G (vertical) position qualifies for indirect butt joints and lap joints in the 1G (flat), 2G (horizontal), and 3G (vertical) positions and for fillet welds in the 1F (flat), 2F (horizontal), and 3F (vertical) positions (see Figure 6.2).

4. Qualification in the 4G (overhead) position qualifies for indirect butt joints and lap joints in the 1G (flat) and 4G (overhead) positions and for fillet welds in 1F (flat), 2F (horizontal), and 4F (overhead) positions (see Figure 6.2).

**6.3.4.3 T-Joint Groove Weld Test.** The position requirements for groove welds shall govern the weld position qualified by the welder (see Figure 6.1).

**6.3.4.4 Fillet Weld Test.** The welder shall be qualified for the position tested (see Figure 6.4).

## **6.3.5 Test Specimens—Number, Type, and Preparation**

**6.3.5.1** The number and type of test assemblies that shall be tested to qualify a welder are shown in Table 6.3. Two test assemblies welded in accordance with 6.3.3.3 are required to qualify welders.

**6.3.5.2 Direct Butt Joints.** Direct butt joint welded test assemblies made by GMAW (except short circuiting transfer), SMAW, or FCAW, shall be tested by radiography, or one test assembly shall be subjected to the full section tension test and the other test assembly to the macroetch test. Radiography shall not be used on joints where split pipe backing is used.

**6.3.5.3 Direct Butt Joints By GMAW-S.** Direct butt joint welded test assemblies made by GMAW using short circuiting transfer shall have one test assembly subjected to the full section tension test and the other to the macroetch test.

**6.3.5.4 Indirect Butt Joints.** Both indirect butt joint welded test assemblies shall be subjected to the macroetch test.

**6.3.5.5 T-Joint Test Assembly.** The two welded T-joint test assemblies shall both be subjected to the macroetch test.

**6.3.5.6 Tension Test Specimens.** Unless a greater length is required for testing, the full section tension test specimen for direct butt joints shall have a minimum length of at least 16 times the diameter for the bar with the weld centrally located [see Figure 6.6(A)].

**6.3.5.7 Tension Test Specimen With Split Pipe Backing.** The split pipe backing need not be removed for tension testing.

**6.3.5.8 Macroetch Test Specimens.** Macroetch test specimens shall be prepared as follows (see Figure 6.6):

1. *Direct Butt and T-Joints.* The test assembly shall be mechanically cut at one location transverse to the direction of welding. The test specimen shall show the full longitudinal cross section of the weld, the root of the weld, and any reinforcement [see Figures 6.6(A) and 6.6(B)].

2. *Indirect Butt Joint.* Each test assembly shall be cut mechanically at one location to provide a transverse cross section of each welded assembly [see Figures 6.6(C) and 6.6(D)].

**6.3.5.9 Fillet Weld Test.** Test welds shall meet the visual quality requirements of 4.4.1 through 4.4.7. Two welded assemblies shall be subjected to bend testing, see 6.3.6.3.

## 6.3.6 Method of Testing Specimens

**6.3.6.1 Full-Section Tension Test.** The minimum distance between jaws of the testing machine shall be equal to at least eight times the diameter of the bar for direct butt joints. The test specimen shall be ruptured under tensile load, and the maximum load shall be determined. The tensile strength shall be obtained by dividing the maximum load by the nominal cross-sectional area of the bar.

**6.3.6.2 Macroetch Test.** All cross sections shall be polished and etched with a suitable solution to give a clear definition of the weld.

**6.3.6.3 Fillet Weld Test.** Testing shall be performed after the bar is allowed to cool to ambient temperature. It shall be bent to an angle not less than 30° from its original axis. Bending may be accomplished by striking the bar with a hammer on the unwelded end or by placing a pipe or other suitable hollow device over the bar and manually or mechanically bending the bar.

## 6.3.7 Test Results Required

**6.3.7.1 Radiographic Test.** For acceptable qualification, the weld as revealed by the radiograph shall conform to the requirements of 4.4.2 and 4.4.8.

**6.3.7.2 Full-Section Tension Test.** The tensile strength shall not be less than 125% of the minimum specified yield strength of the type and grade of bars joined, unless otherwise stipulated by the general specification.

**6.3.7.3 Macroetch Test.** The specimen shall be examined for discontinuities and if any are found that are prohibited by 4.4, it shall be considered as failed. The etched cross section shall show complete fusion for the direct butt joints or the designated effective weld size for the flare groove test assemblies.

**6.3.7.4 Fillet Weld Bend Test.** The bar shall be bent without any separation:

1. Between individual weld passes,
2. At the fusion line between the bar and weld,
3. At the fusion line between the plate and weld,
4. In the heat-affected zone (HAZ).

Separation shall be defined as any length or width that can be seen without magnification. If a separation occurs in either of the fillet welds or heat affected zones of the bar, the test fails. In the event that the failure occurs within the bar, the welder shall be considered qualified.

## 6.4 Retests

In case a welder fails to meet the requirements of one or more test welds, a retest may be allowed under the following conditions:

**6.4.1 Immediate Retest.** An immediate retest may be made consisting of two welds of each type and position that the welder failed. All retest specimens shall meet all of the specified requirements.

**6.4.2 Retest After Further Training or Practice.** A retest may be made, provided there is evidence that the welder has had further training or practice. A complete retest of the types and positions failed shall be made.

## 6.5 Period of Effectiveness

The welder's qualification as specified in this code shall be considered as remaining in effect indefinitely unless (1) the welder is not engaged in a given process of welding for which the welder is qualified for a period exceeding six months, or unless (2) there is some specific reason to question a welder's ability.

## 6.6 Records

Records of the test results shall be kept by the manufacturer or contractor and shall be available to those authorized to examine them.

**Table 6.1**  
**PQR Essential Variable Changes Requiring WPS Requalification**  
**for SMAW, GMAW, and FCAW (see 6.2.1.4)**

| Essential Variable Changes to PQR Requiring Requalification                                                                                                                                                                                                                                           | Process <sup>a</sup>                             |                              |                              |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------|------------------------------|------------------------------|
|                                                                                                                                                                                                                                                                                                       | SMAW                                             | GMAW                         | FCAW                         |
| <b>Electrode</b>                                                                                                                                                                                                                                                                                      |                                                  |                              |                              |
| (1) Increase in filler metal classification strength, e.g., a change from E70XX to E80XX-X, but not vice versa                                                                                                                                                                                        | X                                                | X                            | X                            |
| (2) A change to an electrode or method of shielding not covered in:                                                                                                                                                                                                                                   | AWS A5.1<br>or A5.5                              | AWS A5.18<br>or A5.28        | AWS A5.20<br>or A5.29        |
| (3) A change in electrode diameter by:                                                                                                                                                                                                                                                                | Any increase                                     | Any increase<br>or decrease  | Any increase                 |
| <b>Electrical Parameters</b>                                                                                                                                                                                                                                                                          |                                                  |                              |                              |
| (4) A change in the amperage for each electrode diameter by:                                                                                                                                                                                                                                          | To a value not<br>recommended by<br>manufacturer | >10% increase<br>or decrease | >10% increase<br>or decrease |
| (5) A change in the voltage for each electrode diameter by:                                                                                                                                                                                                                                           | To a value not<br>recommended by<br>manufacturer | >7% increase<br>or decrease  | >7% increase<br>or decrease  |
| (6) A change in type of current (ac or dc), polarity or mode of transfer (GMAW only)                                                                                                                                                                                                                  |                                                  | X                            | X                            |
| (7) A change in the travel speed by:                                                                                                                                                                                                                                                                  |                                                  | >10% increase<br>or decrease | >10% increase<br>or decrease |
| <b>Shielding Gas</b>                                                                                                                                                                                                                                                                                  |                                                  |                              |                              |
| (8) An increase in shielding gas flow rate by 25% or more or a decrease of 25% or more                                                                                                                                                                                                                |                                                  | X                            | X                            |
| (9) A change in shielding gas from a single gas to any other single gas or mixture of gas, or a change of more than 25% in any minor elements of the mixture, or change from a gas mixture to a single gas, or change from external shielding gas to self-shielding (i.e., no external shielding gas) |                                                  | X                            | X                            |
| <b>General</b>                                                                                                                                                                                                                                                                                        |                                                  |                              |                              |
| (10) A change in position not qualified per 6.2.4                                                                                                                                                                                                                                                     | X                                                | X                            | X                            |
| (11) A change in groove type (e.g., flare-V to flare-bevel groove)                                                                                                                                                                                                                                    | X                                                | X                            | X                            |
| (12) A change in the shape or any one type of groove involving:<br>(a) A decrease in the groove angle exceeding 5°<br>(b) A decrease in the root opening exceeding 1/16 in. [1.6 mm]<br>(c) An increase in the root face exceeding 1/16 in. [1.6 mm]                                                  | X                                                | X                            | X                            |
| (13) The omission, but not inclusion, of backing material                                                                                                                                                                                                                                             | X                                                | X                            | X                            |

<sup>a</sup> An "X" indicates applicability for the process; a shaded area indicates non-applicability.

**Table 6.2**  
**Number and Type of Tests for WPS Qualification (see 6.2.4.1)**

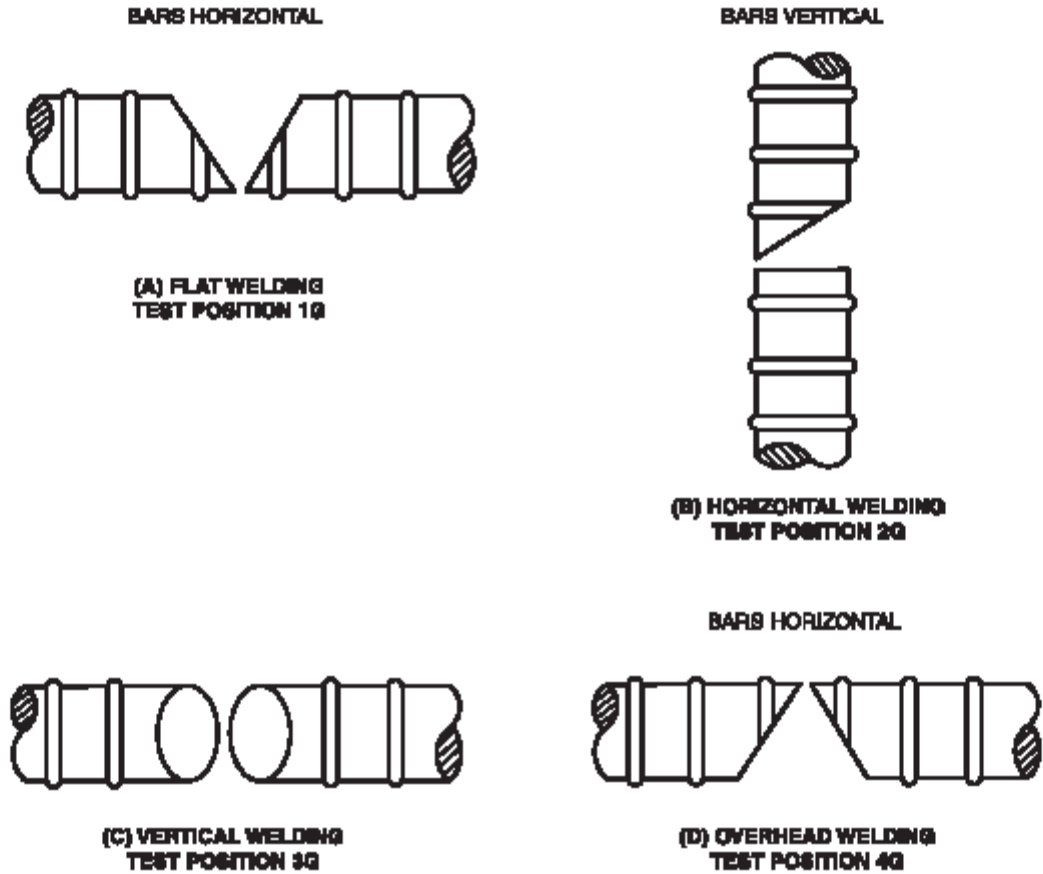
| Production<br>Type of Joint [Figure] | Minimum Number<br>of Test Assemblies | Tension Tests<br>(6.2.4.3) | Macroetch Tests<br>(6.2.4.4) | Joints Qualified<br>per Figure: |
|--------------------------------------|--------------------------------------|----------------------------|------------------------------|---------------------------------|
| Direct butt [6.5(A)]                 | 2                                    | 2                          | 2                            | 3.1, 3.2, 3.5(D)                |
| T-Joint [6.5(B)]                     | 2                                    | 2                          | 2                            | 3.1, 3.5(D)                     |
| Indirect butt [6.5(C)]               | 2                                    | 2                          | 2                            | 3.3(A), (B), 3.4, 3.5(E)        |
| Indirect butt [6.5(D)]               | 2                                    | 2                          | 2                            | 3.3(C)                          |

**Table 6.3**  
**Welder Qualification—Number, Types of Test, Production Welds, and Positions Qualified (see 6.3)**

| Qualification Test           |               | Number and Type of Tests Required  |                       |                    | Production Welding Joint and Position Qualified |                     |               |                                                                                                                                                               |
|------------------------------|---------------|------------------------------------|-----------------------|--------------------|-------------------------------------------------|---------------------|---------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Test Type                    | Test Assembly | Number of Test Assemblies Required | Radiography (6.3.5.2) | Tension (6.3.5.3.) | Macroetch (6.3.5.4)                             | Bend Test (6.3.5.9) | Test Position | Production Welding Joint and Position Qualified                                                                                                               |
|                              |               |                                    |                       |                    |                                                 |                     |               | Direct Butt and T-Joint [Figure 3.1, 3.2, 3.5(D)]<br>Fillet Joint [Figure 3.5(A), (B), and (C)]<br>Indirect Butt Joint (Figure 3.3)<br>Lap Joint (Figure 3.4) |
| Direct Butt                  | Figure 6.6(A) | 2                                  | 2 <sup>a</sup>        | 1 <sup>b</sup>     | 1 <sup>b</sup>                                  | —                   | 1G            | F, H                                                                                                                                                          |
|                              |               |                                    |                       |                    |                                                 |                     | 2G            | F, H                                                                                                                                                          |
|                              |               |                                    |                       |                    |                                                 |                     | 3G            | F, H, V                                                                                                                                                       |
|                              |               |                                    |                       |                    |                                                 |                     | 4G            | F, H, OH                                                                                                                                                      |
| Indirect Butt                | Figure 6.6(B) | 2                                  | —                     | —                  | 2                                               | —                   | 1G            | F, H                                                                                                                                                          |
|                              |               |                                    |                       |                    |                                                 |                     | 2G            | F, H                                                                                                                                                          |
|                              |               |                                    |                       |                    |                                                 |                     | 3G            | F, H, V                                                                                                                                                       |
|                              |               |                                    |                       |                    |                                                 |                     | 4G            | F, H, OH                                                                                                                                                      |
| T-Joint Complete Penetration | Figure 6.6(C) | 2                                  | —                     | —                  | 2                                               | —                   | 1G            | F, H                                                                                                                                                          |
|                              |               |                                    |                       |                    |                                                 |                     | 2G            | F, H                                                                                                                                                          |
|                              |               |                                    |                       |                    |                                                 |                     | 3G            | F, H, V                                                                                                                                                       |
|                              |               |                                    |                       |                    |                                                 |                     | 4G            | F, H, OH                                                                                                                                                      |
| Fillet Weld                  | Figure 6.6(D) | 2                                  | —                     | —                  | —                                               | 2                   | 1F (Rotated)  | F                                                                                                                                                             |
|                              |               |                                    |                       |                    |                                                 |                     | 2F            | F, H                                                                                                                                                          |
|                              |               |                                    |                       |                    |                                                 |                     | 2F (Rotated)  | F, H                                                                                                                                                          |
|                              |               |                                    |                       |                    |                                                 |                     | 4F            | F, H, OH                                                                                                                                                      |
|                              |               |                                    |                       |                    |                                                 |                     | 5F            | All                                                                                                                                                           |

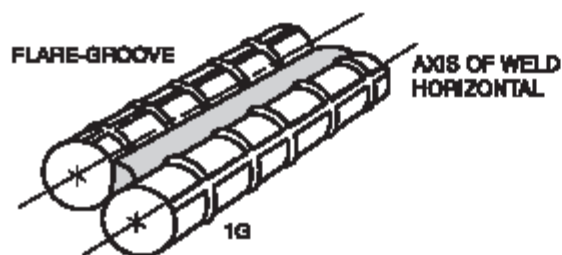
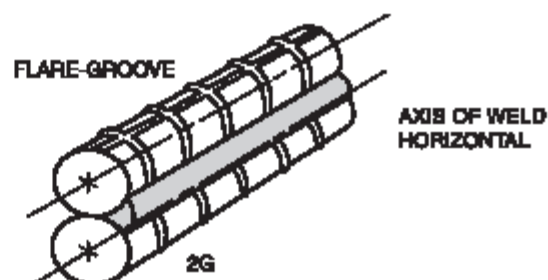
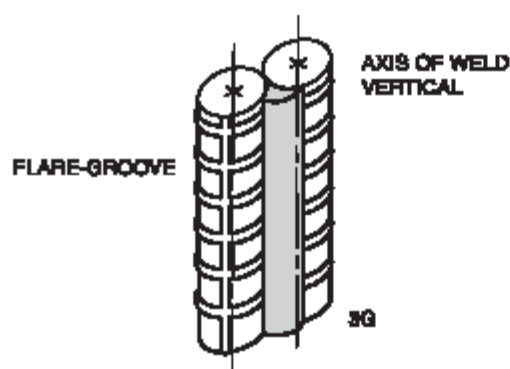
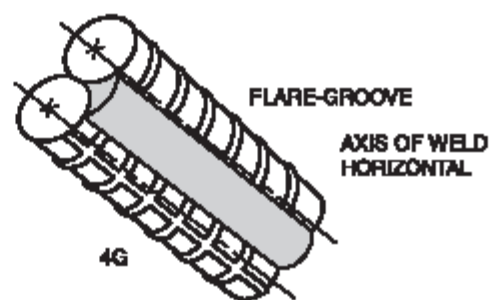
<sup>a</sup> Radiography not permitted for welds made by GMAW short circuiting transfer.

