FERNANDO GROBERMAN

# QUALIFICAÇÃO DE PROCEDIMENTOS DE SOLDAGEM AÇO CARBONO RRSt 44.3 E AÇO INOXIDÁVEL 304L

Trabalho apresentado ao departamento
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SUMÁRIO:

# 1 INTRODUÇÃO:

A soldagem de metais ferrosos é muito provavelmente o meio mais barato, importante e versátil de união entre os materiais após os anos 30, quando utilizavam-se rebites. Sua importância caracteriza-se pelo fato de unir todos os metais ferrosos comerciais, de ser aplicado em qualquer local, qualquer posição, por propiciar flexibilidade de projeto, por reduzir custos de produção e fabricação, e pela facilidade em ser utilizado em recuperação e manutenção de produtos e manufaturados.

No caso de vasos de pressão, dada as condições de operação, ou seja, tensões exercidas nas paredes, o controle de qualidade é um aspecto importante para garantir um bom funcionamento do produto soldado, ou ainda, é um aspecto de vital importância para prevenir/evitar acidentes, que neste caso podem ser desastrosos e às vezes fatais.

Dadas as condições expostas acima, este trabalho está direcionado no sentido de qualificar/aprovar os processos de soldagem baseado no código ASME em vigor, bem como possibilitar comparações entre eficiência dos processos / materiais e conseqüências microestruturais.

# 2 REVISÃO DA LITERATURA

## 2.1 Descrição dos Processos:

a. Processo TIG:

O processo TIG utiliza como fonte de calor um arco elétrico mantido entre um eletrodo não consumível de Tungstênio e a peça a soldar. A proteção da região de soldagem é feita por um fluxo de gás inerte. A soldagem pode ser feita com ou sem metal de adição e pode ser manual ou automática.

Este processo foi patenteado no fim dos anos 20, porém só foi comercialmente utilizado em 1942, nos Estados Unidos, para a soldagem em liga de Magnésio de assentos de aviões. A princípio utilizou-se o gás Hélio e a corrente contínua, devido à dificuldade em estabilizar o arco, posteriormente superada.

Atualmente o processo TIG é mais utilizado na soldagem de ligas de Alumínio, de Magnésio, de Titânio, e aços inoxidáveis, entre outros. A solda produzida é de muito boa qualidade.

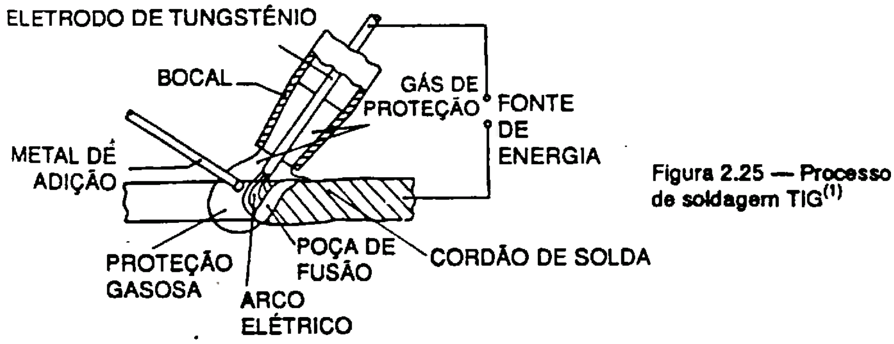



Figura 1. Processo de Soldagem TIG

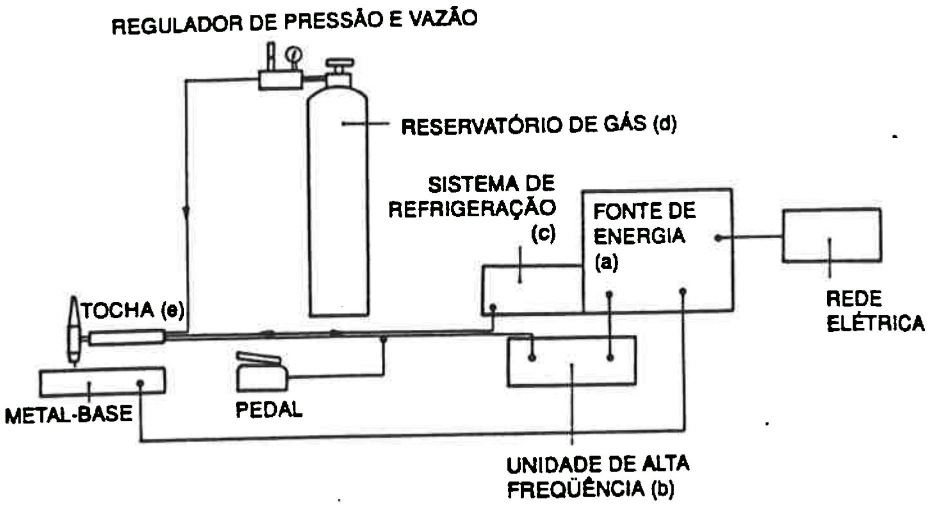



**Figura 2. Esquema Simplificado dos Equipamentos Necessários para o Processo.**

**As variáveis para a qualificação do procedimento de soldagem, segundo a norma ASME Secção IX, são: metal base; metal de adição; pré-aquecimento; tipo de gás de proteção; tipo de junta; posições de soldagem; características**

elétricas e técnicas da soldagem, sendo as quatro primeiras consideradas essenciais.

Para a qualificação do soldador, segundo a norma ASME Secção IX, são variáveis essenciais: tipo de junta; metal base e de adição; posição de soldagem; tipo de gás de proteção; e características elétricas.

A tabela a seguir ilustra o tipo de gases de proteção usados no processo TIG.

| Argônio | Hélio |
|---|---|
| Baixa tensão de arco | Elevada tensão de arco |
| Menor penetração | Maior penetração |
| Adequado à soldagem de chapas finas | Adequado à soldagem de grandes espessuras e materiais de condutibilidade térmica elevada |
| Soldagem manual devido ao pequeno gradiente de tensão na coluna do arco (6 V/cm) | Soldagem automática |
| Maior ação de limpeza | Menor ação de limpeza |
| Arco mais estável | Arco menos estável |
| Fácil abertura do arco | Dificuldade na abertura do arco |
| Utilizado em CC e CA | Geralmente CCPD com eletrodo de tungstênio toriado |
| Custo reduzido | Custo elevado |
| Vazão para proteção pequena | Vazão para proteção de 2 a 3 vezes maior que a de argônio |
| Maior resistência à corrente de ar lateral | Menor resistência à corrente de vento |

b. Processo MAG:

O processo MAG utiliza como fonte de calor um arco elétrico mantido entre um eletrodo nu consumível, alimentado continuamente, e a peça a soldar. A proteção da região de soldagem é feita por meio de um fluxo de gás ativo, podendo ser a soldagem semi automática ou automática.

O processo MAG é utilizado na soldagem de aços de baixo carbono e aços de baixa liga.

As principais vantagens do processo são:

- processo semi automático bastante versátil. podendo ser adaptado facilmente para a soldagem automática;
- o eletrodo nu é alimentado continuamente;
- a soldagem pode ser executada em todas as posições;
- a velocidade de soldagem é elevada;
- taxa de deposição elevada devido à densidade de corrente alta na ponta do arame;
- não há formação de escória e, conseqüentemente, não se perde tempo na sua remoção, nem se corre o risco de inclusão de escória na soldagem em vários passes;
- penetração de raiz mais uniforme que no processo de eletrodo revestido;
- processo com baixo teor de Hidrogênio, ficando ao redor de 5 ppm/100 g de metal;
- problemas de distorção e tensões residuais diminuídos;
-soldagem com visibilidade total da peça de fusão;
- possibilidade de controlar a penetração e a diluição durante a soldagem;
- o soldador pode ser facilmente treinado para soldar em todas as posições.

As limitações são:

- maior velocidade de resfriamento por não haver escória, o que aumenta a ocorrência de trincas, principalmente no caso de aços temperáveis;
- a soldagem deve ser protegida de correntes de ar;
- como o bocal da pistola precisa ficar próximo do metal base a ser soldado, a operação não é fácil em locais de acesso difícil;
- projeções de gotas do metal líquido durante a soldagem;
- grande emissão de raios ultravioleta;
- equipamento de soldagem mais caro e complexo que o do processo com eletrodo revestido;
- equipamento menos portátil que o do processo com eletrodo revestido.

A tabela a seguir representa as características das soldagem pelo processo MIG/MAG.

<table>
<tr><td>Tipo de operação:<br><br>semi-automática ou<br>automática</td><td>Equipamentos:<br>Gerador, retificador<br>Pistola<br>Cilindro de gases<br>Unidade de alimentação do eletrodo nu</td></tr>
<tr><td rowspan="2">Características:<br>Taxa de deposição: 1 a 15 kg/h<br>Espessuras soldadas: 3 mm mínima na soldagem semi-automática e 1,5 mm na soldagem automática<br>Posições de soldagem: todas<br>Diluição: 10 a 30%<br>Tipo de juntas: todas<br>Faixa de corrente: 60 a 500 A</td><td>Custo do equipamento:<br>5 a 10 vezes o custo do equipamento de eletrodo revestido</td></tr>
<tr><td>Consumíveis:<br>Eletrodo nu 0,5 a 1,6 mm<br>Bocal<br>Gases: argônio, hélio, $CO_2$ e misturas (argônio + $CO_2$: argônio + oxigênio)</td></tr>
<tr><td>Vantagens:<br>Taxa de deposição elevada<br>Poucas operações de acabamento<br>Solda com baixo teor de hidrogênio<br>Facilidade de execução da soldagem</td><td>Limitações:<br>Velocidade de resfriamento elevada com possibilidade de trincas<br>Dificuldade na soldagem em locais de difícil acesso</td></tr>
<tr><td colspan="2">Segurança:<br>Proteção ocular<br>Proteção da pele para evitar queimaduras pela radiação ultra-violeta e projeções metálicas</td></tr>
</table>

Figura 3. Esquema dos Equipamentos para o Processo MAG.

As variáveis do processo segundo a norma ASME Secção IX para a qualificação do procedimento são: metal base; metal de adição; tratamento térmico após soldagem; pré-aquecimento; características elétricas e técnicas de soldagem; tipo de gás de proteção; tipo de junta e posição de soldagem, sendo as três primeiras consideradas essenciais, já o pré-aquecimento e o tipo de gás de proteção podem ser essenciais ou não, dependendo da aplicação.

Para a qualificação do soldador todas as variáveis acima mencionadas são essenciais.

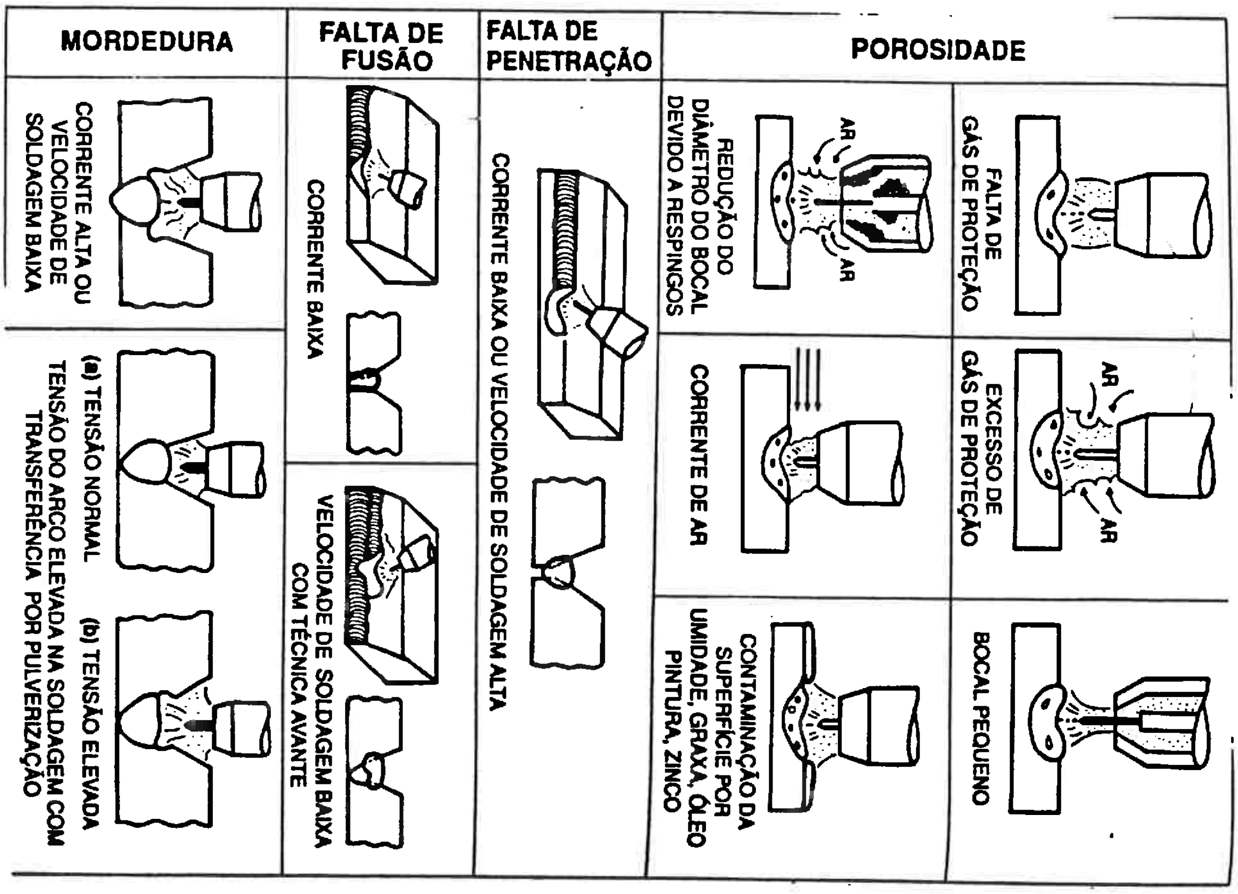



Figura 4. Defeitos mais comuns na soldagem pelo processo MAG.

c. Processo Eletrodo Revestido:

A soldagem com eletrodos revestidos é definida como um processo de soldagem com arco, onde a união é produzida pelo calor do arco criado entre um eletrodo revestido e a peça a soldar.

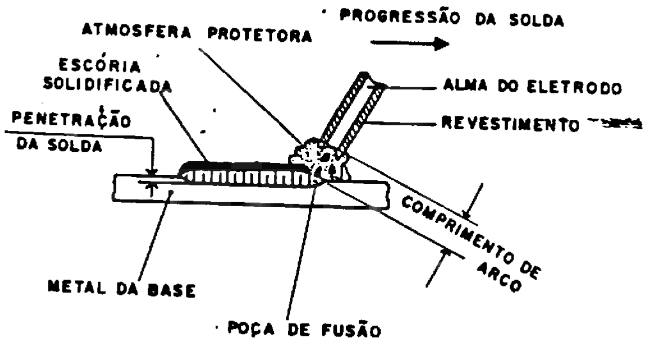



Figura 5. Esquema de funcionamento do processo com eletrodo revestido.

O equipamento básico para a soldagem com eletrodo revestido consiste de uma fonte de energia; alicate para fixação dos eletrodos; cabos de interligação; pinça para ligação à peça; equipamento de proteção individual e equipamento para limpeza da solda.

O uso de corrente contínua é normalmente associado à melhor estabilidade de arco e qualidade de depósitos, em detrimento da suscetibilidade ao sopro magnético. O uso de corrente alternada reduz essa suscetibilidade, mas a estabilidade de arco e a facilidade de ignição são inferiores, porém um fator que favorece é a queda de tensão ao longo do cabo de ligação, que é comparativamente menor.

Uma característica importante da soldagem com eletrodos revestidos, que o diferencia dos demais processos semi-automáticos convencionais, é que a tensão de arco não é controlável independentemente dos outros parâmetros, pelas seguintes razões:

- o controle da distância entre o eletrodo e a peça é realizado manualmente e não pode ser executado com grande precisão;

- a transferência dos glóbulos no arco está associada a variações consideráveis no comprimento efetivo do arco;
- maiores tensões são requeridas para operação normal, à medida que a corrente de soldagem é aumentada.

A corrente de soldagem controla de forma bastante predominante todas as características operatórias do processo, o aspecto do cordão e as propriedades da junta soldada. Ela controla de modo direto a magnitude e a distribuição espacial da energia térmica disponível no arco elétrico e também a maior parte dos fenômenos que ali ocorrem.