<sup>b</sup> Required for welds made by GMAW using short circuiting transfer. Tension and macroetch tests may be used in lieu of radiography for all other welding processes, at the Contractor's option.



Note: See Figure 6.3 for definition of positions for groove welds.

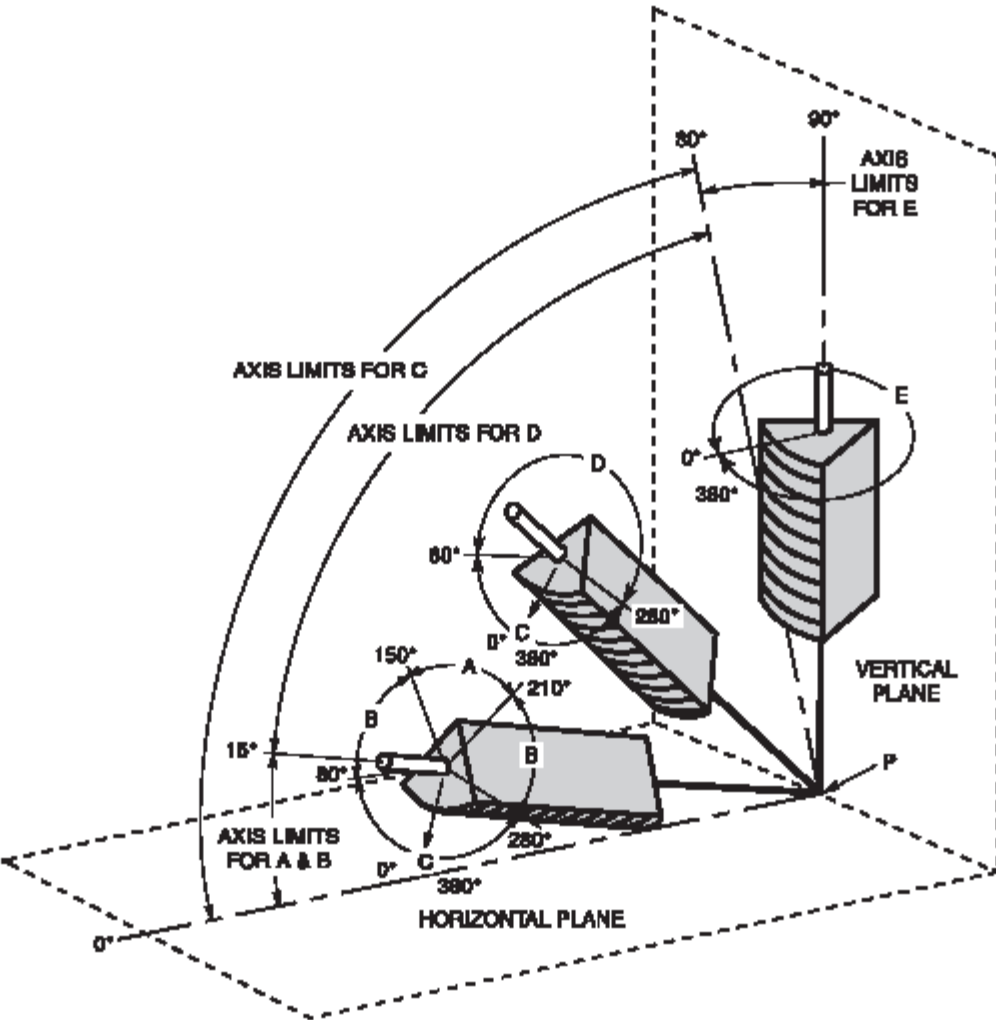
Figure 6.1—Direct Butt Joint Test Positions for Groove Welds (see 6.2.3)

**(A) TEST POSITION : FLAT****(B) TEST POSITION : HORIZONTAL****(C) TEST POSITION : VERTICAL****(D) TEST POSITION : OVERHEAD**

Note: See Figures 6.3 and 6.4 for definitions of positions for flare-groove and fillet welds.

**Figure 6.2—Indirect Butt Joint Test Positions for  
Flare-Groove Welds or Fillet Welds (see 6.2.3)**

| Tabulation of Positions of Groove Welds |                   |                     |                             |
|-----------------------------------------|-------------------|---------------------|-----------------------------|
| Position                                | Diagram Reference | Inclination of Axis | Rotation of Face            |
| Flat                                    | A                 | 0° to 15°           | 150° to 210°                |
| Horizontal                              | B                 | 0° to 15°           | 80° to 150°<br>210° to 280° |
| Overhead                                | C                 | 0° to 80°           | 0° to 80°<br>280° to 360°   |
| Vertical                                | D                 | 15° to 80°          | 80° to 280°                 |
| Vertical                                | E                 | 80° to 90°          | 0° to 360°                  |



- Notes:
1. The horizontal reference plane is always taken to lie below the weld under consideration.
  2. The inclination of axis is measured from the horizontal reference plane toward the vertical reference plane.
  3. The angle of rotation of the face is determined by a line perpendicular to the theoretical face of the weld which passes through the axis of the weld. The reference position (0°) of rotation of the face invariably points in the direction opposite to that in which the axis angle increases. When looking at point P, the angle of rotation of the face of the weld is measured in a clockwise direction from the reference position (0°).

Figure 6.3—Positions of Groove Welds (see 6.2.3)

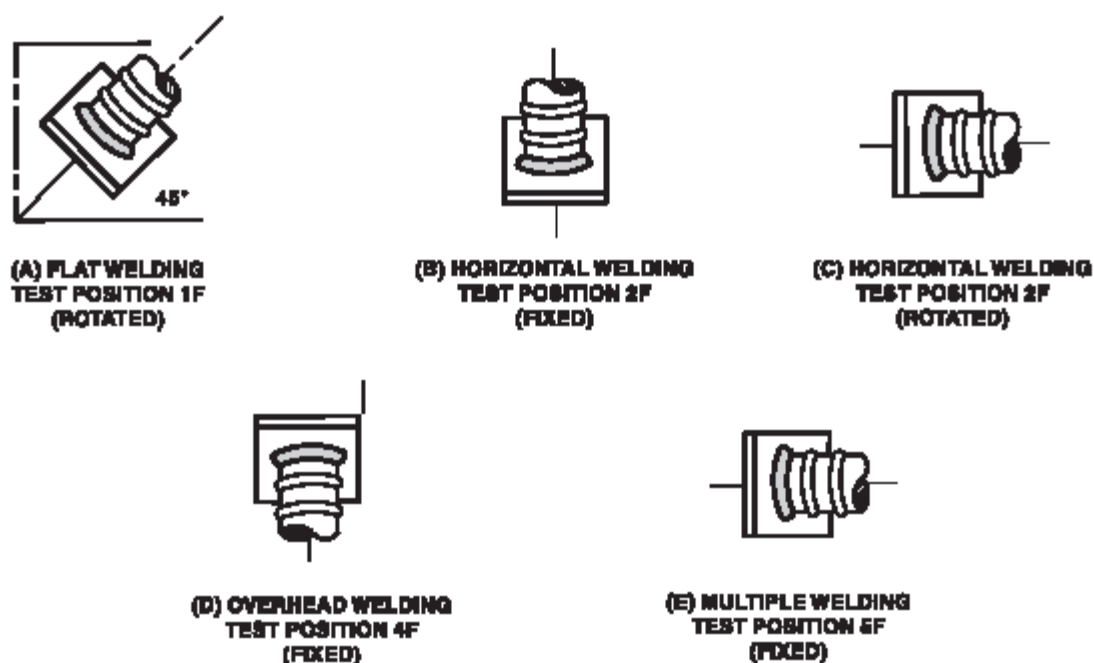


Figure 6.4—Positions of Fillet Welds (see 6.2.3)

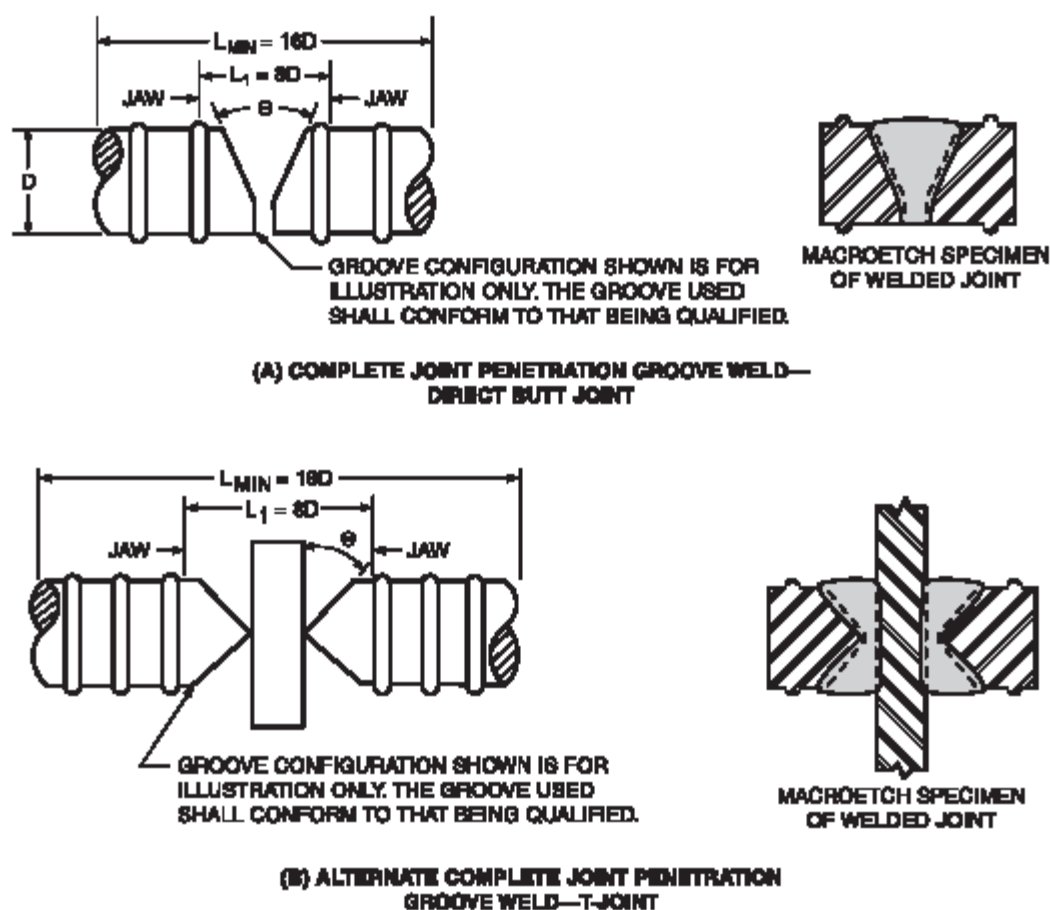


Figure 6.5—Full Section Tension Test Specimens for WPS Qualification Tests (see 6.2.4.2)

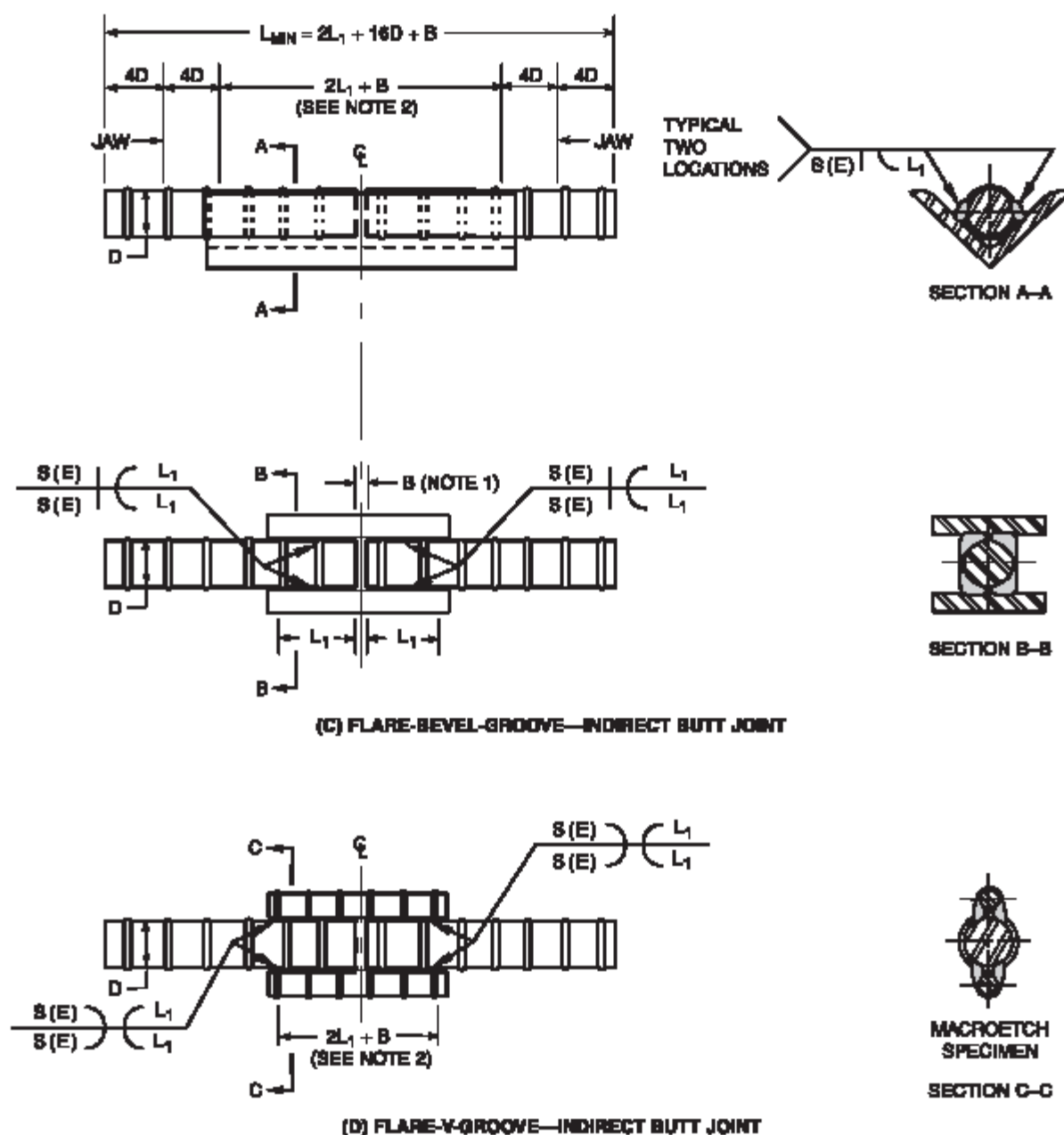
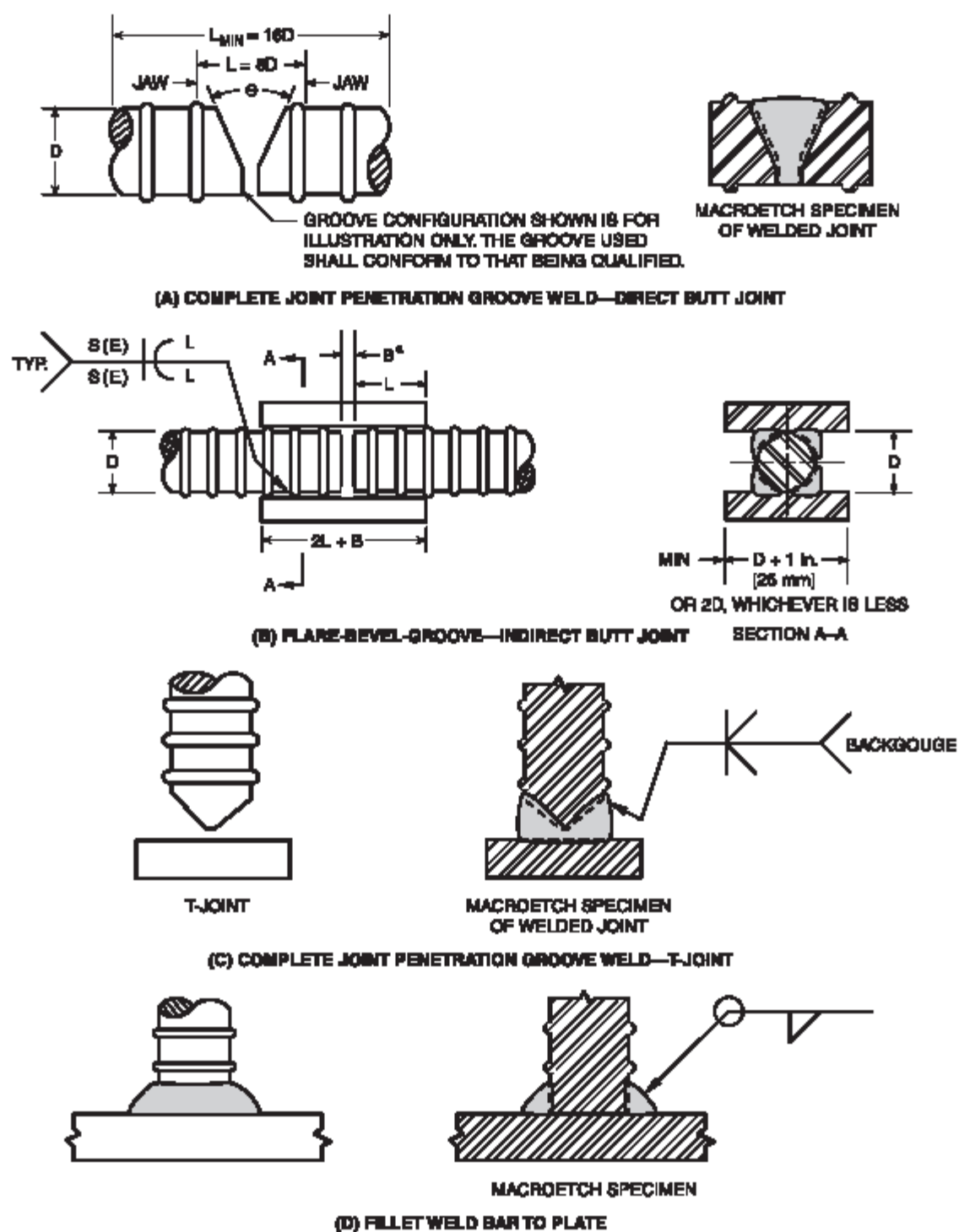


Figure 6.5 (Continued)—Full Section Tension Test Specimens  
for WPS Qualification Tests (see 6.2.4.2)



\*B = Separation between ends of bars. Maximum:  $B = 3/4$  in. [19 mm].