A velocidade de avanço é a segunda mais importante variável operatória do processo, apesar de seu controle ser consideravelmente impreciso no caso de aplicações manuais. Altura e largura do cordão variam inversamente com a velocidade de avanço. Assim, altas taxas de deposição podem ser obtidas, concomitantemente com microestruturas mais refinadas, tanto na zona fundida como na termicamente afetada.

A oscilação do eletrodo tem um caráter intrinseco na soldagem com este processo e é necessária para a obtenção de formatos satisfatórios de cordão.

Os diâmetros de eletrodos normalmente disponíveis variam de 1 a 8 mm e o comprimento de 350 a 470 mm. O diâmetro é um dos principais fatores limitantes da faixa útil de corrente de soldagem, na medida em que ele controla a densidade de corrente elétrica por unidade de área de secção transversal da alma.

O ângulo do eletrodo em relação à peça é normalmente ajustado no sentido de equalizar o fluxo térmico entre as partes soldadas, controlar o banho na poça de fusão e o formato do cordão, em particular, a molhabilidade do líquido nas bordas do chanfro. Portanto é uma variável importante para o controle da ocorrência de defeitos de cordão.

Os eletrodos para soldagem são normalmente obtidos através da extrusão, sob pressão de um revestimento sobre a alma, usualmente um arame endireitado e cortado na dimensão. Os revestimentos consistem de misturas de compostos minerais ou orgânicos, às quais são adicionadas, como aglomerantes, outros compostos com finalidades específicas.

A classificação e normalização dos eletrodos segue a norma ISO 2560, como explicado a seguir:

| | |
|---|---|
| E | - Designa eletrodo revestido; |
| Exx | - Define os limites mínimos de resistência e escoamento; |
| Exxy | - Define o alongamento percentual e temperatura de ensaio; |
| ExxyZZ | - Define o tipo de revestimento. |

O campo de aplicação dos eletrodos revestidos é na atualidade o mais vasto entre todos os processos de soldagem pela sua simplicidade, facilidade de acesso e baixo custo. a variedade de procedimentos aplicáveis é também ampla, indo desde os mais simples serviços de ponteamento até o mais rígido controle na fabricação de vasos nucleares.

O critério para a escolha de um procedimento de soldagem deve incluir a necessidade de estabelecer o balanço ótimo entre o custo da realização, a qualidade do depósito e a segurança dos operadores.

## 2.2 Descrição dos Materiais:

a. Aço Carbono RRSt 44.3:

Norma Básica: DIN 17100-81

Aço Soldável DIN RRSt 44.3

Composição Química:

| Símb. | Elemento | Valor | Símb. | Elemento | Valor | Símb. | Elemento | Valor |
|---|---|---|---|---|---|---|---|---|
| C | Carbono | ≤ 0,25 | S | Enxofre | ≤ 0,05 | | | |
| Mn | Manganês | ≤ 1,50 | N | Nitrogênio | ≤ 0,01 | | | |
| Si | Silicio | ≤ 0,50. | | | | | | |
| P | Fósforo | ≤ 0,05 | | | | | | |

Tab.1 Composição Química em %

Propriedades Mecânicas a Temperatura Ambiente

| Símbolo | Denominação | Unidade | Valor |
|---|---|---|---|
| Rm | Resistência a tração | N/mm² | 410-540 |
| $R_p$ 0,2 | Limite de escoamento | N/mm² | ≥ 265(1) |
| A 5 | Alongamento em Transversal 5) | % | ≥ 20 |

| Símbolo | Denominação | | Unidade | Valor |
|---|---|---|---|---|
| AKV (ISO V) | Resiliência | 0°C | J | ≥ 27 (2) |
| | Longitudinal | - 20°C | | ≥ 23 |
| HB | Dureza Brinell | | | 120-160 |
| | | | | |

Tab.2 Propriedades Físicas a Temperatura Ambiente.

Tratamento Térmico: normalizado

Limite de formação de casca de óxido: 530 graus C

Resistência ao Envelhecimento: Nada consta

Carbono Equivalente *, Max. : 0,49 % (4)

*Fórmula:

$$C_{eq}=C\%+Mn\%/6+Mo\%/4+(Cr\%+V\%)/5+Ni\%/15+Cu\%/13+P\%/2+Si\%/24$$

(1) Válido para espessuras <= 40mm.

(2) Válido para espessuras <= 63 mm

(3) "RR" aço especialmente acalmado

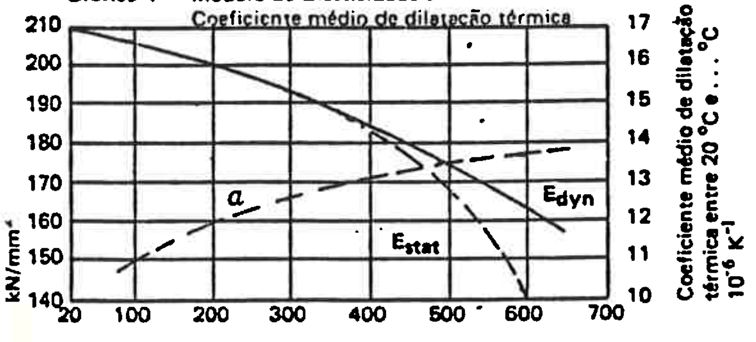
(4) Válido somente para espessuras > 25 mm

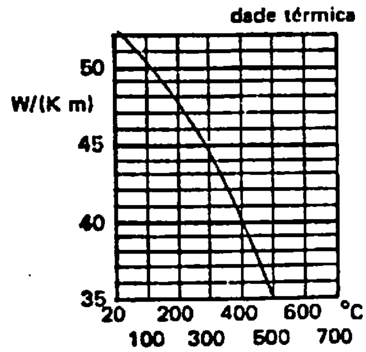
(5) Válido para espessuras <= 40mm

| Temperatura °C | Resistência à tração $R_m$ N/mm² mín. | Limite de Escoamento $R_e$ N/mm² mín. | Resistência ao Envelhecimento $R_m/10^5/t$ N/mm² mín. | | Módulo de Elasticidade $E_{stat}$ kN/mm² | $E_{dyn}$ kN/mm² | Coeficiente médio de dilatação térmica entre 20°C e ..., °C $10^{-6} \cdot K^{-1}$ α | Condutibilidade térmica λ W/(K·m) |
|---|---|---|---|---|---|---|---|---|
| 20 | 410 | 265 | | | 211 | 211 | - | 53 |
| 100 | | | | | 207 | 207 | 11,0 | 51 |
| 200 | | | | | 200 | 200 | 12,0 | 48 |
| 300 | | | | | 193 | 193 | 12,7 | 44 |
| 350 | | | | | 189 | 189 | 13,0 | 42 |
| 400 | | | | | 183 | 184 | 13,2 | 40 |
| 450 | | | | | 177 | 180 | 13,3 | 37 |
| 500 | | | | | 168 | 175 | 13,5 | 35 |
| 550 | | | | | 157 | 170 | 13,6 | - |
| 600 | | | | | 142 | 164 | 13,7 | - |

Tab.3 Propriedades Mecânicas e Físicas na Temperatura de 20 graus C

Fig.6. Gráficos das características mecânicas e físicas



b. Aço inoxidável austenítico 304L

Composição Química: c=0,03% máx. Cr=19% Ni=10%

Norma Básica: NBR 5601

Características gerais: Aço cromo-níquel inoxidável austenítico de extra baixo teor de carbono. Antimagnético, Não temperável. Possui eventualmente pequenos teores de ferrita, apresentando então um leve magnetismo. Quando deformado a frio, torna-se parcialmente martensítico e ligeiramente magnético.

Possui boa resistência à corrosão.

Tem a propriedade de manter boas características de tenacidade até temperaturas extremamente baixas, o que torna um material adequado para aplicações criôgenicas sujeitas a choques e impactos.

Caracteriza-se também por apresentar um coeficiente de dilatação térmica linear, 50% maior do que para os aços carbono comuns.

No estado recozido, as propriedades mecânicas são:

Dureza: 160 HB

Limite de resistência: 520 MPa

Limite de escoamento: 220 MPa

Alongamento: 40%

Estricção:60%

Resistência à corrosão: O aço 304L apresenta suas melhores características de resistência à corrosão no estado solubilizado e com a superfície finamente polida.