**Notes:**

1. For Bars No. 9 [29] or larger, use single-V or single-bevel-groove welds ( $\theta = 45^\circ$ ).
2. For Bars No. 8 [25] or smaller, use single-V with split pipe backing, ( $\theta = 60^\circ$ , as in Figure 3.2(C)).

**Figure 6.6—Full Section Tension Test and Macroetch Test Specimens for Welder Qualification Tests (see 6.3.3.3)**

## 7. Inspection

### 7.1 General Requirements

**7.1.1** The inspector shall ascertain that all fabrication by welding is performed in accordance with the requirements of this code.

**7.1.2** Inspectors responsible for acceptance or rejection of material and workmanship shall be qualified. The basis of Inspector qualification shall be documented. If the Engineer elects to specify the basis of inspector qualification, it shall be so stated in contract documents.

The following are acceptable qualification bases:

1. Current or previous certification as an AWS Certified Welding Inspector (CWI) in accordance with the provisions of AWS QC1, *Standard for AWS Certification of Welding Inspectors*

2. Current or previous qualification by the Canadian Welding Bureau (CWB) to the requirements of the Canadian Standard Association (CSA) Standard W178.2, *Certification of Welding Inspectors*

3. An Engineer or technician who, by training, or experience, or both, in metals fabrication, inspection and testing, is competent to perform inspection of the work

**7.1.3** The Inspector shall be furnished with complete detail drawings showing the size, length, type, and location of all welds to be made.

**7.1.4** The Inspector shall be notified, in advance, of the start of any welding operations.

### 7.2 Inspection of Base Metals

The inspector shall make certain that only base metals are used that conform to the requirements of this code.

### 7.3 Inspection of WPS Qualification and Equipment

The Inspector shall verify the welding and subsequent testing of any WPS qualification specimens that are required. The Inspector shall inspect the welding equipment to be used for the work to make certain that it is in

such condition as to enable qualified welders to apply qualified WPSs and attain results prescribed elsewhere in this code.

### 7.4 Inspection of Welder Qualifications

**7.4.1** The Inspector shall permit welding to be performed only by welders who are qualified in accordance with the requirements of this code. The Inspector shall witness the welding and testing of qualification specimens for each welder, or shall make certain that each welder has previously demonstrated those qualifications under other acceptable supervision.

**7.4.2** When the quality of the welder's work appears to be below the requirements of this code, the Inspector may require testing of a welder's qualification by means of partial or complete requalification in accordance with 6.3.

### 7.5 Inspection of Work and Records

**7.5.1** The Inspector shall verify that the size, length, and location of all welds conform to the requirements of this code and to the detail drawings, that no specified welds are omitted, and that no unspecified welds have been added without approval.

**7.5.2** The Inspector shall verify that the WPSs used meet the provisions of this code.

**7.5.3** The Inspector shall verify that welders have copies of, or access to, the WPSs, and that the welding is performed in conformance with the WPS and code requirements.

**7.5.4** The Inspector shall, at suitable intervals, observe the technique and performance of each welder to verify that the applicable requirements of this code are met.

**7.5.5** The Inspector shall examine the work to verify that it meets the requirements of this code. Size and length of welds shall be measured with suitable gages. Visual

inspection for cracks and other discontinuities in the welds and base metal should be aided by a strong light, magnifiers, or other helpful devices as necessary.

**7.5.6** Inspectors shall identify with a distinguishing mark or other recording methods all parts or joints that they have inspected and accepted. Any recording method which is mutually agreeable may be used. Die stamping of dynamically loaded members is not permitted without the approval of the Engineer.

**7.5.7** The Inspector shall keep a record of qualifications of all welders, all WPS qualifications or other tests that are made, and other such information as may be required.

## 7.6 Obligations of the Contractor

**7.6.1** The contractor shall be responsible for visual inspection and necessary correction of all deficiencies in materials and workmanship in accordance with the requirements of Sections 3 and 4, and 4.4 or other parts of the code, as applicable.

**7.6.2** The contractor shall comply with all requests of the Inspector(s) to correct deficiencies in materials and workmanship as provided in the contract documents.

**7.6.3** In the event that faulty welding or its removal for rewelding damages the base metal so that in the judgment of the Engineer its retention is not in accordance with the intent of the contract documents, the contractor shall remove and replace the damaged base metal or shall compensate for the deficiency in a manner approved by the Engineer.

**7.6.4** When nondestructive testing other than visual inspection is specified in the information furnished to bidders, it shall be the contractor's responsibility to ensure that all specified welds meet the quality requirement or 4.4.

**7.6.5** If nondestructive testing other than visual inspection is not specified in the original contract agreement but is subsequently requested by the owner, the contractor shall perform any requested testing or shall permit any testing to be performed in accordance with 7.7. The owner shall be responsible for all associated costs including handling, surface preparation, nondestructive testing, and repair of discontinuities other than those listed in 4.4.1 to 4.4.7 inclusive, at rates mutually agreeable between owner and contractor. However, if such testing should disclose an attempt to defraud or gross nonconformance to this code, repair work shall be done at the contractor's expense.

## 7.7 Nondestructive Testing

**7.7.1** When nondestructive testing other than visual is required, it shall be so stated in the information furnished to the bidders. This information shall designate the welds to be examined, the extent of the examination of each weld, and method of testing.

**7.7.2** Welds tested nondestructively that do not meet the requirements of this code shall be repaired using the applicable provisions of this code.

**7.7.3** When radiographic testing is used, the procedure and technique shall be in accordance with 7.9.

**7.7.4** When magnetic particle testing is used, the procedure and technique shall be in accordance with ASTM E 709, *Standard Guide for Magnetic Particle Examination*, and the standard of acceptance shall be in accordance with 4.4 of this code.

**7.7.5** For detecting discontinuities that are open to the surface, liquid penetrant inspection may be used. The standard methods set forth in ASTM E 165, *Standard Test Method for Liquid Penetrant Inspection*, shall be used for liquid penetrant inspection, and the standards of acceptance shall be in accordance with 4.4 of this code.

**7.7.6** Ultrasonic inspection of direct butt joints in deformed reinforcing bars is not considered feasible except by highly specialized techniques and is not recommended.

## 7.8 Personnel Qualification

**7.8.1** Personnel performing nondestructive testing other than visual shall be qualified in accordance with the current edition of the American Society for Nondestructive Testing's *Recommended Practice No. SNT-TC-1A*. Only individuals qualified for NDT Level I and working under the NDT Level II or individuals qualified for NDT Level II may perform nondestructive testing.

**7.8.2** Certification of Level I and Level II individuals shall be performed by a Level III individual who has been certified by (1) The American Society for Nondestructive Testing, or (2) has the education, training, experience, and has successfully passed the written examination prescribed in SNT-TC-1A.

## 7.9 Radiographic Testing

### 7.9.1 Radiographic Testing of Direct Butt Joints

**7.9.1.1 Procedures and Standards.** The procedures and standards set forth in this code are to govern radiographic testing of welds when such inspection is required by the contract documents as provided in 7.6. The requirements listed herein are specifically for testing groove welds in direct butt joints in reinforcing steel bars by X-ray or gamma-ray sources. The methodology shall conform to ASTM E 94, *Standard Guide for Radiographic Testing*, and ASTM E 1032, *Standard Test Method for Radiographic Examination of Weldments*. *Note: Inspection of flare-V- and flare-bevel-groove welds or fillet welds by radiographic testing method is, in general, not considered feasible, except by highly specialized techniques, and is not recommended.*

**7.9.1.2 Weld Quality.** Prior to radiographic testing, welds shall meet the visual criteria described in 4.4. When radiographic testing of direct butt joints is required, the maximum dimension of any single porosity or fusion-type discontinuity, or the sum of the maximum dimensions of all porosity and fusion-type discontinuities, shall not exceed the limits given in Table 4.1. Welds tested nondestructively that do not meet the requirements of this code shall be repaired using the applicable provisions of this code.

**7.9.1.3 Variations.** Variations in testing procedures, equipment, and acceptance standards may be used with approval of the Engineer. Such variations include, but are not limited to, the following. Changes in source-to-film distance; unusual application of film; unusual hole-type image quality indicators (IQI) applications (including film side IQI); film types, densities, and variations in exposure, development, and viewing techniques.

### 7.9.2 Radiographic Procedures

**7.9.2.1 Procedure.** Radiographs shall be made using a single source of either X-ray or gamma-ray radiation. The radiographic sensitivity shall be judged based on hole-type image quality indicators (IQI). Radiographic technique and equipment shall provide sufficient sensitivity to clearly delineate the required hole type IQIs and the essential holes as described in IQI Selection and Placement, Table 7.1 and Figure 7.1. Identifying letters and numbers shall show clearly in the radiograph.

**7.9.2.2 Safety Requirements.** Radiography shall be performed in accordance with all applicable safety requirements.

**7.9.2.3 Weld Reinforcement.** Weld reinforcement shall not exceed 1/8 in. [3 mm]. Weld surfaces need not be ground or otherwise smoothed for purposes of radio-

graphic testing unless surface irregularities or the junction between weld and base metal exist that may cause weld discontinuities to be obscured in the radiograph.

**7.9.2.4 Tabs.** Weld tabs shall be removed prior to radiographic inspection.

**7.9.2.5 Steel Backing.** When required by the contract documents, steel backing shall be removed, and the surface shall be finished flush by grinding prior to radiography.

**7.9.2.6 Reinforcement.** When weld reinforcement or backing, or both, is not removed, steel shims which extend at least 1/8 in. [3 mm] beyond three sides of the required IQI shall be placed under the hole type IQI. The total thickness of steel between the IQI and the film is approximately equal to the average thickness of the weld measured through its reinforcement and backing.

**7.9.2.7 Radiographic Film.** Radiographic film shall be as described in ASTM E 94. Lead foil screens shall be used as described in ASTM E 94. Fluorescent screens shall not be permitted.

**7.9.2.8 Technique.** Radiographs shall be made with a single source of radiation centered as near as practicable with respect to the centerline of the weld and width of the bar. The source shall be positioned so that the inspecting radiation passes through the plane of the weld at an angle normal to the long axis of the bar. No inspecting radiation shall penetrate any portion of the weld represented in the radiograph at an angle greater than 26-1/2° from a line normal to the weld surface. See Figure 7.1 for source position.

**7.9.2.9 Two Direction Radiography.** Two exposures shall be made for each direct butt joint tested. The first exposure shall be made with the radiation source placed at zero degrees from the top of the weld and exactly perpendicular to the weld root or backing bar and identified with a lead station mark of "0." The second exposure shall be at 90 degrees to the "0" station mark and shall be identified with a lead station mark "90." When obstructions prevent an exact 90-degree placement of the radiation source, for the second exposure, the source may be rotated around the centerline of the reinforcing bar weld  $\pm 35$  degrees from 90°, and identified with a lead station mark appropriate to the location. Deviation from 0° and 90° positions shall require approval of the Engineer.

**7.9.2.10 Backing Bar Width.** The width of the backing bar shall not project beyond the diameter of the reinforcing bar in order to facilitate the perpendicular placement of the film in relation to the source of the 90-degree exposure.

**7.9.2.11 Backing Bar Length.** The length of the backing bar shall be sufficient to extend past the radiographic area of interest and allow for placement of the IQI within the radiographic image of the backing bar.

**7.9.2.12 Film Placement.** The radiographic film shall be placed perpendicular to the radiation source at all times and in contact with the bar. The film shall be placed at the root of the joint for the zero degree exposure. See Figure 7.2 for film placement.

**7.9.2.13 Geometric Unsharpness.** Gamma ray sources, regardless of size, shall be capable of meeting the geometric unsharpness limitation of ASME *Boiler and Pressure Vessel Code*, Section V, Article 2, regardless of the size of the reinforcing bar.

**7.9.2.14 Source-to-Subject Distance.** The source-to-subject distance shall be maintained so as to not violate the maximum geometric unsharpness criteria of 0.020, at all times, as specified in ASME *Boiler and Pressure Vessel Code*, Section V, Article 2. The source-to-subject distance shall not be less than seven times the thickness of weld plus reinforcement and backing, if any.

**7.9.2.15 Sources.** X-ray units, 600 kVp maximum, and iridium 192 may be used as a source for all radiographic inspection provided they have adequate penetrating ability. Other radiographic sources shall be subject to the approval of the Engineer.

**7.9.2.16 IQI Selection and Placement.** Hole type IQIs shall be selected and placed on the source side of the bar, perpendicular to the radiation source and nearest the area of interest being radiographed. One hole type IQI shall be placed in the center of each bar to be radiographed with the 2 T hole being closest to the weld and the IQI identification numbers being furthest from the weld. IQI image shall not appear in the radiographic image of the weld. When more than one bar is being radiographed each shall have an IQI placed as described above. Wire penetrameters or penetrameter blocks shall not be used. Penetrameter image density shall be maintained in accordance with the density limitations specified for the area of interest.

**7.9.2.17 Technique Coverage.** Welded joints shall be radiographed by methods that will provide complete inspection of the joint within the limits specified to be examined. Short film, short screens, excessive undercut by scattered radiation, or any other process that obscures portions of the total weld shall render the radiograph unacceptable.

**7.9.2.18 Film Length.** Film shall have sufficient length and shall be placed to provide at least 1/2 in. [12 mm] of film beyond the projected edge of the weld.

**7.9.2.19 Film Width.** Film widths shall be sufficient to depict all portions of the weld joint, including the heat-affected zones (HAZs), and shall provide sufficient additional space for the required hole type IQIs and film identification without infringing upon the areas of interest in the radiograph.

**7.9.2.20 Backscatter.** To check for backscatter radiation, a lead symbol "B," 1/2 in. [12 mm] high, 1/16 in. [2 mm] thick shall be attached to the back of each film cassette. If the "B" image appears on the radiograph, the radiograph shall be considered unacceptable. A dark image of the "B" on a lighter background is not cause for rejection.

**7.9.2.21 Quality of Radiograph.** All radiographs shall be free from mechanical, chemical, or other blemishes to the extent that they cannot mask or be confused with the image of any discontinuity in the area of interest in the radiograph. Such blemishes include, but are not limited to, the following:

1. fogging
2. processing defects such as streaks, water marks, or chemical stains.
3. scratches, finger marks, crimps, dirtiness, static marks, smudges, or tears.
4. loss of detail due to poor screen-to-film contact.
5. false indications due to defective screens or internal faults.

**7.9.2.22 Density Limitations.** The transmitted film density through the radiographic image of the body of the required hole type IQI(s) and the area of interest shall be 1.8 minimum for single film viewing for radiographs made with an X-ray source and 2.0 minimum for radiographs made with a gamma-ray source. For composite viewing of double film exposures, the minimum density shall be 2.6. Each radiograph of a composite set shall have a minimum density of 1.3. The maximum density shall be 4.0 for either single or composite viewing.

**7.9.2.23 Transitions.** When welds between bars with differing diameters are radiographed and the ratio of the thickness of the thicker section of the thickness of the thinner section is 3 or greater, radiographs should be exposed to produce single film densities of 3.0 to 4.0 in the thinner section. When this is done, the minimum density requirements stated above shall be waived unless otherwise provided in the contract documents.

**7.9.2.24 Double Loaded Cassettes.** Due to the geometric condition of reinforcing bars, the use of double loaded cassettes with film of differing speeds may be required in order to maintain proper density throughout the full cross-sectional area thickness of the bar. Variations in density between double loaded film shall be maintained by film speed and exposure time and not by

reducing or increasing the development time beyond the film manufacturer's recommended development duration. When utilizing double loaded cassettes the radiographic film density shall comply with the requirements for single film viewing in the area represented by the film. The middle portions or through thickness of the bar shall be represented by one film that has a faster exposure speed and the outer radius portion of the bar shall be represented by a second film that has a slower exposure speed. Each film is viewed separately and the evaluations are combined to determine the disposition of the weld in accordance with Table 4.1.

**7.9.2.25 H & D Density.** The density measured shall be H & D density (radiographic density), which is a measure of film blackening, expressed as:

$$D = \log I_0/I$$

where

$D$  = H & D (radiographic) density

$I_0$  = light intensity on the film, and

$I$  = light transmitted through the film.

**7.9.2.26 Identification Marks.** A radiograph identification mark and station identification marks shall be placed on the bar at each radiograph location. A corresponding radiograph identification mark and station identification marks, all of which shall show in the radiograph, shall be produced by placing lead numbers or letters, or both, over each of the identical identification and location marks made on the steel to provide a means for matching the developed radiograph to the weld. Additional identification information may be pre-printed no less than 3/4 in. [20 mm] from the edge of the weld or shall be produced on the radiograph by placing lead figures on the steel. Information required to show on the radiograph shall include the contract identification, initials of the radiographic inspection company, initials of the fabricator, the fabricator shop order number, the radiographic identification mark, the date, and the weld repair number, if applicable. Each piece of film identi-

cation information shall be clearly legible. Film shall be identified by lead letters or numbers.

### **7.9.3 Examination, Report, and Disposition of Radiographs**

**7.9.3.1 Equipment Provided by Contractor.** The contractor shall provide a suitable variable intensity illuminator (viewer) with spot review or masked spot review capability. The viewer shall incorporate a means for adjusting the size of the spot under examination. The viewer shall have sufficient capacity to properly illuminate radiographs with an H&D density of 4.0. Film review shall be done in an area of subdued light.

**7.9.3.2 Reports.** Before a weld subject to radiographic testing is accepted, all of its radiographs, including any that show unacceptable quality prior to repair, and a report interpreting them shall be submitted to the Engineer.

**7.9.3.3 Record Retention.** A full set of radiographs for welds subject to radiographic testing by the contractor for the owner, including any that show unacceptable quality prior to repair, shall be delivered to the owner upon completion of the work. The contractor's obligation to retain radiographs shall cease: (1) upon delivery of this full set to the owner, or (2) one full year after the completion of the contractor's work, provided the owner is given prior written notice.

**7.9.3.4 Radiograph Interpretation.** All radiographs shall be interpreted by an individual certified as a Level II in accordance with the latest edition of the American Society for Nondestructive Testing's Recommended Practice No. SNT-TC-1A. Interpretation of direct butt joints in steel reinforcing bars is considerably more difficult than interpreting groove welds in butt joints between plates. Individuals responsible for interpreting reinforcing bar weld radiographs shall be experienced in the radiographic techniques required to evaluate the complex geometric characteristics of cylindrical objects.

**Table 7.1**  
**Hole-Type Image Quality Indicator (IQI) Requirements (see 7.9.2.1)**

| Bar Size |    | Source Side (IQI) |                |
|----------|----|-------------------|----------------|
| in.      | mm | Designation       | Essential Hole |
| 3        | 10 | 12                | 4T             |
| 4        | 13 | 15                | 4T             |
| 5        | 16 | 15                | 4T             |
| 6        | 19 | 17                | 4T             |
| 7        | 22 | 20                | 4T             |
| 8        | 25 | 20                | 4T             |
| 9        | 29 | 25                | 4T             |
| 10       | 32 | 30                | 2T             |
| 11       | 36 | 30                | 2T             |
| 14       | 43 | 35                | 2T             |
| 18       | 57 | 40                | 2T             |

Notes:

1. Weld reinforcement has been accounted for in the above table.
2. No increase in IQI designation or change in essential hole is permitted to account for weld reinforcement or backing.
3. Film side IQIs are prohibited.

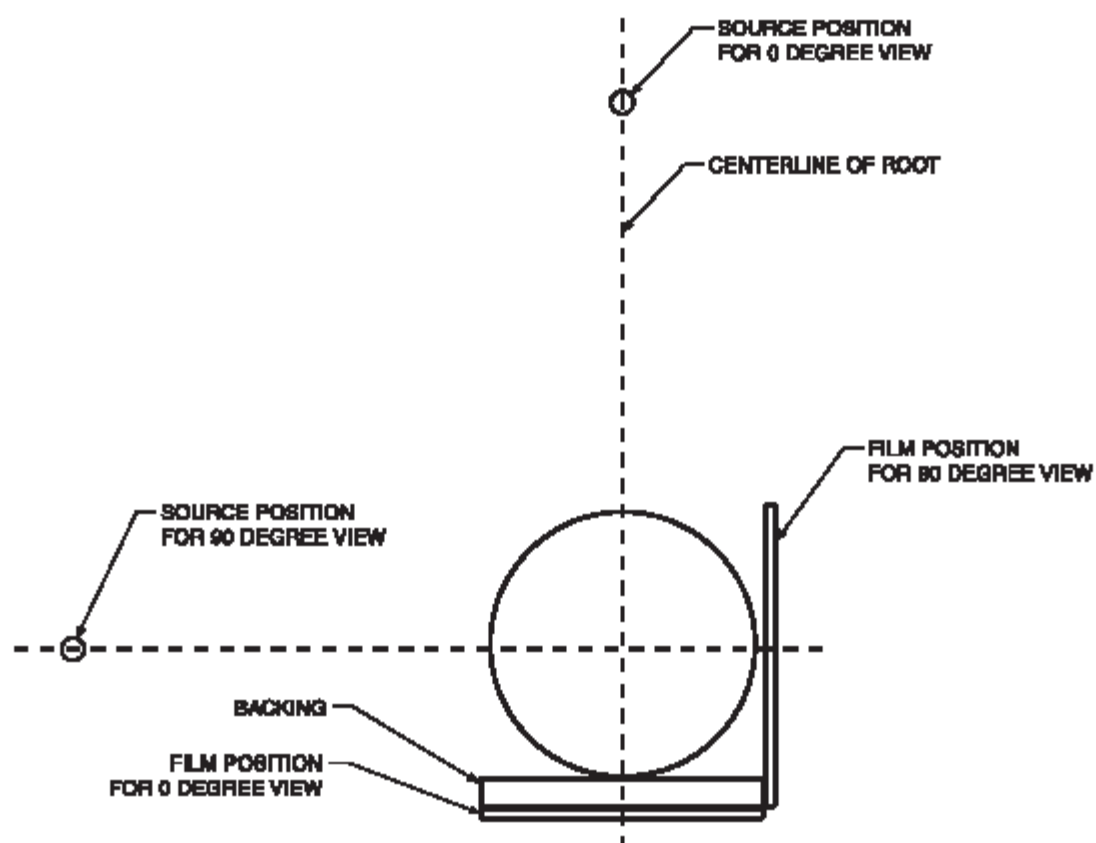


Figure 7.1—Source Position (see 7.9.2.1)

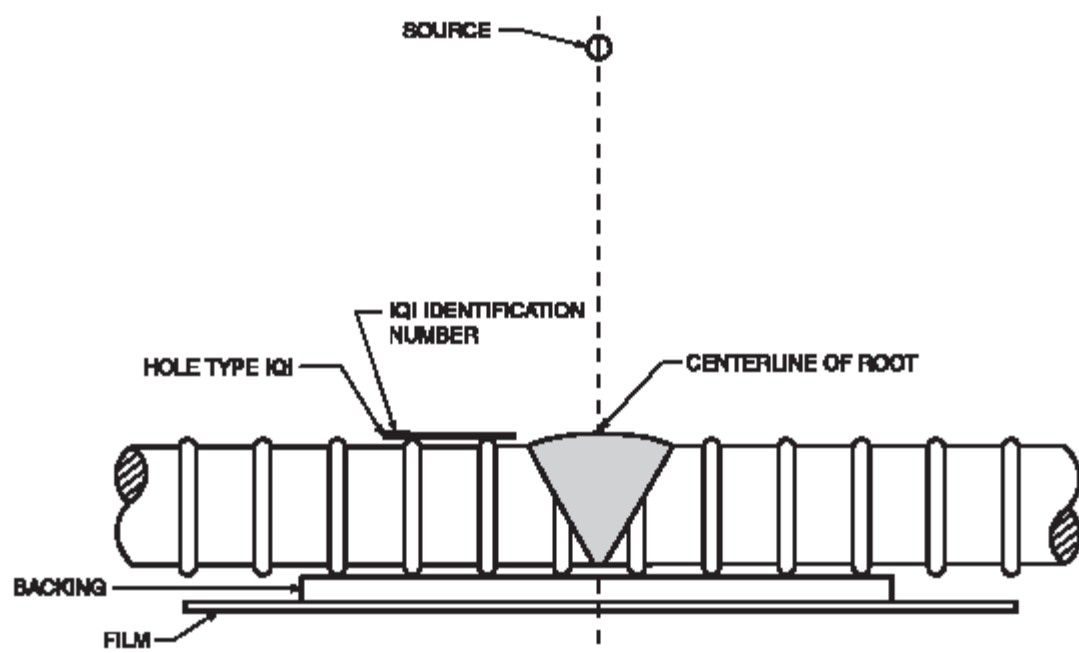


Figure 7.2—Film Placement (see 7.9.2.12)

## **Annex A (Informative)**

### **Sample Welding Forms**

This annex is not a part of AWS D1.4/D1.4M:2005, *Structural Welding Code—Reinforcing Steel*, but is included for informational purposes only.

This annex contains three sample forms.

## Sample Procedure Qualification Record (PQR) Form

Procedure Qualification Record (PQR) No. \_\_\_\_\_

Contractor \_\_\_\_\_

Authorized by \_\_\_\_\_

Revision No. \_\_\_\_\_

Welder \_\_\_\_\_

Test Date \_\_\_\_\_

Welding Process: ☐ FCAW-G ☐ FCAW-S ☐ GMAW ☐ SMAW**PQR JOINT TYPE**☐ Direct Butt ☐ Indirect Butt ☐ T-JointTest Assembly: ☐ Figure 6.5(A) ☐ Figure 6.5(B) ☐ Figure 6.5(C) ☐ Figure 6.5(D)Position \_\_\_\_\_ Groove Type \_\_\_\_\_ ☐ Single Bevel ☐ Double Bevel

Root Opening \_\_\_\_\_ Root Face \_\_\_\_\_ Groove Angle \_\_\_\_\_

Backing: ☐ Yes ☐ No Backing Type \_\_\_\_\_Backgouging: ☐ Yes ☐ No Backgouging Method \_\_\_\_\_Technique: ☐ Stringers ☐ Weave**ELECTRICAL CHARACTERISTICS**Current: ☐ AC ☐ DCEP ☐ DCENTransfer Mode (GMAW): ☐ Short-circuiting ☐ Globular ☐ Spray**BASE METAL**

Material Specification \_\_\_\_\_ Grade \_\_\_\_\_

welded to Material Specification \_\_\_\_\_ Grade \_\_\_\_\_

Carbon Equivalent (Bar) \_\_\_\_\_ Bar size \_\_\_\_\_

Coated Bar: ☐ Yes ☐ No Type of Coating \_\_\_\_\_**FILLER METAL**

AWS Specification \_\_\_\_\_ AWS Classification \_\_\_\_\_

Describe filler metal (if not covered by AWS specification) \_\_\_\_\_

**SHIELDING**Gas: ☐ Single ☐ Mixture Composition \_\_\_\_\_ Flow rate \_\_\_\_\_**PREHEAT/INTERPASS**

Preheat/Interpass Temperature (Min) \_\_\_\_\_

Interpass Temperature (Max) \_\_\_\_\_

**WELDING PARAMETERS**

| Pass Number | Electrode Diameter | Current |          |           |       |                     | Travel Speed (ipm) | Joint Detail |
|-------------|--------------------|---------|----------|-----------|-------|---------------------|--------------------|--------------|
|             |                    | Type    | Amperage | WFS (ipm) | Volts | Electrical Stickout |                    |              |
|             |                    |         |          |           |       |                     |                    |              |
|             |                    |         |          |           |       |                     |                    |              |
|             |                    |         |          |           |       |                     |                    |              |
|             |                    |         |          |           |       |                     |                    |              |
|             |                    |         |          |           |       |                     |                    |              |

Note: Attach additional sheets as required for detailing each pass.

Form A-1 (front)

# Sample Procedure Qualification Record (PQR) Form

Continuation of Procedure Qualification Record (PQR) No. \_\_\_\_\_

## TEST RESULTS

### VISUAL EXAMINATION

Test Assembly Number One☐ Pass ☐ Fail (AWS D1.4, Section 4.4)

Comments \_\_\_\_\_

Test Assembly Number Two☐ Pass ☐ Fail (AWS D1.4, Section 4.4)

Comments \_\_\_\_\_

### TENSILE TEST

Test Assembly Number One☐ Pass ☐ Fail (AWS D1.4, Section 6.3.7.2)Test Assembly Number Two☐ Pass ☐ Fail (AWS D1.4, Section 6.3.7.2)

| Specimen No. | Width | Thickness | Area | Ultimate Tensile Load (lbs) | Ultimate Unit Stress (psi) | Character of Failure and Location |
|--------------|-------|-----------|------|-----------------------------|----------------------------|-----------------------------------|
|              |       |           |      |                             |                            |                                   |
|              |       |           |      |                             |                            |                                   |

### MACROETCH TEST

Test Assembly Number One☐ Pass ☐ Fail (AWS D1.4, Section 6.3.7.3)Test Assembly Number Two☐ Pass ☐ Fail (AWS D1.4, Section 6.3.7.3)

| Specimen No. | Results | Remarks |
|--------------|---------|---------|
|              |         |         |
|              |         |         |

Welder's Name \_\_\_\_\_

Clock No. \_\_\_\_\_ Stamp No. \_\_\_\_\_

Test conducted by \_\_\_\_\_ (Laboratory)

Test Number \_\_\_\_\_

Per \_\_\_\_\_

We, the undersigned, certify that the statements in this record are correct and that the welds were prepared and tested in accordance with the requirements of AWS D1.4/D1.4M:2005, *Structural Welding Code—Reinforcing Steel*.