Solda: Basicamente, o aço 304L pode ser soldado pelos processos usuais de solda; entretanto, deve-se evitar, sempre que possível o uso de solda oxi-acetilênica. Na grande maioria dos casos, não é necessário realizar qualquer tratamento térmico após a soldagem. Contudo peças que ficarão expostas a agentes agressivos severos, recomenda-se um recozimento para solubilização em seguida à soldagem.

## 2.3 DESCRIÇÃO DOS ENSAIOS:

### 2.3.1 EXAME VISUAL:

O exame visual é o ensaio não destrutivo básico que tem como finalidade detectar defeitos de geometria da junta antes da soldagem tais como ângulo do bisel, ângulo do chanfro, abertura da raiz e alinhamento das partes a serem soldadas. Após a operação de soldagem tem como finalidade detectar possíveis descontinuidades induzidas na soldagem, tais como as previamente descritas.

As principais vantagens para este ensaio são: é o ensaio não destrutivo de mais baixo custo; permite detectar e eliminar possíveis descontinuidades; se bem realizado diminui a quantidade posterior de reparos e conseqüentemente diminui o custo da obra.

A principal limitação para o ensaio esta relacionada a grande experiência do inspetor em soldagem; limitando a detecção de defeitos superficiais.

### 2.3.2 ENSAIO POR PARTÍCULAS MAGNÉTICAS:

O ensaio de partículas magnéticas é utilizado para localizar descontinuidades superficiais e sub-superficiais em peças de material ferromagnético, tais como ligas de Fe e Ni. O método consiste na aplicação de uma corrente de magnetização, ou de um campo magnético à peça inspecionada, com o objetivo de se ter um campo magnético nesta. A presença de descontinuidades superficiais ou sub-superficiais irá produzir campos de fuga na região da descontinuidade, causando uma polarização localizada, que é detectada pelas partículas ferromagnéticas que são aplicadas sobre a peça.

As principais técnicas de exame são : a) técnica de Yoke, que induz um campo magnético longitudinal, gerado por CA; b) técnica dos eletrodos onde ocorre injeção de CC na peça através de dois eletrodos; c)técnica da bobina um campo magnético longitudinal; d) técnica de contato direto com aplicação de CC pelas extremidades das peças. As partículas ferromagnéticas utilizadas por estas técnicas podem ser contrastadas com as cores preta, cinza ou vermelha, ou por luzes fluorescentes, visíveis sob luz negra.

As principais vantagens do ensaio são: detectada descontinuidades superficais; é mais barato que o exame por meio de líquido penetrante e fornece resultados imediatos.

As principais limitações do ensaio são: aplicável somente em materiais ferromagnéticos; o exame é dificultado em áreas com materiais de características magnéticas diferentes; limitado pela geometria da peça.

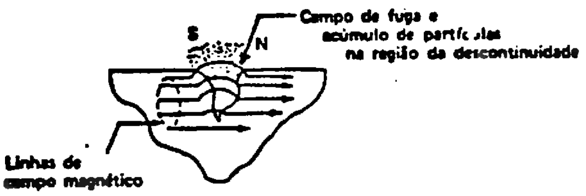



Fig.8. Detecção de descontinuidades por meio de partículas magnéticas

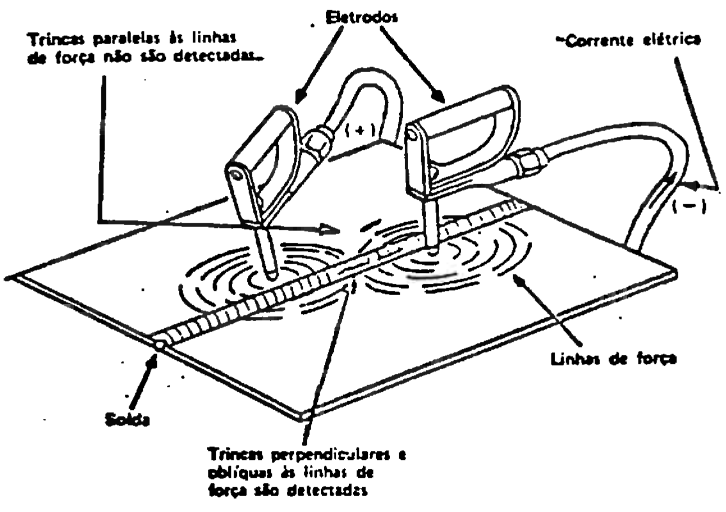



Fig 9. Ensaio por partícula magnética - Técnica dos eletrodos

### 2.3.3 ENSAIO POR LÍQUIDO PENETRANTE:

O ensaio de líquido penetrante é utilizado na detecção de descontinuidades abertas para a superfície de materiais sólidos não porosos. O ensaio se compõe em cinco etapas: 1) Limpeza inicial; 2) Aplicação do penetrante, que contém em solução ou suspensão, pigmentos coloridos para ambientes claros sendo visível com luz natural ou pigmentos fluorescentes para ambientes escuros sendo visível com luz UV; 3) Remoção do excesso de penetrante; 4) Aplicação do revelador, do tipo talco, e aplicado na forma seca, úmida ou líquida; 5) Inspeção final, para procurar indicações de descontinuidade.

As principais vantagens do ensaio são: boa sensibilidade até para detectar descontinuidade muito pequenas; independente da forma da peça; exame fácil, rápido e de baixo custo; aplicável em materiais magnéticos e não magnéticos.

As principais limitações do ensaio são: somente para descontinuidade abertas para a superfície; difícil remoção do resíduo penetrante.

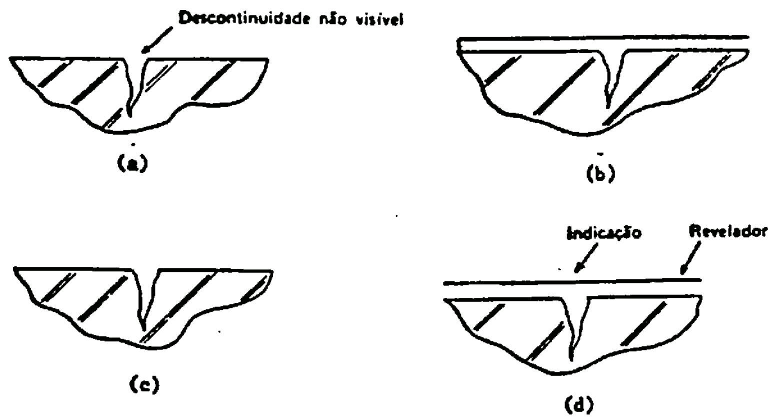



Fig 10. Ensaio por liquido penetrante

**2.3.4 ENSAIO POR ULTRA SOM:**

O ensaio por ultra-som consiste em emitir pulsos de alta frequência através de um transdutor com cristal piezoeléctrico, que caminham através do material. Estes pulsos refletem quando encontram uma descontinuidade interna ou superficial do material. Esta energia mecânica é recebida de volta pelo cristal, que converte estes em sinais elétricos, os quais podem ser monitorados. Os cabeçotes podem ser : normal, duplo cristal e angular.

As principais vantagens deste ensaio são: para qualquer material; permite locar e dimensionar com precisão as descontinuidades; executável em juntas com geometria complexa.

As principais limitações são: não se aplica em superfícies que impeçam o perfeito acoplamento do cabeçote a peça, o grão grosseiro de certos metais da base e da solda, particularmente ligas de Ni e aços inoxidáveis austeníticos, podem dispersar a onda de ultra-som; não indicado para peças pequenas ou pouco espessas; o equipamento ultra-som é caro; difícil interpretação, o que requisita técnicos com maior treinamento e experiência.

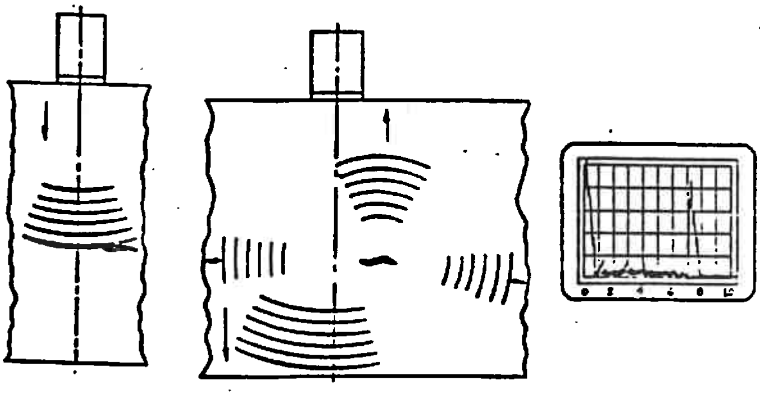


Fig 11. - Ensaio por ultra som.