Manufacturer or Contractor \_\_\_\_\_

Authorized by \_\_\_\_\_ Date \_\_\_\_\_

Form A-1 (back)

# Sample Welding Procedure Specification (WPS) Form

Welding Procedure Specification (WPS) No. \_\_\_\_\_

Contractor \_\_\_\_\_

Authorized by \_\_\_\_\_

Revision No. \_\_\_\_\_

Supporting PQR Identification \_\_\_\_\_

Test Date \_\_\_\_\_

WELDING PROCESS: ☐ FCAW-S ☐ FCAW-G ☐ GMAW ☐ SMAW

WELD TYPE: ☐ Groove ☐ Fillet

JOINT TYPE: ☐ Direct Butt ☐ Indirect Butt ☐ T-Joint

Joint(s) Qualified (see Table 6.2) \_\_\_\_\_

Position \_\_\_\_\_ Groove Type \_\_\_\_\_

Root Opening \_\_\_\_\_ Root Face \_\_\_\_\_ Groove Angle \_\_\_\_\_

Backing: ☐ Yes ☐ No Backing Type \_\_\_\_\_

Backgouging: ☐ Yes ☐ No Backgouging Method \_\_\_\_\_

TECHNIQUE: ☐ Stringers ☐ Weave

## ELECTRICAL CHARACTERISTICS

Current: ☐ AC ☐ DCEP ☐ DCEN

Transfer Mode (GMAW): ☐ Short-circuiting ☐ Globular ☐ Spray

## BASE METAL

Material Specification \_\_\_\_\_ Grade \_\_\_\_\_

Welded to: Material Specification \_\_\_\_\_ Grade \_\_\_\_\_

Maximum Carbon Equivalent \_\_\_\_\_ Bar size \_\_\_\_\_ Plate Thickness \_\_\_\_\_

Coated Bar: ☐ Yes ☐ No Type of Coating \_\_\_\_\_

## FILLER METAL

AWS Specification \_\_\_\_\_ AWS Classification \_\_\_\_\_

Describe filler metal (if not covered by AWS specifications) \_\_\_\_\_

## SHIELDING

Gas: ☐ Single ☐ Mixture Composition \_\_\_\_\_ Flow rate \_\_\_\_\_

## PREHEAT/INTERPASS

Preheat/Interpass Temperature (Min) \_\_\_\_\_ Interpass Temperature (Max) \_\_\_\_\_

## WELDING PARAMETERS

| Pass<br>Number(s) | Electrode<br>Diameter | Current |                   |                |                        | Travel<br>Speed<br>(ipm) | Joint<br>Detail |
|-------------------|-----------------------|---------|-------------------|----------------|------------------------|--------------------------|-----------------|
|                   |                       | Type    | Amperage<br>Range | Volts<br>Range | Electrical<br>Stickout |                          |                 |
|                   |                       |         |                   |                |                        |                          |                 |
|                   |                       |         |                   |                |                        |                          |                 |
|                   |                       |         |                   |                |                        |                          |                 |
|                   |                       |         |                   |                |                        |                          |                 |

Manufacturer or Contractor \_\_\_\_\_

Authorized by \_\_\_\_\_ Date \_\_\_\_\_

## Sample Welder Qualification Test Record

Welder's Name &amp; ID No. \_\_\_\_\_ Date \_\_\_\_\_

Welding Procedure Specification No. \_\_\_\_\_ Revision No. \_\_\_\_\_

|                                                                                                                                          |                                                                                                                                                    |                                                                                                                                                                                                                             |
|------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Process:<br><input type="checkbox"/> GMAW <input type="checkbox"/> FCAW<br><input type="checkbox"/> SMAW <input type="checkbox"/> GMAW-S | Material Specification:<br>Bar _____<br>Structural Steel _____                                                                                     | <input type="checkbox"/> T-Joint [Figure 6.5(B)]<br><input type="checkbox"/> Direct Butt [Figure 6.5(A)]<br><input type="checkbox"/> Indirect Butt [Figure 6.5(C) & (D)]<br><input type="checkbox"/> Fillet [Figure 6.6(D)] |
| Backing:<br><input type="checkbox"/> Yes <input type="checkbox"/> No                                                                     | Position:<br><input type="checkbox"/> Vertical Up <input type="checkbox"/> OH<br><input type="checkbox"/> Horizontal <input type="checkbox"/> Flat | Material Specification:<br>Bar to Bar _____<br>Bar to Structural Steel _____                                                                                                                                                |

### FILLER METAL

|                             |                          |
|-----------------------------|--------------------------|
| AWS Specification No. _____ | AWS Classification _____ |
| Electrode _____             | Diameter/F No. _____     |
| Shielding Gas _____         | Trade Name _____         |

### TEST RESULTS

|                                                                                                                                                                                  |                                                                                                                                                                            |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Visual Weld Appearance: (Section 4.4)<br>1. <input type="checkbox"/> Pass <input type="checkbox"/> Fail<br>2. <input type="checkbox"/> Pass <input type="checkbox"/> Fail        | Tensile Strength, psi: (Subsection 6.3.7.2)<br>1. _____<br>2. _____                                                                                                        |
| Macroetch Test Results: (Subsection 6.3.7.3)<br>1. <input type="checkbox"/> Pass <input type="checkbox"/> Fail<br>2. <input type="checkbox"/> Pass <input type="checkbox"/> Fail | Fillet Weld Test: (Subsection 6.3.7.4)<br>1. <input type="checkbox"/> Pass <input type="checkbox"/> Fail<br>2. <input type="checkbox"/> Pass <input type="checkbox"/> Fail |
| Interpreted by _____<br>Organization _____                                                                                                                                       | Test No. _____<br>Date _____                                                                                                                                               |

### RADIOGRAPHIC TEST RESULTS

| Film Identification | Results | Remarks | Film Identification | Results | Remarks |
|---------------------|---------|---------|---------------------|---------|---------|
|                     |         |         |                     |         |         |
|                     |         |         |                     |         |         |
|                     |         |         |                     |         |         |

|                      |                |
|----------------------|----------------|
| Interpreted by _____ | Test No. _____ |
| Organization _____   | Date _____     |

We, the undersigned, certify that the statements in this record are correct and that the welds were prepared and tested in accordance with the requirements of AWS D1.4/D1.4M:2005, *Structural Welding Code—Reinforcing Steel*.

Manufacturer or Contractor \_\_\_\_\_

Authorized by \_\_\_\_\_ Date \_\_\_\_\_

### QUALIFICATION RESULTS

The Welder/Operator identified above ☐ DOES ☐ DOES NOT meet the performance qualifications specified in the AWS D1.4/D1.4M:2005 code for the variables stated.

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## Annex B (Informative)

### Nominal Dimensions of ASTM Standard Reinforcing Bars

This annex is not a part of AWS D1.4/D1.4M:2005, *Structural Welding Code—Reinforcing Steel*, but is included for informational purposes only.

| Bar Size <sup>a,b</sup> |    | Unit Weight |       | Diameter |       | Cross-Sectional Area |                 |
|-------------------------|----|-------------|-------|----------|-------|----------------------|-----------------|
| in.                     | mm | lb/ft       | kg/m  | in.      | mm    | in. <sup>2</sup>     | mm <sup>2</sup> |
| 3                       | 10 | 0.376       | 0.56  | 0.375    | 9.52  | 0.11                 | 71.0            |
| 4                       | 13 | 0.668       | 1.00  | 0.500    | 12.70 | 0.20                 | 129.0           |
| 5                       | 16 | 1.043       | 1.55  | 0.625    | 15.88 | 0.31                 | 200.0           |
| 6                       | 19 | 1.502       | 2.26  | 0.750    | 19.05 | 0.44                 | 283.9           |
| 7                       | 22 | 2.044       | 3.64  | 0.875    | 22.22 | 0.60                 | 387.1           |
| 8                       | 25 | 2.670       | 3.98  | 1.000    | 25.40 | 0.79                 | 509.7           |
| 9                       | 29 | 3.400       | 5.07  | 1.128    | 28.65 | 1.00                 | 645.2           |
| 10                      | 32 | 4.303       | 6.41  | 1.270    | 32.26 | 1.27                 | 819.4           |
| 11                      | 36 | 5.313       | 7.92  | 1.410    | 35.81 | 1.56                 | 1006.5          |
| 14                      | 43 | 7.65        | 11.40 | 1.693    | 43.00 | 2.25                 | 1451.7          |
| 18                      | 57 | 13.60       | 20.26 | 2.257    | 57.33 | 4.00                 | 2580.8          |

<sup>a</sup> The nominal dimensions of a deformed bar are equivalent to those of a plain round bar having the same weight per foot as the deformed bar.

<sup>b</sup> The bar size number is based on the number of eighths of an inch in the nominal diameter of the bar.

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## Annex C (Informative)

# Guidelines for Preparation of Technical Inquiries for the Structural Welding Committee

This annex is not a part of AWS D1.4/D1.4M:2005, *Structural Welding Code—Reinforcing Steel*, but is included for informational purposes only.

## C1. Introduction

The AWS Board of Directors has adopted a policy whereby all official interpretations of AWS standards will be handled in a formal manner. Under that policy, all interpretations are made by the committee that is responsible for the standard. Official communication concerning an interpretation is through the AWS staff member who works with that committee. The policy requires that all requests for an interpretation be submitted in writing. Such requests will be handled as expeditiously as possible, but due to the complexity of the work and the procedures that must be followed, some interpretations may require considerable time.

## C2. Procedure

All inquiries must be directed to:

Technical Director  
American Welding Society  
550 N.W. LeJeune Road  
Miami, FL 33126

All inquiries must contain the name, address, and affiliation of the inquirer, and they must provide enough information for the committee to fully understand the point of concern in the inquiry. Where that point is not clearly defined, the inquiry will be returned for clarification. For efficient handling, all inquiries should be type-written and should also be in the format used here.

**C2.1 Scope.** Each inquiry must address one single provision of the code, unless the point of the inquiry involves two or more interrelated provisions. That provision must be identified in the scope of the inquiry, along with the

edition of the code that contains the provisions or that the inquirer is addressing.

**C2.2 Purpose of the Inquiry.** The purpose of the inquiry must be stated in this portion of the inquiry. The purpose can be either to obtain an interpretation of a code requirement, or to request the revision of a particular provision in the code.

**C2.3 Content of the Inquiry.** The inquiry should be concise, yet complete, to enable the committee to quickly and fully understand the point of the inquiry. Sketches should be used when appropriate and all paragraphs, figures, and tables (or the Annex), which bear on the inquiry must be cited. If the point of the inquiry is to obtain a revision of the code, the inquiry must provide technical justification for that revision.

**C2.4 Proposed Reply.** The inquirer should, as a proposed reply, state an interpretation of the provision that is the point of the inquiry, or the wording for a proposed revision, if that is what the inquirer seeks.

## C3. Interpretation of Code Provisions

Interpretations of code provisions are made by the Structural Welding Committee. The secretary of the committee refers all inquiries to the chair of the particular subcommittee that has jurisdiction over the portion of the code addressed by the inquiry. The subcommittee reviews the inquiry and the proposed reply to determine what the response to the inquiry should be. Following the subcommittee's development of the response, the inquiry and the response are presented to the entire Structural Welding Committee for review and approval. Upon approval by the committee, the interpretation will be an

official interpretation of the American Welding Society, and the secretary will transmit the response to the inquirer and to the *Welding Journal* for publication.

#### **C4. Publication of Interpretations**

All official interpretations will appear in the *Welding Journal* and will be posted on the AWS web site.

#### **C5. Telephone Inquiries**

Telephone inquiries to AWS Headquarters concerning the *Structural Welding Code* should be limited to questions of a general nature or to matters directly related to the use of the code. The Board of Directors' policy requires that all staff members respond to a telephone request for an official interpretation of any AWS standard with the information that such an interpretation

can be obtained only through a written request. AWS Headquarters staff cannot provide consulting services. The staff can, however, refer a caller to any of those consultants whose names are on file at AWS Headquarters.

#### **C6. The Structural Welding Committee**

The Structural Welding Committee's activities, in regard to interpretations, are limited strictly to the interpretation of code provisions or to consideration of revisions to existing provisions on the basis of new data or technology. Neither the committee nor the staff is in a position to offer interpretive or consulting services on (1) specific engineering problems, or (2) code requirements applied to fabrications outside the scope of the code or points not specifically covered by the code. In such cases, the inquirer should seek assistance from a competent Engineer experienced in the particular field of interest.

## Annex D (Informative)

### Safe Practices

This annex is not a part of AWS D1.4/D1.4M:2005, *Structural Welding Code—Reinforcing Steel*, but is included for informational purposes only.

This annex covers many of the basic elements of safety general to arc welding processes. It includes many, but not all, of the safety aspects related to structural welding. The hazards that may be encountered and the practices that will minimize personal injury and property damage are reviewed here.

#### D1. Electrical Hazards

Electric shock can kill. However, it can be avoided. Live electrical parts should not be touched. Read and understand the manufacturer's instructions and recommended safe practices. Faulty installation, improper grounding, and incorrect operation and maintenance of electrical equipment are all sources of danger.

All electrical equipment and the workpiece should be grounded. A separate connection is required to ground the workpiece. The worklead should not be mistaken for a ground connection.

To prevent shock, the work area, equipment, and clothing should be kept dry all times. Dry gloves and rubber-soled shoes should be worn. The welder should stand on a dry board or insulated platform.

Cables and connectors should be kept in good condition. Worn, damaged, or bare cables should be turned off immediately. If the rescuer must resort to pulling the victim from the live contact, nonconducting materials should be used. A physician should be called and CPR administered until breathing has been restored, or until a physician has arrived. See References 8, 9, and 14.

#### D2. Fumes and Gases

Many welding, cutting, and allied processes produce fumes and gases which may be harmful to one's health. Fumes originate from welding consumables, the base

metal, and any coatings present on the base metal. Gases are produced during the welding process or may be produced by the effects of process radiation on the surrounding environment. Everyone associated with the welding operation should acquaint themselves with the effects of these fumes and gases.

The possible effects of over-exposure to fumes and gases range from irritation of eyes, skin, and respiratory system to more severe complications. Effects may occur immediately or at some later time. Fumes can cause symptoms such as nausea, headaches, dizziness, and metal fume fever.

Sufficient ventilation, exhaust at the arc, or both, should be used to keep fumes and gases from breathing zones and the general work area.

For more detailed information on fumes and gases produced by the various welding processes, see References 1, 5, and 15.

#### D3. Noise

Excessive noise is a known health hazard. Exposure to excessive noise can cause a loss of hearing. This loss of hearing can be either full or partial, and temporary or permanent. Excessive noise adversely affects hearing capability. In addition, there is evidence that excessive noise affects other bodily functions and behavior.

Personal protective devices such as ear muffs or ear plugs may be employed. Generally, these devices are only accepted when engineering controls are not fully effective. For more information see References 1 and 15.

#### D4. Burn Protection

Molten metal, sparks, slag, and hot work surfaces are produced by welding, cutting, and allied processes.

These can cause burns if precautionary measures are not used.

Workers should wear protective clothing made of fire-retardant material. Pant cuffs or clothing with open pockets or other places on clothing that can catch and retain molten metal or sparks should not be worn. High-top shoes or leather leggings and fire-retardant gloves should be worn. Pant legs should be worn over the outside of high-top boots. Helmets or hand shields that provide protection for the face, neck, and ears should be worn, as well as a head covering to protect the head. Clothing should be kept free of grease and oil. Combustible materials should not be carried in pockets. If any combustible substance is spilled on clothing, it should be replaced with clean fire-retardant clothing before working with open arcs or flame.

Appropriate eye protection should be used at all times. Goggles or equivalent also should be worn to give added eye protection.

Insulated gloves should be worn at all times when in contact with hot items or handling electrical equipment.

For more detailed information on personal protection, References 1, 6, 8 and 15 should be consulted.

## D5. Fire Prevention

Molten metal, sparks, slag, and hot work surfaces are produced by welding, cutting, and allied processes. These can cause fire or explosion if precautionary measures are not used.

Explosions have occurred where welding or cutting has been performed in spaces containing flammable gases, vapors, liquids, or dust. All combustible material should be removed from the work area. Where possible, move the work to a location well away from combustible materials. If neither action is possible, combustibles should be protected with a cover of fire-retardant material. All combustible materials should be removed or safely protected within a radius of 35 ft [11 m] around the work area.

Welding or cutting should not be done in an atmosphere containing dangerously reactive or flammable gases, vapors, liquids, or dust. Heat should not be applied to a container that has held an unknown substance or a combustible material and whose contents when heated can produce flammable or explosive vapors. Adequate ventilation should be provided in work areas to prevent accumulation of flammable gases, vapors, or dusts. Containers should be cleaned and purged before applying heat.

For more detailed information on fire hazards from welding and cutting operations, see References 2, 8, and 15.

## D6. Radiation

Welding, cutting, and allied operations may produce radiant energy (radiation) harmful to health. Everyone associated with the welding operation should acquaint themselves with the effects of this radiant energy.

Radiant energy may be ionizing (such as X-rays) or nonionizing (such as ultraviolet, visible light, or infrared). Radiation can produce a variety of effects such as skin burns and eye damage, if excessive exposure occurs.

Some processes such as resistance welding and cold pressure welding ordinarily produce negligible quantities of radiant energy. However, most arc welding and cutting processes (except submerged arc when used properly), laser welding and torch welding, cutting, brazing, or soldering can produce quantities of nonionizing radiation such that precautionary measures are necessary.

Protection from possible harmful radiation effects include the following:

1. Welding arcs should not be viewed except through welding filter plates (see Reference 3). Transparent welding curtains are not intended as welding filter plates, but rather, are intended to protect passersby from incidental exposure.
2. Exposed skin should be protected with adequate gloves and clothing as specified. See Reference 8.
3. The casual passerby of welding operations should be protected by the use of screens, curtains, or adequate distance from aisles, walkway, etc.
4. Safety glasses with ultraviolet protective side shields have been shown to provide some beneficial protection from ultraviolet radiation produced by welding arcs.

## D7. Radiographic Procedures

The problems of personnel protection against X-rays and gamma rays are not covered in this standard. Radiographic procedures should be carried out under protected conditions so that the radiographer will not receive a maximum whole-body radiation dosage exceeding that permitted by city, state, or national codes. Mandatory rules and regulations are published by governmental licensing agencies. Careful radiation surveys should be made in accordance with appropriate regulations and codes and should be conducted in the inspection area as well as adjacent areas under all possible operating conditions.

For more complete information, the user should refer to References 4, 10, 11, 12, and 16.

## References Cited

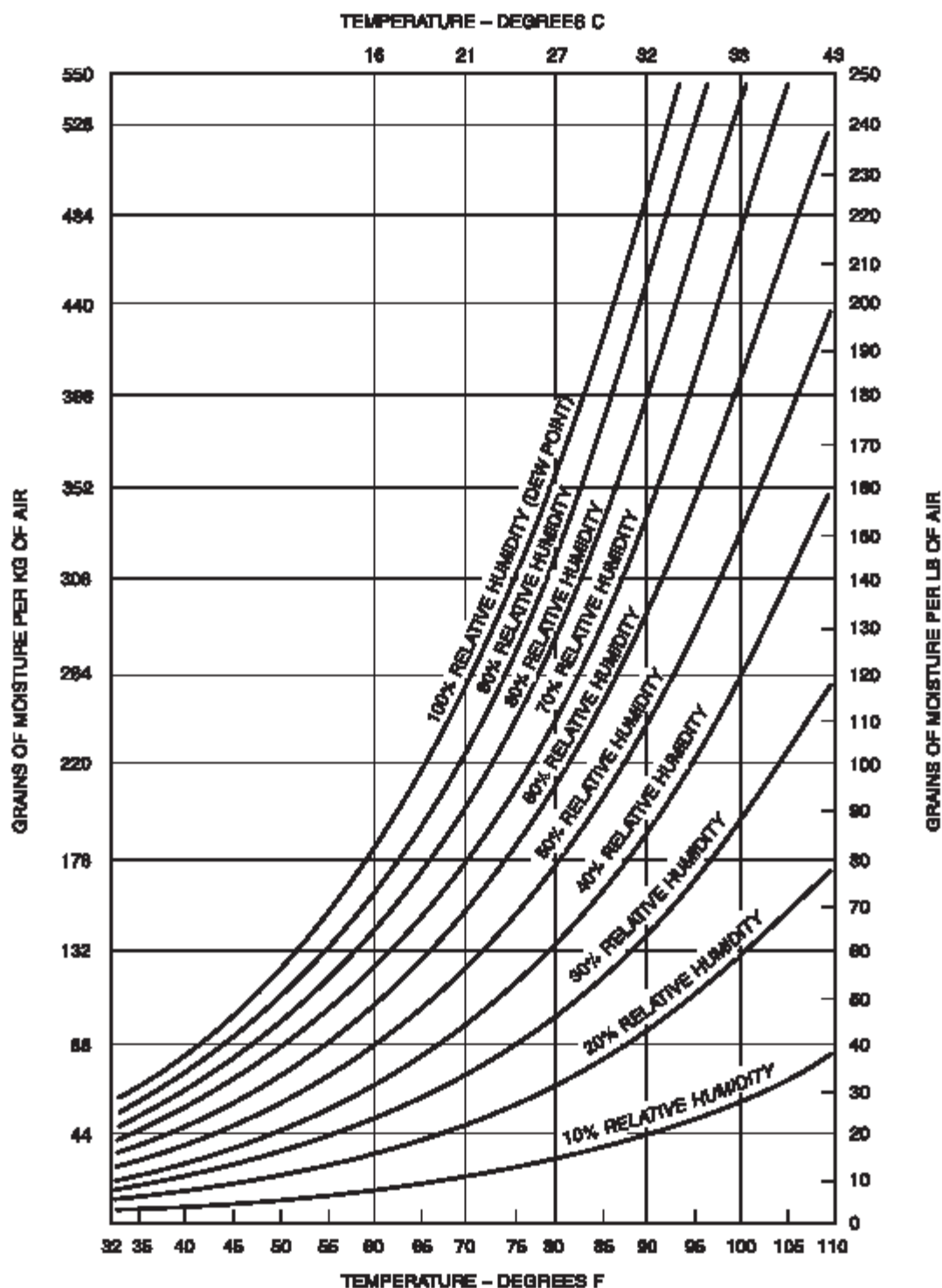
1. American Conference of Governmental Industrial Hygienists. *Threshold Limit Values for Chemical Substances and Physical Agents in the Workroom Environment*. Cincinnati, OH: American Conference of Governmental Industrial Hygienists (ACGIH).
2. American National Standards Institute. *Practice for Occupational and Educational Eye and Face Protection*, ANSI/ASC Z87.1. New York: American National Standards Institute.
3. *Personal Protection—Protective Footwear*, ANSI/ASC Z41.1. New York: American National Standards Institute.
4. ASTM. "Definitions of terms relating to gamma and x-radiography," E 586, *1988 Annual Book of ASTM Standards*, Section 3, Volume 03.03. Philadelphia, PA: ASTM, 1988.
5. American Welding Society. *Fumes and Gases in the Welding Environment*, AWS report. Miami, FL: American Welding Society.
6. ——. *Method for Sound Level Measurement of Manual Arc Welding and Cutting Processes*, ANSI/AWS F6.1. Miami, FL: American Welding Society.
7. ——. *Recommended Safe Practices for the Preparation for Welding and Cutting Containers and Piping*, AWS F4.1. Miami, FL: American Welding Society.
8. ——. *Safety in Welding, Cutting, and Allied Processes*, ANSI Z49.1. Miami, FL: American Welding Society.
9. ——. *Safe Practices*, Reprint from Welding Handbook, Volume 1, Eighth Edition. Miami, FL: American Welding Society.
10. National Bureau of Standards. *General Safety Standard for Installation Using Non-medical X-ray and Sealed Gamma Ray Sources up to 10 MeV Equipment Design and Use*, NBS-HDBK-114. Gaithersburg, Maryland: National Bureau of Standards.
11. ——. *Safety Standard for Non-medical X-ray and Sealed Gamma-ray Sources*, NBS-HDBK-93. Gaithersburg, Maryland: National Bureau of Standards.
12. ——. *X-ray Protection*, NBS-HDBK-60. Gaithersburg, Maryland: National Bureau of Standards.
13. National Fire Protection Association. *Fire Prevention in Use of Cutting and Welding Processes*, NFPA Standard 51B. Quincy, Massachusetts: Fire Protection Association, latest edition.
14. ——. *National Electrical Code*, NFPA No. 70. Quincy, Massachusetts: National Fire Protection Association.
15. U.S. Government Printing Office. *Code of Federal Regulations (CFR)*, Title 29, Subtitle B Chapter XVII, Part 1910. Occupational Safety and Health Standards Washington, DC: U.S. Government Printing Office.
16. ——. "Safety requirements for cabinet x-ray," Federal Standard No. 21—*Code of Federal Regulations*. Washington, DC: U.S. Government Printing Office.

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## **Annex E (Informative)**

### **Temperature-Moisture Content Charts**

This annex is not a part of AWS D1.4/D1.4M:2005, *Structural Welding Code—Reinforcing Steel*, but is included for informational purposes only.



General Notes:

(a) Any standard psychrometric chart may be used in lieu of this chart.

(b) See Figure E-2 for an example of the application of this chart in establishing electrode exposure conditions.

**Figure E.1—Temperature-Moisture Content Chart to be Used in Conjunction with Testing Program to Determine Extended Atmospheric Exposure Time of Low-Hydrogen Electrodes (see 5.7.3)**

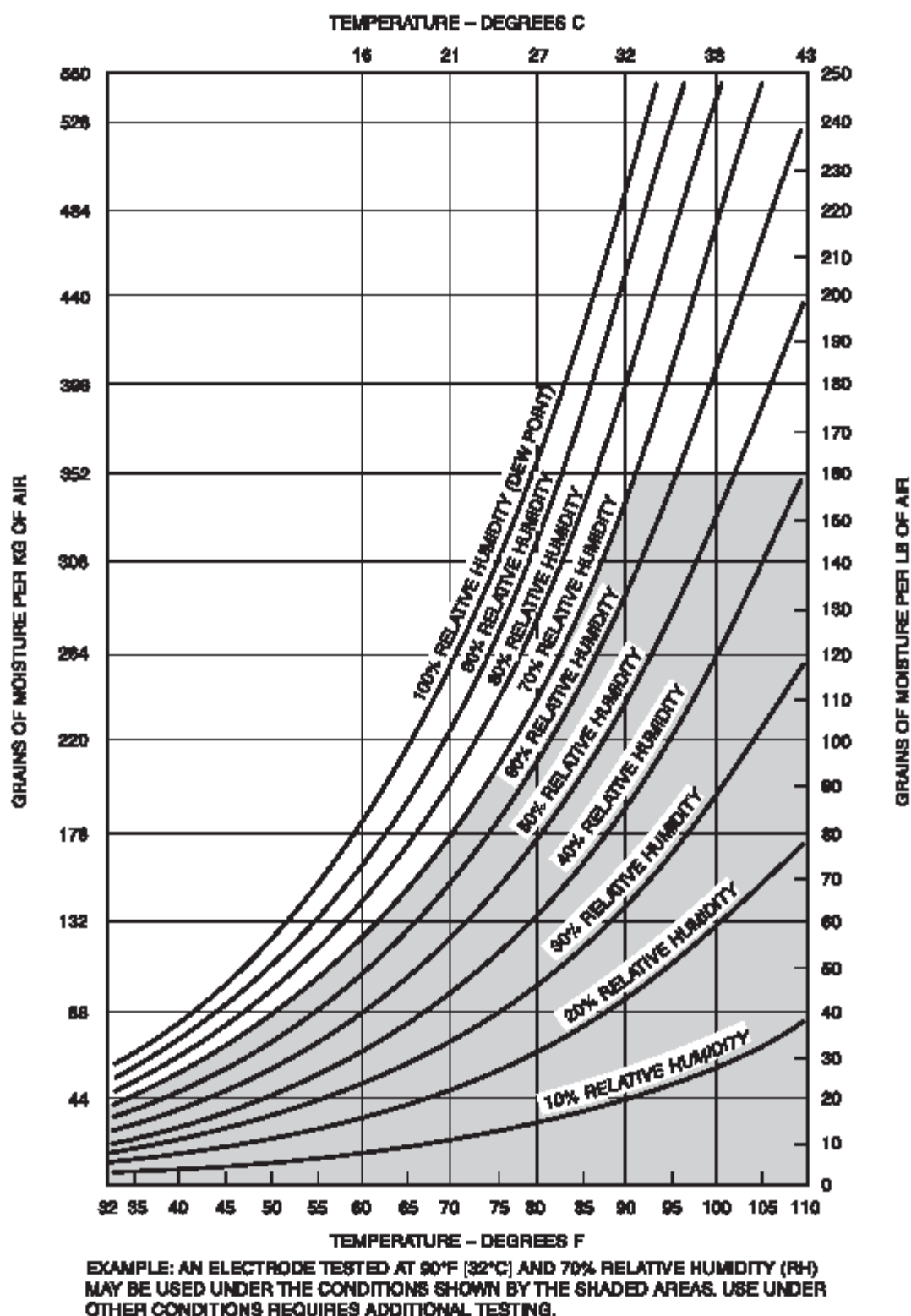


Figure E.2—Application of Temperature-Moisture Content Chart in Determining Atmospheric Exposure Time of Low-Hydrogen Electrodes (see 5.7.3)

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### List of AWS Documents on Structural Welding Code

| Designation | Title                                                                   |
|-------------|-------------------------------------------------------------------------|
| D1.1/D1.1M  | <i>Structural Welding Code—Steel</i>                                    |
| D1.2/D1.2M  | <i>Structural Welding Code—Aluminum</i>                                 |
| D1.3        | <i>Structural Welding Code—Sheet Steel</i>                              |
| D1.4/D1.4M  | <i>Structural Welding Code—Reinforcing Steel</i>                        |
| D1.5/D1.5M  | <i>Bridge Welding Code</i>                                              |
| D1.6        | <i>Structural Welding Code—Stainless Steel</i>                          |
| D1.8/D1.8M  | <i>Structural Welding Code—Seismic Supplement (publication pending)</i> |
| D1.9/D1.9M  | <i>Structural Welding Code—Titanium (publication pending)</i>           |

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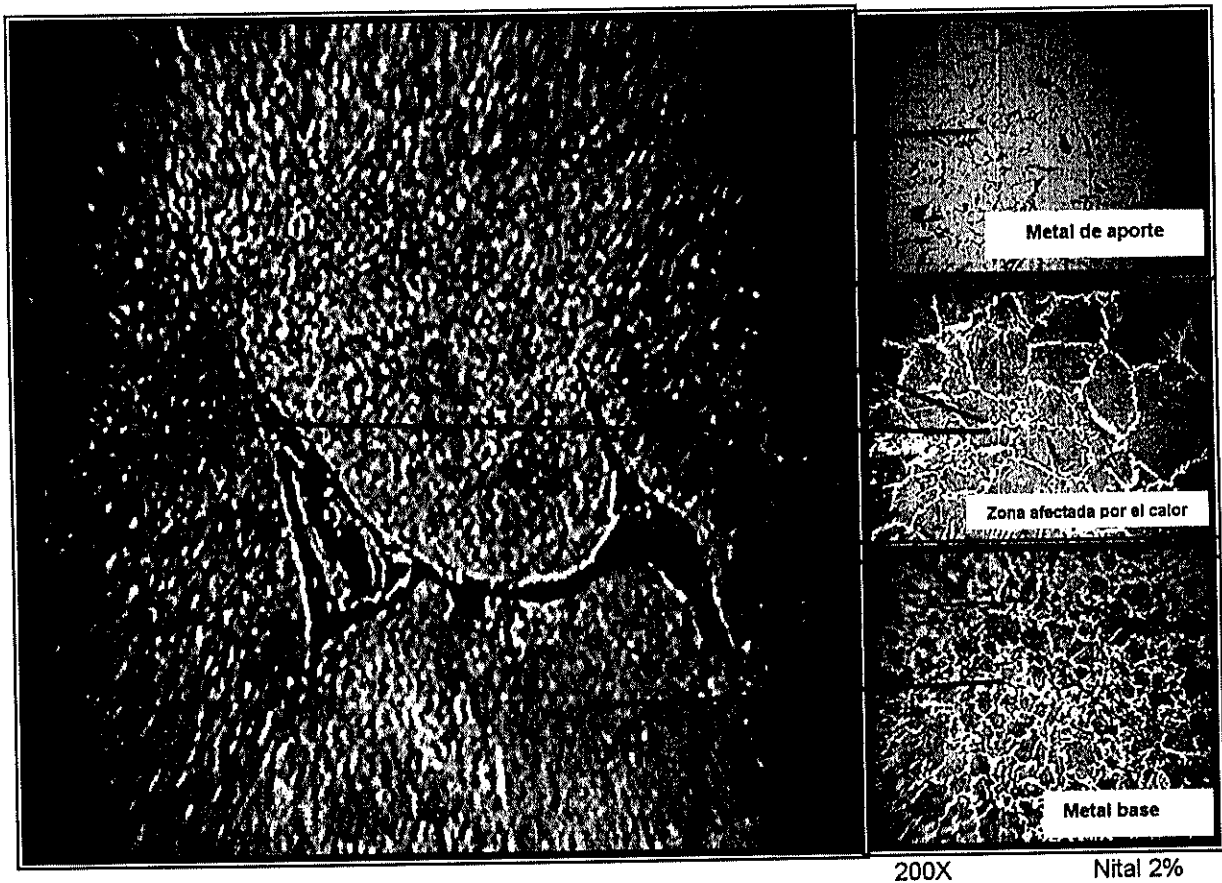


APENDICE A

MACRO ATAQUE DE PROBETA SOLDADA CON ELECTRODO 7018 Y  
MICROESTRUCTURA EN ZONAS DE INTERÉS



CIB-ESPOL



200X

Nital 2%



CIB-ESPOL

## APENDICE B

MACRO ATAQUE DE PROBETA SOLDADA CON ELECTRODO 9018 Y

MICROESTRUCTURA EN ZONAS DE INTERÉS



200X

Nital 2'



CM-ESPOL

## APENDICE C

### REPORTE DE ANALISIS QUIMICO



DPTO. DESARROLLO Y CONTROL  
LAB. QUIMICO METALURGICO  
PLANTA DE ELECTRODOS

## REPORTE DE ANALISIS QUIMICO

VARILLA

X

**MATERIAL :** Varilla de Construcción **PROVEEDOR :** Ing. Wilmer Ramirez  
**DIAMETRO :** **TAMAÑO DE LOTE :**  
**PRODUCTOR :** **INGRESO A BODEGA :** I/L: 11/05/2006

### PARAMETROS ANALIZADOS

| Varilla Construcción | %C     | %Mn     | %Si     | %S      | %P      |
|----------------------|--------|---------|---------|---------|---------|
| 1                    | 0.4184 | 0.55824 | 0.08843 | 0.03310 | 0.02113 |

| Varilla Construcción | %Cu     | %Ni    |
|----------------------|---------|--------|
| 1                    | 0.02496 | 0.0269 |

OBSERVACIONES :

Trazas :  $\leq 0,0009$

REPORTE # : Varilla de Construcción

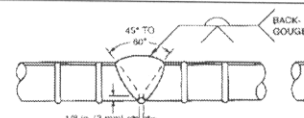
| FECHA DE REPORTE | REPORTADO POR :       | FECHA DE APROBADO | APROBADO POR : |
|------------------|-----------------------|-------------------|----------------|
| Mayo 15 de 2006  | <i>Rodrigo Torres</i> |                   |                |

APENDICE D  
PROCEDURE QUALIFICATION RECORD  
PQR N° 001  
WELDING PROCEDURE SPECIFICATION  
WPS N° 001  
ELECTRODO E-9018 – G H4R

Referencia AWS D1.4/D1.4:2005

**PROCEDURE QUALIFICATION RECORD**  
**PQR N° 001**Contractor: AGA S.A.Authorized by: NOVACERORevision No. 001Welder: JOHN BAUTISTA ANGULOTest Date: 12-05-2006Welding Process: ☐ FCAW-S ☐ FCAW-G ☐ GMAW ☒ SMAWPQR JOINT TYPE: ☒ Direct Butt ☐ Indirect Butt ☐ T-JointTest Assembly: ☒ Figure 6.5 (A) ☐ Figure 6.5 (B) ☐ Figure 6.5 (C) ☐ Figure 6.5 (D)Position: 3G Groove Type: A TOPE ☒ Single Bevel ☐ Double BevelRoot Opening: 3 mm Root Face: 3 mm Groove Angle: 60°Backing: ☐ Yes ☒ No Backing Type: \_\_\_\_\_Backgouging: ☒ Yes ☐ No Backgouging Method: ESMERILADOTechnique: ☐ Stringers ☒ Weave**ELECTRICAL CHARACTERISTICS**Current: ☐ AC ☒ DCEP ☐ DCENTransfer Mode (GMAW) ☐ Short-circuiting ☐ Globular ☐ Spray**BASE METAL**Material Specification: ASTM A615M Grade: 420Welded to: Material Specification: ASTM A615M Grade: 420Carbon Equivalent (Bar): 0.50 % Bar size: 28 mmCoated Bar: ☐ Yes ☒ No Type of Coating: \_\_\_\_\_**FILLER METAL**AWS Specification: A 5.5 AWS Classification: E-9018-G H4RDescribe filler metal (If not covered by AWS specifications) N.A.**SHIELDING**Gas: ☐ Single ☐ Mixture Composition: \_\_\_\_\_ Flow rate: \_\_\_\_\_**PREHEAT/INTERPASS**Preheat/Interpass temperature (Min): N.A.Interpass Temperature (Max): N.A.**WELDING PARAMETERS**

| Pass Number(s) | Electrode Diameter | Current      |                |             |                     | Travel Speed (ipm) |
|----------------|--------------------|--------------|----------------|-------------|---------------------|--------------------|
|                |                    | Type         | Amperage Range | Volts Range | Electrical Stickout |                    |
| 1 - n          | E-9018-G Ø 1/8     | Continua (+) | 110 - 130      | 20- 28      | ---                 | ---                |
|                |                    |              |                |             |                     |                    |
|                |                    |              |                |             |                     |                    |
|                |                    |              |                |             |                     |                    |

**Joint Detail**

(A) SINGLE-V-GROOVE WELD

Note: Attach additional sheets as required for detailing pass.