## 2.3.5 ENSAIO RADIOGRÁFICO:

O ensaio radiográfico utiliza os raios X e raios gama para evidenciar a presença e certas características de descontinuidades internas ao material. O método consiste em propagar tais raios através do corpo sólido, e na ocorrência de vazios ou descontinuidades haverá uma diferença de comprimento de onda de radiação, logo o filme colocado no outro lado da peça irá se impressionar de maneira distinta. A vantagem dos raios-x sobre os raios gama é o fato de poder regular a tensão anódica e por conseqüente, o poder de penetração.

As principais vantagens deste ensaio são: registro permanente dos resultados; detectada facilmente defeitos volumétricos.

As principais limitações são: difícil avaliação de descontinuidade bidimensionais; é necessário acesso a ambas superfícies da peça; limitado pela geometria da peça; radiografia afeta a saúde dos operadores; custo do equipamento é alto; aparelho no máximo semi-portátil; difícil interpretação, o que requisita técnico com maior treinamento e experiência.

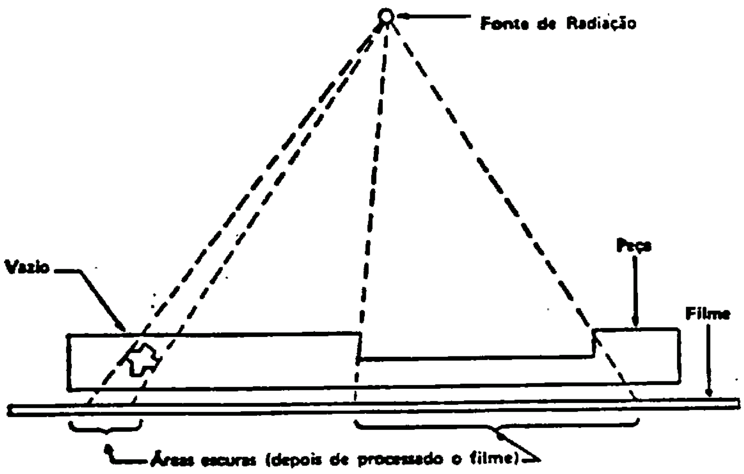



Fig. 12. Ensaio radiográfico

**2.3.6 ENSAIO DE TRAÇÃO:**

O ensaio de tração objetiva fornecer dados relativos à capacidade de um sólido, em suportar solicitações quando aplicado à uma estrutura, determinando o comportamento das propriedades de resistência tais como limite de escoamento e limite de resistência; e dutilidade tais como alongamento e redução de área. A verificação destas propriedades é feita através de uma máquina de ensaio que aplica esforços crescentes na direção axial de um corpo de prova c.p., cujas dimensões devem estar de acordo com uma norma, especificação ou capacidade da máquina . Como resultado de aplicação destas forças crescentes obtém-se um gráfico tensão versus deformação ,que mostra o comportamento elástico dom material. Na região plástica há o limite de escoamento (transição da região elástica e plástica), o limite de resistência (carga máxima atingida), e a tensão de ruptura (onde se dá a ruptura do c.p.). Entretanto é através da análise dimensional do corpo de prova que se conhece a dutilidade dos materiais. Isto é obtido através do acréscimo de comprimento de referência, depois da ruptura, em relação ao comprimento inicial do c.p., ou seja, o alongamento percentual; e através do coeficiente de estricção (ou redução de área), que é a relação em porcentagem entre a diminuição de área da seção transversal relativamente a área inicial, por ocasião da ruptura, e a área inicial.

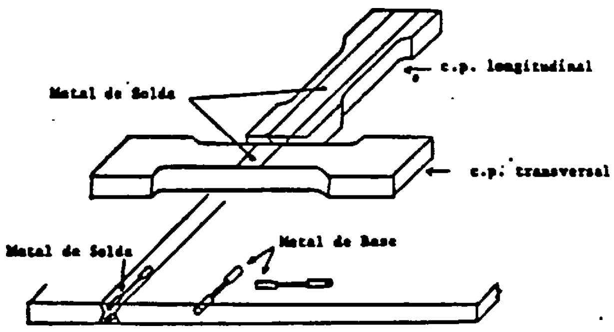



Fig.13. Corpos de Prova para ensaio de tração

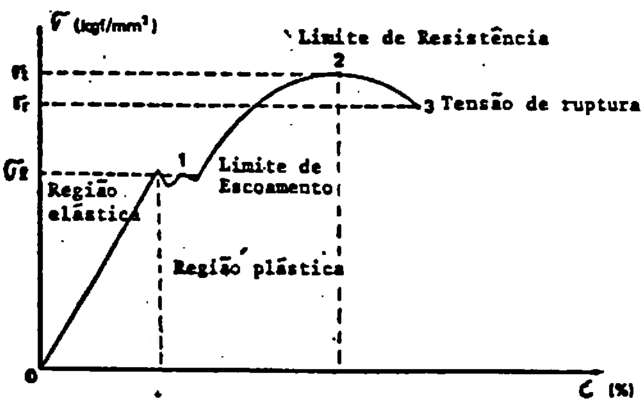



Fig.14 Curva tensão-deformação

## 2.3.6 ENSAIO DE DOBRAMENTO:

O ensaio de dobramento fornece uma indicação qualitativa da dutilidade do material. Consiste em dobrar um corpo de prova de eixo retilíneo e secção circular, tubular, retangular ou quadrada, assentada em dois apoios afastados a uma distância especificada, de acordo com o tamanho do c.p., por intermédio de um cutelo, que aplica um esforço de flexão neste c.p. até que seja atingido um ângulo de dobramento especificado. Atingido este ângulo, examina-se a olho nu a zona tracionada do c.p., que não deve conter trincas ou descontinuidades acima de um determinado valor. Se o c.p. apresentar estes defeitos ou romper antes de atingir o ângulo especificado, o material não passou no ensaio. Para juntas de topo, dependendo da região da solda a ser examinada, o ensaio pode ser realizado de 5 maneiras distintas: dobramento lateral transversal, transversal de face, transversal da raiz, longitudinal da face e longitudinal da raiz. Convém salientar que no caso de juntas soldadas é utilizado o método de dobramento guiado, sendo que os apoios devem ser bem lubrificados para diminuir ao máximo o atrito.

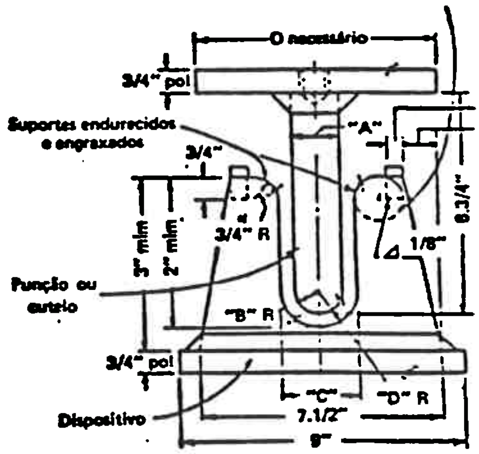



Fig.15. Ensaio de dobramento

## 2.3.7 EXAME METALOGRÁFICO:

É através da microestrutura que o mundo físico das forças interatômicas está ligada a realidade das propriedades mecânicas dos materiais. A microestrutura é importante na forma de arranjo de grãos tanto em materiais com uma única fase quanto multifásicos. As propriedades que dependem da microestrutura são: elétricas, magnéticas e propriedades plásticas dos materiais. Ao examinarmos uma microestrutura através de microscópios óticos sobre uma superfície polida e atacada quimicamente, examina-se normalmente agregados de milhões de átomos. Desde que estas dimensões estejam dentro de 0,01 á 100 micrômetros consideramos estudos microscópios. Já para dimensões superiores a 100 micrômetros tratamos de um estudo macroscópio, sendo inclusive possível de observação visual sem auxílio de microscópios amplificadores, ou somente com auxílio de lupas. Neste caso geralmente também se utiliza um ataque químico na superfície a ser observada. Com ensaios macrográficos objetiva-se verificar a estrutura bruta de fusão do metal de solda; as homogeneidades ou heterogeneidade do produto, as descontinuidades, etc.