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FAX: 267-5126**GUAYAQUIL**Km. 11 1/2 Via a Daule  
PEDIDOS: 1-800-AGA GAS  
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CELULAR: 09-9202442  
FAX: 210-1153 / 210-0394**CUENCA**Sebastián de Benalcázar  
entre Gil Ramírez Dávalos  
y Av. España  
Telfs.: 280-8988/286-8753/4  
Fax: 286-8769**MANTA**Av. 113 No. 1104 y  
Calle 118  
Telefax: 292-0434  
292-2778**AMBATO**Av. Atahualpa Km. 2 1/2  
Telf.: 284-6080  
Fax: 284-5757**SANTO DOMINGO**Km. 2 1/2 Via a Quevedo  
Telf.: 370-3940  
Fax: 370-3957**AMAZONIA**Km. 1 1/2 Via Coca - Lago Agrio  
Telf.: 288-1387  
Fax: 288-1388  
El Coca

## Continuation of PQR N° 001

## TEST RESULTS

## VISUAL EXAMINATION

## Test Assembly Number One

☒ Pass ☐ Fail (AWS D1.4, Section 4.4)

Comments: \_\_\_\_\_

## Test Assembly Number Two

☒ Pass ☐ Fail (AWS D1.4, Section 4.4)

Comments: \_\_\_\_\_

## TENSILE TEST

## Test Assembly Number One

☒ Pass ☐ Fail (AWS D1.4, Section 6.3.7.2)

## Test Assembly Number Two

☒ Pass ☐ Fail (AWS D1.4, Section 6.3.7.2)

| Specimen No. | Width | Diameter (mm) | Area (mm <sup>2</sup> ) | Ultimate Tensile Load (Kg) | Ultimate Unit Stress (Kgf/mm <sup>2</sup> ) | Character of Failure and Location |
|--------------|-------|---------------|-------------------------|----------------------------|---------------------------------------------|-----------------------------------|
| 1            | ---   | 28            | 615.44                  | 35,332                     | 57.41                                       | Material Base                     |
| 2            | ---   | 28            | 615.44                  | 35,233                     | 57.25                                       | Material Base                     |

## MACROETCH TEST

## Test Assembly Number One

☒ Pass ☐ Fail (AWS D1.4, Section 6.3.7.3)

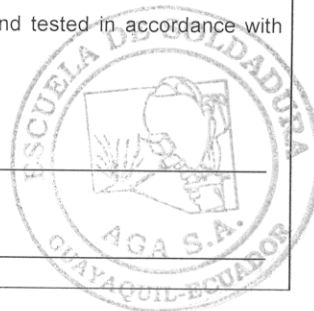
## Test Assembly Number Two

☒ Pass ☐ Fail (AWS D1.4, Section 6.3.7.3)

| Specimen No. | Results  | Remarks |
|--------------|----------|---------|
| 1            | ACEPTADO | ----    |
| 2            | ACEPTADO | ----    |

Welder's Name: JOHN BAUTISTA ANGULO Clock No. 1 y 2 Stamp No. 1 y 2Test conducted by: INEN, LABORATORIO DE ENSAYOS FISICOS Y MECANICOS (Laboratory)Test Number 2006-078Per Sr. Wilson Angulo

We, the undersigned, certify that statements in this record are correct and that welds were prepared and tested in accordance with requirements of AWS D1.4/D1.4M:2005, *Structural Welding Code---Reinforce Steel*

Manufacturer or Contractor: Ing. Wilmer Ramírez M., AGA S.A. Firma: \_\_\_\_\_Authorized by: Ing. Rodrigo Corral, NOVACERODate: 12 de Junio del 2006

Referencia AWS D1.4/D1.4:2005

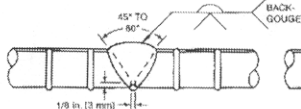
# WELDING PROCEDURE SPECIFICATION

## WPS N° 001

Contractor: AGA S.A.Authorized by: NOVACERORevision No. 001Supporting PQR Identification: 001Test Date: 12-05-2006WELDING PROCESS: ☐ FCAW-S ☐ FCAW-G ☐ GMAW ☒ SMAWWELD TYPE: ☒ Groove ☐ FilletJOINT TYPE: ☒ Direct Butt ☐ Indirect Butt ☐ T-JointJoint(s) Qualified (see Table 6.2): FIG. 6.5 (A): COMPLETE JOINT PENETRATION GROOVE WELD - DIRECT BUTT JOINT.Position: 3G Groove Type: A TOPERoot Opening: 3 mm Root Face: 3 mm Groove Angle: 60°Backing: ☐ Yes ☒ No Backing Type: \_\_\_\_\_Backgouging: ☒ Yes ☐ No Backgouging Method: ESMERILADOTECHNIQUE: ☐ Stringers ☒ Weave**ELECTRICAL CHARACTERISTICS**Current: ☐ AC ☒ DCEP ☐ DCENTransfer Mode (GMAW) ☐ Short-circuiting ☐ Globular ☐ Spray**BASE METAL**Material Specification: ASTM A615M Grade: 420Welded to: Material Specification: ASTM A615M Grade: 420Maximum Carbon Equivalent: 0.50 % Bar size: 28 mm Plate Thickness: N.A.Coated Bar: ☐ Yes ☒ No Type of Coating: \_\_\_\_\_**FILLER METAL**AWS Specification: A 5.5 AWS Classification: E-9018-G H4R

Describe filler metal (If not covered by AWS specifications) \_\_\_\_\_

**SHIELDING**Gas: ☐ Single ☐ Mixture Composition: \_\_\_\_\_ Flow rate: \_\_\_\_\_**PREHEAT/INTERPASS**Preheat/Interpass temperature (Min): N.A. Interpass Temperature (Max): N.A.**WELDING PARAMETERS**

| Pass Number(s) | Electrode Diameter | Current      |                |             |                     | Travel Speed (ipm) | Joint Detail                                                                                                          |
|----------------|--------------------|--------------|----------------|-------------|---------------------|--------------------|-----------------------------------------------------------------------------------------------------------------------|
|                |                    | Type         | Amperage Range | Volts Range | Electrical Stickout |                    |                                                                                                                       |
| 1 - n          | E-9018-G Ø 1/8     | Continua (+) | 110 - 130      | 20 - 28     | ---                 | ---                |  <p>(A) SINGLE-V GROOVE WELD</p> |
|                |                    |              |                |             |                     |                    |                                                                                                                       |
|                |                    |              |                |             |                     |                    |                                                                                                                       |

Manufacture or Contractor: Ing. Wilmer Ramírez M., AGA S.A.Authorized by: Ing. Rodrigo Corral, NOVACERO Date 12 de Junio del 2006**QUITO**

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 PEDIDOS: 1-800-AGA GAS  
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**GUAYAQUIL**

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**CUENCA**

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 Fax: 284-5757

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Km. 2 1/2 Via a Quevedo  
 Telf.: 370-3940  
 Fax: 370-3957

**AMAZONIA**

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 Telf.: 288-1387  
 Fax: 288-1388  
 El Coca

APENDICE E

PROCEDURE QUALIFICATION RECORD

PQR N° 003

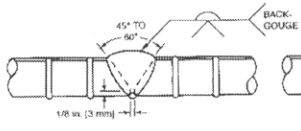
WELDING PROCEDURE SPECIFICATION

WPS N° 003

ELECTRODO E-7018

Referencia AWS D1.4/D1.4:2005

**PROCEDURE QUALIFICATION RECORD**  
**PQR N° 003**Contractor: AGA S.A.Authorized by: NOVACERORevision No. 001Welder: JOHN BAUTISTA ANGULOTest Date: 12-05-2006Welding Process: ☐ FCAW-S ☐ FCAW-G ☐ GMAW ☒ SMAWPQR JOINT TYPE: ☒ Direct Butt ☐ Indirect Butt ☐ T-JointTest Assembly: ☒ Figure 6.5 (A) ☐ Figure 6.5 (B) ☐ Figure 6.5 (C) ☐ Figure 6.5 (D)Position: 3G Groove Type: A TOPE ☒ Single Bevel ☐ Double BevelRoot Opening: 3 mm Root Face: 3 mm Groove Angle: 60°Backing: ☐ Yes ☒ No Backing Type: \_\_\_\_\_Backgouging: ☒ Yes ☐ No Backgouging Method: ESMERILADOTechnique: ☐ Stringers ☒ Weave**ELECTRICAL CHARACTERISTICS**Current: ☐ AC ☒ DCEP ☐ DCENTransfer Mode (GMAW) ☐ Short-circuiting ☐ Globular ☐ Spray**BASE METAL**Material Specification: ASTM A615M Grade: 420Welded to: Material Specification: ASTM A615M Grade: 420Carbon Equivalent (Bar): 0.50 % Bar size: 28 mmCoated Bar: ☐ Yes ☒ No Type of Coating: \_\_\_\_\_**FILLER METAL**AWS Specification: A 5.1 AWS Classification: E-7018Describe filler metal (If not covered by AWS specifications) N.A.**SHIELDING**Gas: ☐ Single ☐ Mixture Composition: \_\_\_\_\_ Flow rate: \_\_\_\_\_**PREHEAT/INTERPASS**Preheat/Interpass temperature (Min): N.A.Interpas Temperature (Max): N.A.**WELDING PARAMETERS**

| Pass Number(s) | Electrode Diameter | Current      |                |             |                     | Travel Speed (ipm) | Joint Detail                                                                                                      |
|----------------|--------------------|--------------|----------------|-------------|---------------------|--------------------|-------------------------------------------------------------------------------------------------------------------|
|                |                    | Type         | Amperage Range | Volts Range | Electrical Stickout |                    |                                                                                                                   |
| 1 - n          | E-7018 Ø 1/8       | Continua (+) | 130 - 150      | 22- 30      | ---                 | ---                | <br>(A) SINGLE-V GROOVE WELD |
|                |                    |              |                |             |                     |                    |                                                                                                                   |
|                |                    |              |                |             |                     |                    |                                                                                                                   |
|                |                    |              |                |             |                     |                    |                                                                                                                   |

Note: Attach additional sheets as required for detailing pass.

**QUITO**Av. Maldonado 10499  
PEDIDOS: 1-800-AGA GAS  
PBX: 267-3011  
FAX: 267-5126**GUAYAQUIL**Km. 11½ Via a Daule  
PEDIDOS: 1-800-AGA GAS  
Telfs.: 210-1060 / 210-1303  
CELULAR: 09-9202442  
FAX: 210-1153 / 210-0394**CUENCA**Sebastián de Benalcázar  
entre Gil Ramírez Dávalos  
y Av. España  
Telfs.: 280-8988/286-8753/4  
Fax: 286-8769**MANTA**Av. 113 No. 1104 y  
Calle 118  
Telefax: 292-0434  
292-2778**AMBATO**Av. Atahualpa Km. 2½  
Telf.: 284-6080  
Fax: 284-5757**SANTO DOMINGO**Km. 2½ Via a Quevedo  
Telf.: 370-3940  
Fax: 370-3957**AMAZONIA**Km. 1½ Via Coca - Lago Agall  
Telf.: 288-1387  
Fax: 288-1388  
El Coca

## Continuation of PQR N° 003

## TEST RESULTS

## VISUAL EXAMINATION

## Test Assembly Number One

☒ Pass ☐ Fail (AWS D1.4, Section 4.4)

Comments: -----

## Test Assembly Number Two

☒ Pass ☐ Fail (AWS D1.4, Section 4.4)

Comments: -----

## TENSILE TEST

## Test Assembly Number One

☒ Pass ☐ Fail (AWS D1.4, Section 6.3.7.2)

## Test Assembly Number Two

☐ Pass ☐ Fail (AWS D1.4, Section 6.3.7.2)

| Specimen No. | Width | Diameter (mm) | Area (mm <sup>2</sup> ) | Ultimate Tensile Load (Kg) | Ultimate Unit Stress (Kgf/mm <sup>2</sup> ) | Character of Failure and Location |
|--------------|-------|---------------|-------------------------|----------------------------|---------------------------------------------|-----------------------------------|
| 3            | ---   | 28            | 615.44                  | 35,381                     | 57.49                                       | Material Base                     |
|              |       |               |                         |                            |                                             |                                   |

## MACROETCH TEST

## Test Assembly Number One

☒ Pass ☐ Fail (AWS D1.4, Section 6.3.7.3)

## Test Assembly Number Two

☐ Pass ☐ Fail (AWS D1.4, Section 6.3.7.3)

| Specimen No. | Results  | Remarks |
|--------------|----------|---------|
| 3            | ACEPTADO | -----   |
|              |          |         |

Welder's Name: JOHN BAUTISTA ANGULO Clock No. 3 Stamp No. ---ATest conducted by: INEN, LABORATORIO DE ENSAYOS FISICOS Y MECANICOS (Laboratory)Test Number 2006-078Per Sr. Wilson Angulo

We, the undersigned, certify that statements in this record are correct and that welds were prepared and tested in accordance with requirements of AWS D1.4/D1.4M:2005, *Structural Welding Code---Reinforce Steel*

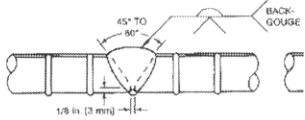
Manufacturer or Contractor: Ing. Wilmer Ramírez M., AGA S.A. Firma: Authorized by: Ing. Rodrigo Corral, NOVACERO Date: 12 de Junio del 2006

Referencia AWS D1.4/D1.4:2005

**WELDING PROCEDURE SPECIFICATION**  
**WPS N° 003**Contractor: **AGA S.A.**Authorized by: **NOVACERO**Revision No. **001**Supporting PQR Identification: **003**Test Date: **12-05-2006**WELDING PROCESS: ☐ FCAW-S ☐ FCAW-G ☐ GMAW ☒ SMAWWELD TYPE: ☒ Groove ☐ FilletJOINT TYPE: ☒ Direct Butt ☐ Indirect Butt ☐ T-JointJoint(s) Qualified (see Table 6.2): **FIG. 6.5 (A): COMPLETE JOINT PENETRATION GROOVE WELD - DIRECT BUTT JOINT.**Position: **3G** Groove Type: **A TOPE**Root Opening: **3 mm** Root Face: **3 mm** Groove Angle: **60°**Backing: ☐ Yes ☒ No Backing Type: \_\_\_\_\_Backgouging: ☒ Yes ☐ No Backgouging Method: **ESMERILADO**TECHNIQUE: ☐ Stringers ☒ Weave**ELECTRICAL CHARACTERISTICS**Current: ☐ AC ☒ DCEP ☐ DCENTransfer Mode (GMAW) ☐ Short-circuiting ☐ Globular ☐ Spray**BASE METAL**Material Specification: **ASTM A615M** Grade: **420**Welded to: Material Specification: **ASTM A615M** Grade: **420**Maximum Carbon Equivalent: **0.50 %** Bar size: **28 mm** Plate Thickness: **N.A.**Coated Bar: ☐ Yes ☒ No Type of Coating: \_\_\_\_\_**FILLER METAL**AWS Specification: **A 5.1** AWS Classification: **E-7018**

Describe filler metal (If not covered by AWS specifications) \_\_\_\_\_

**SHIELDING**Gas: ☐ Single ☐ Mixture Composition: \_\_\_\_\_ Flow rate: \_\_\_\_\_**PREHEAT/INTERPASS**Preheat/Interpass temperature (Min): **N.A.** Interpass Temperature (Max): **N.A.****WELDING PARAMETERS**

| Pass Number(s) | Electrode Diameter | Current      |                |             |                     | Travel Speed (ipm) | Joint Detail                                                                          |
|----------------|--------------------|--------------|----------------|-------------|---------------------|--------------------|---------------------------------------------------------------------------------------|
|                |                    | Type         | Amperage Range | Volts Range | Electrical Stickout |                    |                                                                                       |
| 1 - n          | E-7018 Ø 1/8       | Continua (+) | 130 - 150      | 22- 30      | ---                 | ---                |  |
|                |                    |              |                |             |                     |                    |                                                                                       |
|                |                    |              |                |             |                     |                    |                                                                                       |
|                |                    |              |                |             |                     |                    |                                                                                       |

(A) SINGLE-V-GROOVE WELD

Manufacture or Contractor: **Ing. Wilmer Ramírez M., AGA S.A.**Authorized by: **Ing. Rodrigo Corral, NOVACERO** Date **12 de Junio del 2006**

## APENDICE F

### REPORTE DE ENSAYO MECANICO



LABORATORIO DE  
ENSAYOS FISICOS Y  
MECANICOS

## INFORME DE ENSAYOS

LEFM No.: 2006-078

Fecha: 2006-05-29

Páginas: 2 de 2

### RESULTADO DE LOS ENSAYOS

#### ENSAYO: TRACCIÓN

NORMA DE ENSAYO No.: NTE INEN 109.....