**2.4 DESCONTINUIDADES:**

Descontinuidade é a interrupção das estruturas típicas de uma peça, no que se refere a homogeneidade de características físicas, mecânicas ou metalúrgicas. A descontinuidade só deve ser considerada defeito, quando , por sua natureza, dimensão ou efeito acumulado, tornar a peça inaceitável, por não satisfazer os requisitos mínimos da norma técnica aplicável.

As descontinuidades de juntas soldadas, e obtidas por processos de soldagem por fusão, podem ser classificadas em 3 grandes grupos: a) relacionados ao processo e procedimento de soldagem. Neste caso incluem-se os fatores geométricos tais como desalinhamento, embicamento, concavidade ou convexidade excessiva do metal de solda, deformação angular excessiva, deposição insuficiente, falta de fusão, falta de penetração, mordedura, penetração excessiva, reforço excessivo, sobreposição, solda em ângulo assimétrico. Outras descontinuidades inscritas neste item são o rechupe da cratera, inclusões de escória, inclusões de W, respingos, abertura do arco. b) metalúrgico: do tipo trinca a frio induzida pelo hidrogênio, trinca de solidificação, decoesão lamelar, trinca de reaquecimento. Aqui também se inserem a porosidade, a alteração microestrutural da ZAT, a segregação do MB e ZAT, e a laminação do metal de base. c) relacionados ao projeto, que influi no tipo de junta, e outros aspectos relacionados a concentração de tensões.

* Abertura de arco: Imperfeição local na superfície do metal da base resultante da abertura do arco elétrico.

* Concavidade: Reentrância na raiz da solda, podendo ser central, situada ao longo do cardão de solda, ou lateral, situada nas laterais do cordão.

* Concavidade excessiva: Solda em ângulo com a face excessivamente côncava.

* Convexidade excessiva: Solda em ângulo com a face excessivamente convexa.

* Deformação angular: Distorção angular de uma junta em relação a configuração de projeto, exceto para junta soldada de topo.

* Deposição insuficiente: Insuficiência de metal na face da solda.

* Desalinhamento: junta soldada de topo, cuja superfície das peças, embora paralelas, apresentam-se desalinhadas, excedendo a configuração do projeto.

* Embicamento: Deformação angular de junta soldada de topo

* Falta de fusão: Fusão incompleta entre o metal de solda e o metal de base, ou entre passes do metal de solda, podendo estar localizada na linha de fusão, entre passes, ou na raiz da solda.

* Falta de penetração: Insuficiência de metal na raiz da solda.

* Inclusão de escória: Material não metálico retido no metal de solda 'podendo ser alinhada, isolada , ou agrupada.

* Inclusão de tungstênio: Tungstênio retido no metal de solda, oriundo do eletrodo dos processos TIG e arco submerso.

* Mordedura: Depressão sob a forma de entalhe, no metal de base, acompanhando a margem da solda, podendo ser na superfície , ou na raiz.

* Penetração excessiva: Metal de solda em excesso na raiz.

* Rechupe da Cratera: Falta de metal resultante da contração de solidificação, localizada na cratera do cordão de solda.

* Respingos: Glóbulos de metal de adição transferidos durante a soldagem a superfície do MS, MB, ZAT.

* Sobreposição: Excesso de metal sobreposto ao metal de base na margem da solda, sem estar fundido ao metal de base.
* Solda em Ângulo Assimétrica: Solda em ângulo, cujas pernas são significativamente desiguais, e em desacordo com a configuração do projeto.

A. Decoesão Lamelar

A decoesão lamelar é um tipo de trinca que ocorre no metal de base de uma junta soldada, devido aos efeitos combinados de alta tensão localizada e baixa dutilidade do MB ao longo de sua espessura. Ocorre geralmente em juntas de ângulo T e L, particularmente em peças de grande espessura, e quando a linha de fusão é praticamente paralela à superfície do metal de base. As trincas aparecem muito próximas ou a poucos milímetros da linha de fusão, em forma parecida a degraus, cujos pisos são paralelos a superfície do MB.

Estas trincas ocorrem essencialmente em juntas soldadas com MB laminado, sendo que a baixa dutilidade é devido as inclusões não metálicas, do tipo silicatos, com forma retangular ou alongada. A decoesão lamelar inicia-se em vazios formados entre a inclusão não metálica e o metal de base. Estes vazios são então interligados de maneira planar por micro-vazios, coalescência, ou cisalhmento, por ação determinante da tensão residual da junta soldada.

A prevenção desta decoesão lamelar pode ser feita por vários modos: a) tomar esféricas as inclusões não metálicas. Isto poderá ser feito durante a produção do aço, e geralmente com tratamento do banho com metais raros; b) melhorar o projeto da junta; c) fazer o amanteigamento com metal de elevada dutilidade; d) diminuir o teor de S; e) com pré-aquecimento do MB; f) utilizar forjados ou extrudados no lugar de laminados.

B. Porosidade

A porosidade é o termo para bolhas de gás, do tipo CO, ou vazios arredondados, de tamanho macro ou microscópico, encontrados freqüentemente em metais de solda. É formada principalmente pela evolução de gases durante a solidificação da poça metálica, cuja solubilidade diminui conforme a temperatura decresce. Este gás origina-se da contaminação da superfície a ser soldada, como exemplo por graxa, tinta, etc, dos consumíveis, ou da atmosfera. Se o arame de soldagem não possui desoxidante suficiente, provavelmente também facilitará a formação da porosidade.

A porosidade pode ocorrer na superfície ou no interior do metal de solda, e pode ser: a) agrupada; b)alinhada, que é o conjunto de poros em linha, seguindo uma direção paralela ao eixo longitudinal da solda; c) vermiforme, que é o conjunto de poros alongados ou em forma de espinha de peixe situados no metal de solda.

A prevenção da porosidade pode ser feita de vários modos; a)removendo-se a fonte de gás. Para tanto deve-se evitar ou remover a tinta, graxa, etc. da superfície da junta soldada; b)utilizando-se um gás protetor adequado; c) utilizando-se consumíveis com alto teor de elementos desoxidantes.

C. Trinca a frio

Um dos maiores problemas na soldagem de aços tem sido as trincas a frio induzidas pelo hidrogênio. Essas trincas são influenciadas pelos seguintes fatores: a) teor de hidrgênio; b) microestrutura do MS e ZAT; c) nível de tensão imposto a solda; e) temperatura. Todos estes fatores apresentam a mesma importância, mas dependendo da situação pode ser dominante.

Uma característica marcante nas trincas a frio é o seu período de demora da ocorrência , ou seja, estas trincas nem sempre ocorrem logo após a soldagem quanto atinge a temperatura ambiente, mas sim demora algum tempo até que sua presença seja detectada. Neste caso, recomenda-se submeter a junta soldada a ensaios de raio-x ou ultra-som apenas 24 horas após a realização da soldagem, de forma a não se ter surpresas posteriores.

As trincas a frio são assim denomimadas por ocorrer sempre abaixo de 200 graus C e basicamente a temperatura ambiente, e podem estar tanto no MS quanto no ZAT, podendo ser transversal ou longitudinal, e preferencialmente inicia-se nos pontos de máxima concentração de tensão, como exemplo nos cantos vivos da raiz. Podem ter alguns microns até centímetros de comprimento e são trincas essencialmente transgranulares.

Para se previnir contra as tricas a frio causadas pelo hidrogênio pode-se utilizar os seguintes procedimentos: a) evitar ou reduzir ao máximo o teor de hidrogênio dufusível no MS ou ZAT. Isto poderá ser efetivado com a limpesa das superfícies a serem soldadas, com ressecagem dos consumíveis, ou com pós aquecimento que facilitará a difusão do hidrogênio para fora do MS ou ZAT; b) facilitar a formação de microestruturas menos susceptíveis as trincas a frio, como exemplo a ferrita acicular. Este fator é influenciado pela composição química e taxa de resfriamento, que deve ser a menor possível. Isto pode ser feito com pré-aquecimento, com alta energia de soldagem, etc. c) evitar metais com alto limite de resistência.

Convém salientar que existem inúmeras tabelas, ábacos e procedimentos de soldagem, que minimizam ou evitam estas trincas a frio.