MÉTODO DE ENSAYO: Cuantitativo.....

UNIDAD DE MEDIDA: kgf / mm<sup>2</sup>.....

LUGAR DE EJECUCIÓN DEL ENSAYO: Laboratorio de Ensayos Físicos y Mecánicos.....

CONDICIONES AMBIENTALES: TEMPERATURA (°C) .....20 ± 5..... HUMEDAD RELATIVA (%): .....60 ± 5.....

CUADERNO DE TRABAJO: Págs.

#### EQUIPO: Máquina Universal de Ensayos RAT

Capacidad: 200000 kgf

Rango: 50000 kgf

Calibrador Pie de Rey MITUTOYO

Amplitud: 300 x 0,02 mm

### DATOS OBTENIDOS

Código de Muestra: VAC-2006-130

\* Material: acero para hormigón armado

\* Características : varilla con resaltes

\* Especificación: ASTM A615M Grado 420

\* Diámetro: 28mm

\* Proceso de Soldadura: SMAW

\* Electrodo: E-7018 (1 probeta) y E-9018-G H4R (4 probetas)

\* Diámetro de los electrodos: 1/8" (3.2 mm)

| Probeta No. | * Prueba No. | * Tipo de Junta | * Posición | * Electrodo | Límite de Fluencia kgf/mm <sup>2</sup> | Resistencia la Tracción kgf/mm <sup>2</sup> | Alargamiento % |
|-------------|--------------|-----------------|------------|-------------|----------------------------------------|---------------------------------------------|----------------|
| 1           | 1            | a tope en V     | 3G         | E-9018-G    | 31,67                                  | 57,41                                       | 22,23          |
| 2           | 2            | a tope en V     | 3G         | E-9018-G    | 31,67                                  | 57,25                                       | 22,79**        |
| 3           | --A          | a tope en V     | 3G         | E-7018      | 31,67                                  | 57,49                                       | 22,96**        |
| 4           | 1            | Traslape        | 1G         | E-9018-G    | -----                                  | 31,02                                       | -----          |
| 5           | 2            | Traslape        | 1G         | E-9018-G    | -----                                  | 31,99                                       | -----          |

\* Datos proporcionados por la Empresa.

\*\* Rompió fuera de marcas

LOS RESULTADOS DE ESTE INFORME SON EXCLUSIVOS DE LAS MUESTRAS ENSAYADAS.

ESTE INFORME NO SIGNIFICA CERTIFICACIÓN DE CALIDAD. NO DEBE SER USADO CON FINES PUBLICITARIOS Y NO DEBE SER REPRODUCIDO SIN AUTORIZACIÓN ESCRITA Y CERTIFICADA DEL ENTE EMISOR.

### RESPONSABLES

Sr. Wilson Angulo

LABORATORIO DE ENSAYOS FISICOS  
Y MECANICOS

AB

APENDICE G

ELECTRODO E9018-G H4R

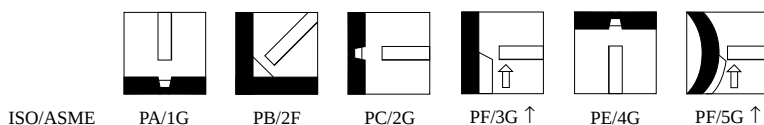
## Clasificación

AWS A5.5 : E9018-G H4R  
UNE-EN 757: E 55 6 Z B 32 H5

## Descripción General

Electrodo básico para todas posiciones en offshore para aceros de alto límite elástico (Lím.Elást. 420-500 N/mm<sup>2</sup>)  
Rendimiento 110-120%  
Contenido en hidrógeno extremadamente bajo ( $H_{DM} < 3\text{ml}/100\text{ g}$ )  
Excelentes propiedades de impacto a -60°C  
Buen CTOD a -10°C  
Empaquetado al vacío en Sahara Ready Pack  
También disponible en paquetes de cartón

## Posiciones de Soldadura



## Tipo de Corriente

CA / CC electr. +/-

## Homologaciones

UDT

+

## Composición química (% en peso), típica, metal depositado

| C    | Mn  | Si  | P     | S    | Ni  |
|------|-----|-----|-------|------|-----|
| 0,05 | 1,6 | 0,3 | 0,015 | 0,01 | 1,5 |

## Propiedades mecánicas, metal depositado

| Condición          | Lim. Elast.0,2%<br>(N/mm <sup>2</sup> ) | R. Tracción<br>(N/mm <sup>2</sup> ) | Alargamiento<br>(%) | Impacto ISO-V(J)<br>-40°C -50°C -60°C |     |         |
|--------------------|-----------------------------------------|-------------------------------------|---------------------|---------------------------------------|-----|---------|
| Sin tratamiento    |                                         |                                     |                     | --                                    | --  | --      |
| Requerido AWS min. | 530                                     | 620                                 | 17                  | --                                    | --  | --      |
| Requerido EN       | 550 min                                 | 610-780                             | 18 min              | --                                    | --  | 47 min. |
| Valores típicos    | 570                                     | 650                                 | 22                  | 140                                   | 110 | 60      |

CTOD- valores a -15°C > 0.30 mm

## Empaquetado, tamaños disponibles e identificación

|                                 |     |     |     |     |
|---------------------------------|-----|-----|-----|-----|
| Diámetro(mm)                    | 2,5 | 3,2 | 4,0 | 5,0 |
| Longitud (mm)                   | 350 | 450 | 450 | 450 |
| Unidad: Sahara Ready Pack (SRP) |     |     |     |     |
| Piezas/unid.                    | 70  | 50  | 28  | 23  |
| Peso neto/unid. (Kg)            | 1,4 | 2,4 | 2,0 | 2,5 |
| Unidad: Paquete                 |     |     |     |     |
| Piezas/unid.                    | 135 | 120 | 85  | 55  |
| Peso neto/unid. (Kg)            | 2,7 | 5,8 | 5,9 | 5,7 |

Identificación

Marcado: Kryo2/9018-G

Color punta: Verde

Nota: Lincoln KD,S.A. se reserva el derecho de modificar sin previo aviso las características de los productos presentados en este documento, y puede considerarse únicamente como guía de consulta.

## Materiales a soldar

|                           |            |                                     |
|---------------------------|------------|-------------------------------------|
| Acero general estructural | EN 10025   | S355                                |
| Acero fundido             | EN 10213-2 | GP240R                              |
| Tubería                   | EN 10208-1 | L290GA, L360GA                      |
|                           | EN 10208-2 | L290, L360, L415, L445, L480        |
|                           | API 5LX    | X42, X46, X52, X60, X65, X70        |
|                           | EN 10216-1 | P275 T1                             |
|                           | EN 10217-1 | P275 T2, P355N                      |
| Acero de grano fino       | EN 10113-2 | S275, S355, S420, S460              |
|                           | EN 10113-3 | S275, S355, S420, S460              |
|                           | EN 10137-2 | S460, S500                          |
| Acero baja temperatura    | EN 10028-4 | 11 MnNi 5-3, 13 MnNi 6-3, 15 NiMn 6 |
|                           | EN 10222-3 | 13 MnNi 6-3, 15 NiMn 6              |

## Hoja de cálculo

| Tamaño<br>Diam.xlong.<br>(mm) | Corriente<br>Rango<br>(A) | Tipo | Tiempo<br>por electrodo<br>(s)* | Energía<br>E (KJ) | V. Dep.<br>a Intensidad máx.<br>H(kg/h) | Peso/<br>1000 unid.<br>(kg) | Electrodos/<br>kg metal dep.<br>B | kg Electrodos/<br>kg metal dep.<br>1/N |
|-------------------------------|---------------------------|------|---------------------------------|-------------------|-----------------------------------------|-----------------------------|-----------------------------------|----------------------------------------|
| 2,5x350                       | 55-85                     | CC+  | 59                              | 85                | 0,72                                    | 20,0                        | 86                                | 1,65                                   |
| 3,2x450                       | 80-140                    | CC+  | 80                              | 268               | 1,2                                     | 48,3                        | 36                                | 1,70                                   |
| 4,0x450                       | 120-170                   | CC+  | 89                              | 445               | 1,8                                     | 69,4                        | 22                                | 1,52                                   |
| 5,0x450                       | 180-240                   | CC+  | 96                              | 598               | 2,6                                     | 103,6                       | 14                                | 1,51                                   |

\*punta: 35 mm

## Parámetros óptimos de soldadura

| Posición<br>Diámetro (mm) | 1G<br>Intensidad (A) | 2F  | 2G  | 3G<br>(ascen.) | 4G  | 5G<br>(ascen.) |
|---------------------------|----------------------|-----|-----|----------------|-----|----------------|
| 2,5                       | 80                   | 80  | 80  | 85             | 80  | 80             |
| 3,2                       | 140                  | 120 | 145 | 120            | 120 | 120            |
| 4,0                       | 150                  | 140 | 150 | 140            | 135 | 140            |
| 5,0                       | 220                  | 210 | 210 | 170            |     |                |

APENDICE H  
ELECTRODO E7018

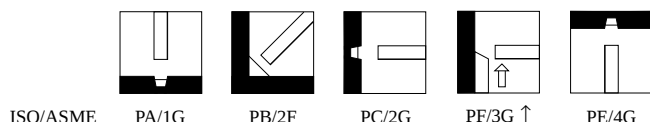
## Clasificación

AWS A5.1 : E7018-1  
UNE-EN 499: E 42 4 B 22 H5

## Descripción General

**Electrodo básico, de muy bajo contenido en hidrógeno.**  
**Excelente para soldadura en general.**  
**Excelentes propiedades al impacto a -46°C.**

## Posiciones de Soldadura



## Tipo de Corriente

CC +/-  
CA (OCV>75V)

## Homologaciones

| LR     | BV      | ABS    | DNV    | TÜV | RINA   | GL     | DB | UDT |
|--------|---------|--------|--------|-----|--------|--------|----|-----|
| 4Y40H5 | 4Y40HHH | 4Y40H5 | 4Y40H5 | +   | 4Y40H5 | 4Y40H5 | +  | +   |

## Composición química (% en peso), típica, metal depositado

| C    | Mn  | Si  |
|------|-----|-----|
| 0,05 | 1,0 | 0,3 |

## Propiedades mecánicas típicas del metal depositado

| Condición          | Lim. Elast<br>(N/mm <sup>2</sup> ) | R. Tracción<br>(N/mm <sup>2</sup> ) | Alargamiento<br>(%) | Impacto ISO-V(J) |       |
|--------------------|------------------------------------|-------------------------------------|---------------------|------------------|-------|
|                    |                                    |                                     |                     | -40°C            | -46°C |
| Sin tratamiento    |                                    |                                     |                     |                  |       |
| Requerido AWS min. | 399                                | 482                                 | 22                  | --               | 27    |
| Requerido EN       | 420 min                            | 500-640                             | 20 min              | 47min            | --    |
| Valores típicos    | 436                                | 533                                 | 29                  | 100              | 90    |

## Empaquetado, tamaños disponibles e identificación

|                      |     |     |     |     |     |     |
|----------------------|-----|-----|-----|-----|-----|-----|
| Diámetro(mm)         | 2,5 | 3,2 | 3,2 | 4,0 | 4,0 | 5,0 |
| Longitud (mm)        | 350 | 350 | 450 | 350 | 450 | 450 |
| Unidad: Paquete      |     |     |     |     |     |     |
| Piezas/unid.         | 175 | 115 | 115 | 80  | 80  | 55  |
| Peso neto/unid. (Kg) | 3,9 | 4,0 | 5,2 | 4,1 | 5,3 | 5,6 |

Identificación

Marcado: LINCOLN 7018-1 / 7018-1

Nota: Lincoln KD,S.A. se reserva el derecho de modificar sin previo aviso las características de los productos presentados en este documento, y puede considerarse únicamente como guía de consulta.

## Materiales a soldar

|                      |             |                                   |
|----------------------|-------------|-----------------------------------|
| Acero estructural    | EN 10025    | S185, S235, S275, S355            |
| Chapa naval          |             | Grado A, B, C, D, A(H)32 a D(H)36 |
| Acero fundido        | EN 10213-2  | GP240R                            |
| Tubería              | EN 10208-1  | L210, L240, L290, L360            |
|                      | EN 10208-2  | L240, L290, L360, L415            |
|                      | API 5LX     | X42, X46, X52, X60                |
|                      | EN 10216-1/ | P235T1, P235T2, P275T1            |
|                      | EN 10217-1/ | P275T2, P355N                     |
| Calderería           | EN 10028-2  | P235GH, P265GH, P295GH, P355GH    |
| y aparatos a presión |             |                                   |
| Acero de grano fino  | EN 10113-2  | S275, S355, S420                  |
|                      | EN 10113-3  | S275, S355, S420                  |

## Hoja de cálculo

| Tamaño<br>Diam.xlong.<br>(mm) | Corriente<br>Rango<br>(A) | Tipo | Tiempo<br>por electrodo<br>(s)* | Energía<br>E (KJ) | V. Dep.<br>a Intensidad máx.<br>H(kg/h) | Peso/<br>1000 unid.<br>(kg) | Electrodos/<br>kg metal dep.<br>B | kg Electrodos/<br>kg metal dep.<br>1/N |
|-------------------------------|---------------------------|------|---------------------------------|-------------------|-----------------------------------------|-----------------------------|-----------------------------------|----------------------------------------|
| 2,5x350                       | 70-90                     | DC+  | 59                              | 132               | 0.86                                    | 22,3                        | 71                                | 1.59                                   |
| 3,2x350                       | 100-130                   | DC+  | 65                              | 221               | 1.16                                    | 34,8                        | 48                                | 1.66                                   |
| 3,2x450                       | 100-135                   | DC+  | 75                              | 272               | 1.35                                    | 45,2                        | 36                                | 1.61                                   |
| 4,0x350                       | 130-180                   | DC+  | 64                              | 313               | 1.90                                    | 51,3                        | 29                                | 1.51                                   |
| 4,0x450                       | 130-190                   | DC+  | 77                              | 410               | 2.19                                    | 66,3                        | 21                                | 1.41                                   |
| 5,0x450                       | 220-260                   | DC+  | 84                              | 657               | 3.03                                    | 101,8                       | 14                                | 1.43                                   |

\*punta: 35 mm

## Parámetros óptimos de soldadura

| Posición                     | 1G  | 2F  | 2G  | 3G ascend. | 4G  |
|------------------------------|-----|-----|-----|------------|-----|
| Diámetro (mm) Intensidad (A) |     |     |     |            |     |
| 2,5                          | 80  | 85  | 85  | 85         | 80  |
| 3,2                          | 120 | 115 | 115 | 115        | 110 |
| 4,0                          | 170 | 180 | 180 | 180        | 160 |
| 5,0                          | 240 | 250 | 250 | 250        | 230 |

## Observaciones

Utilizar electrodos secos.

Se recomienda resecar los electrodos en estufa a 350°C durante 1 hora, y luego mantenerlos, y utilizarlos, a 120°C.

## **BIBLIOGRAFIA**

1. AVNER, SYDNEY. "Introducción a la metalurgia física". 2<sup>da</sup> edición. México D.F. McGRAW HILL 1996.
2. ASKELAND, DONALD. "La Ciencia e Ingeniería de los materiales". Grupo Editorial IBEROAMERICA, 1985
3. INEN. "Código Ecuatoriano de la Construcción".
4. NTE INEN 102:2003. "Varillas con resaltes de acero al carbono laminadas en caliente para hormigón armado".
5. ASTM A615:A615M-01. "Standard Especification for Deformed and Plain Billet-Steel Bar for Concrete Reinforcement".
6. AWS D1.4/D1.4M:2005. "Structural Welding Code – Reinforcing Steel".
7. TESIS DE GRADO DE JULIO MEDINA MAZON. "Estudio sobre el efecto de los puntos de Soldadura en las Propiedades Mecánicas de los Hierros Corrugados de Producción Nacional".
8. ESPOL. "Seminario de Soldadura al Arco". 1980
9. ACI 318-05 "Building Code Requirements for Structural Concrete and Commentary". ACI Committee 318, 2005.