D. Trinca de Reaquecimento:

As trincas de reaquecimento ocorrem na ZAT em soldas de aços, durante o tratamento térmico após a soldagem, ou durante o serviço a elevadas temperaturas. Este tratamento pode ser alívio de tensões. As trincas ocorrem devido ao efeito combinado de fragilização e deformação. Estas trincas diferem das trincas a firo, pois são essencialmente intergranulares.

Os fatores que influenciam as trincas de reaquecimento são: a) composição química; b) microestrutura da ZAT; c) alto nível de tensão residual associado ao grau de triaxialidade; d) temperatura na faixa da relaxação de deformação ou fluência.

O mecanismo da fratura aproxima-se ao encontrado para fluência. A altas temperaturas, entre 450 e 600 graus C para aço carbono, o carbono difunde para o contorno de grão e forma carbonetos, que bloqueiam toda a deformação plástica a seu nível, e conduzem a uma ruptura sem deformação no contorno de grão, além de endurecer a matriz.

Diversos fatores podem ser observados para se evitar as trincas de reaquecimento; a) selecionar o melhor procedimento de soldagem. Por exemplo, soldas multipasses formam grãos menos grosseiros na ZAT; b) reduzir a concentração de tensões, melhorando-se o projeto; c) melhorar a composição química do MB, diminuindo os teores de Cr, Cu,  Mo, B, V, Nb e Ti que são elementos fragilizantes; d) propiciar a formação de microestruturas no ZAT não fragilizante a altas temperaturas. Por exemplo, evitar microestruturas de pouca dutilidade, do tipo bainita superior; d) utilizar ciclos térmicos adequados para o tratamento térmico de alívio de tensão; e) utilizar metal de adição de boa dutilidade á altas temperaturas.

E. Trinca de Solidificação:

As trincas de solidificação, ou trincas a quente, formam-se durante a solidificação da poça metálica, seguindo em geral, o contorno das dendritas, sendo portanto sua aparência tipicamente intergranular, e formando MS. Em alguns casos, excepcionalmente pode ocorrer na ZAT de metais com baixa resistência a altas temperaturas e alto teor de P e S.

Estas trincas de solidificação ocorrem principalmente no sentido longitudinal e no centro da solda, mas podendo também ser tranversais. Podem apresentar-se em todos os processos de soldagem por fusão, e é resultante dos efeitos combinados das condições de solidificação, principalmente rejeição da solutos de baixo ponto de fusão, e tensão imposta a solda.

Para se evitar estas trincas de solidificação pode-se utilizar os seguintes recursos: a) reduzir o teor de S, P, C, Si, Ni. Neste caso quando o teor de P e S for superior á 0,040% em aços carbono e baixa liga, o P associa-se ao Fe, Mn, Ni e Cr, e o S ao Fe, para formar eutéticos de baixo ponto de fusão; b) melhorar a geometria da junta, evitando-se chanfros com pequenos ângulos; c) diminuir a energia de soldagem; d) minimizar restrições; e) diminuir a abertura da raiz.

## 2.4.1 FIGURAS:

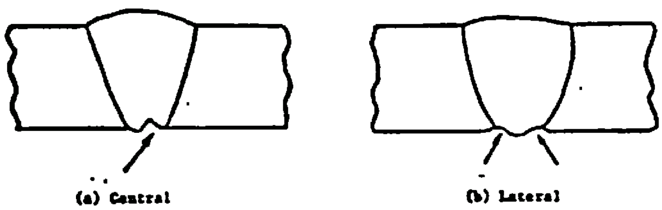



FIGURA 16 - Concavidade.

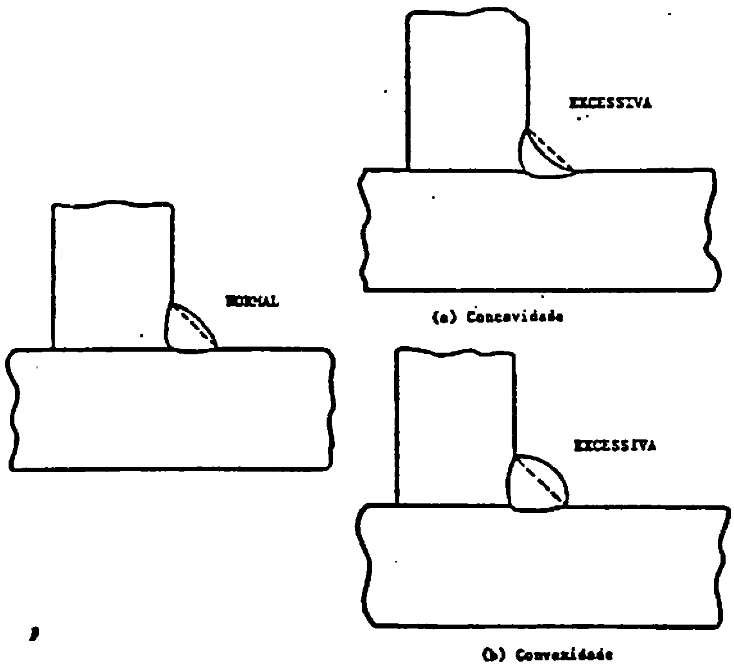



FIGURA 17 - Concavidade e convexidade excessiva.

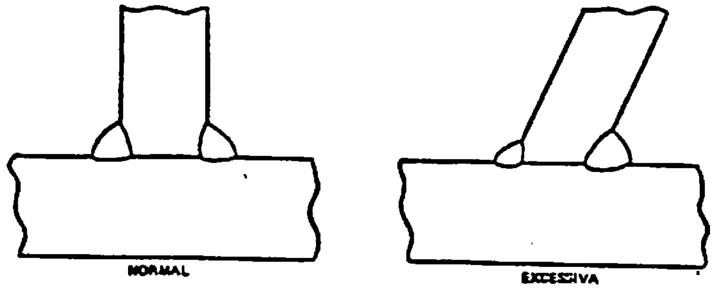



FIGURA 18 - Deformação angular.

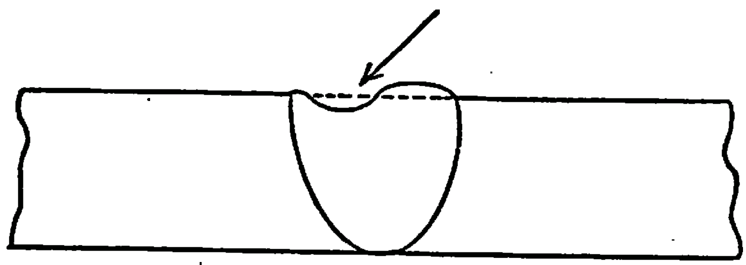


FIGURA 19 - Deposição insuficiente.

FIGURA 20 - Desalinhamento.

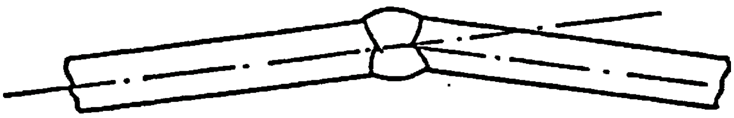


FIGURA 21 - Embicamento.

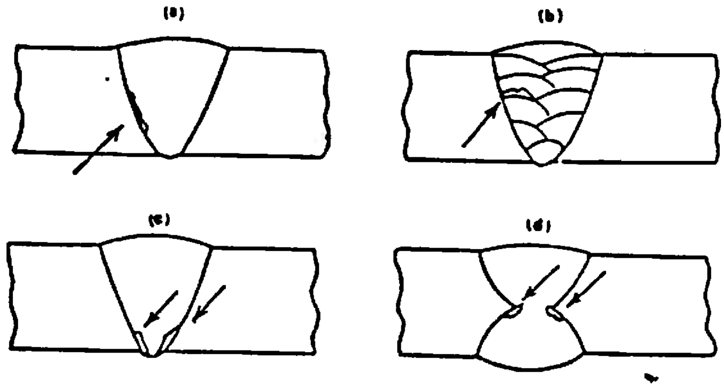



FIGURA 22 - Falta de fusão.

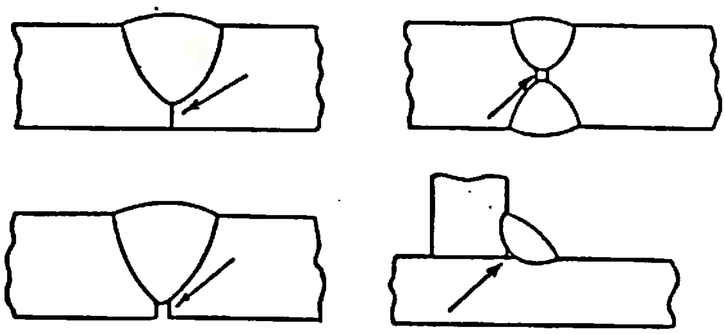


FIGURA 23 - Falta de penetração.

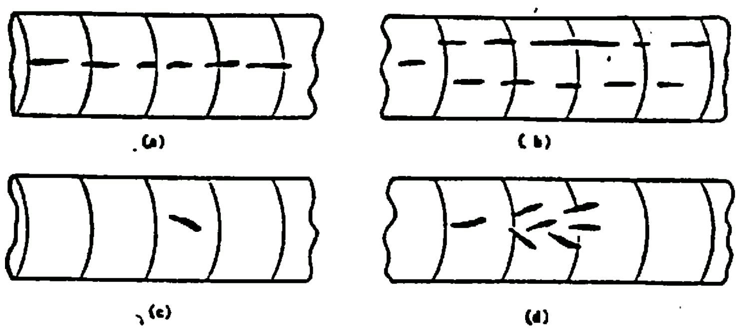



FIGURA 23 a Inclusão de escória.

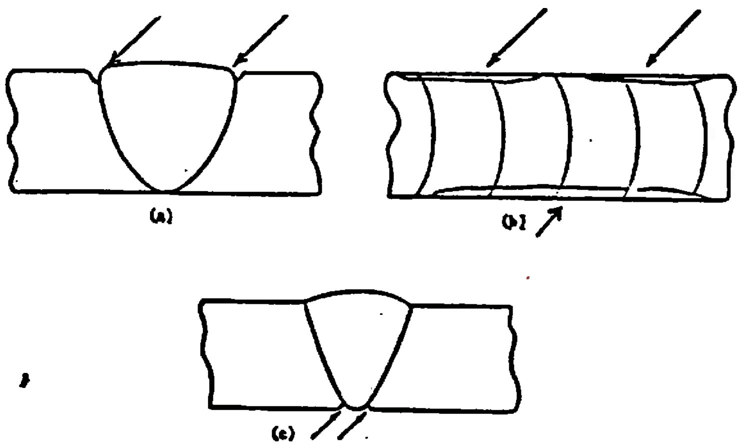



FIGURA 23 b Mordedura.

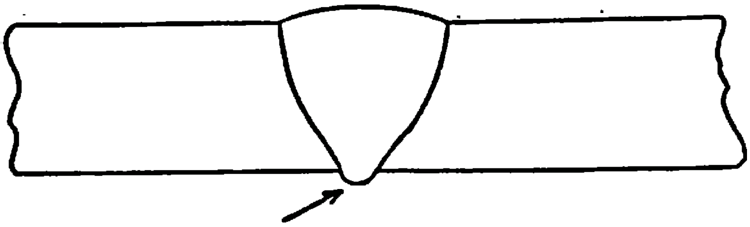


FIGURA 23 C - Penetração escessiva.

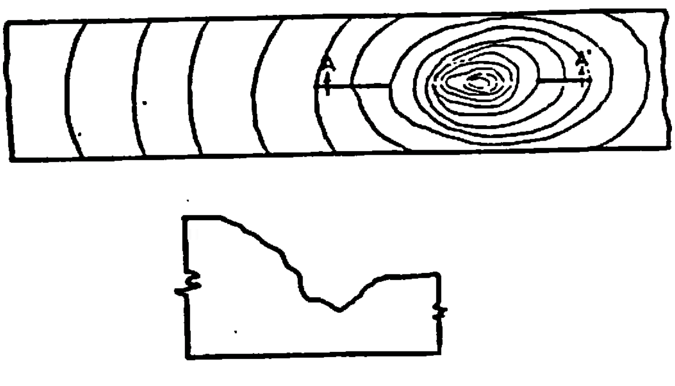


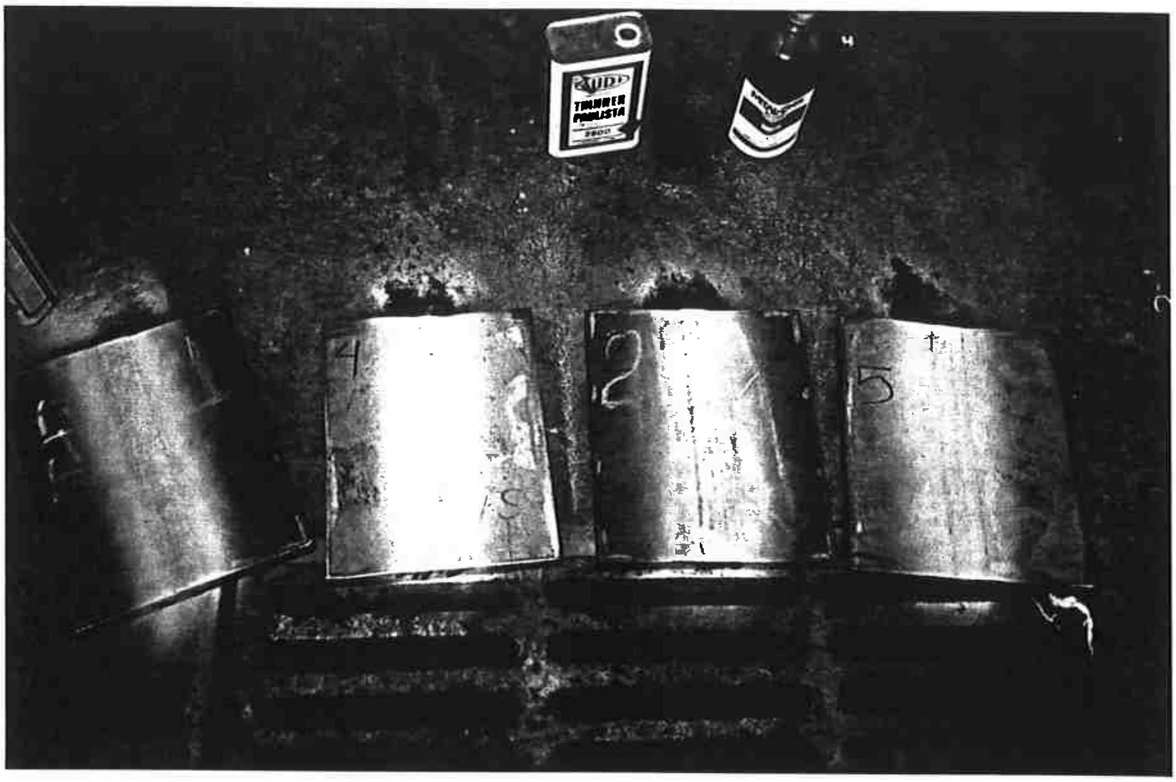

FIGURA 23 D- Rechupe da cratera.

6. **CONCLUSAO:**

Aprovado conforme norma ASME Seção IX ,ed.89 ,ad.90 .

<u>**Ensaio por Líquido Penetrante:**</u>

A foto a seguir ilustra a preparação para o ensaio por líquido penetrante:




| ABB ASEA BROWN BOVERI | RELATÓRIO DE CONTROLE<br>CONTROL REPORT | Data / Date: 20-08-93 | Nº Fls. / Nr Pgs.: 01 | Fl. Nº / Pg. Nr: 01 | Nº RC – |
|---|---|---|---|---|---|

| Denominação / Denomination | Desenho Nº / Drawing Nr | Mod. |
|---|---|---|
| Qualificação de Soldador e Processo. | | |

| Cliente / Client | Ordem de Fabricação / Fabrication Order | Nº de Série ou de Fabricação / Product Serial Number | Pedido Interno / Internal Order |
|---|---|---|---|
| | | | |

**ENSAIO POR LÍQUIDO PENETRANTE**
**LIQUID PENETRANT EXAMINATION**

| Material / Material | Trat. Térmico / Heat Treatment | Instrução Interna/Procedimento / Procedure | Estado da Superfície / Surface conditions/preparations |
|---|---|---|---|
| RRST 44,3 | ☐ Antes - Before ☐ Depois - After | BBQL 01078-Rev. H | Escovada |

| Local Ensaiado / Equipment/Part | Técnica Utilizada / Technique |
|---|---|
| 100% da solda. (CP 01 e 02) | B-1 |

| Produto Tipo / Type of material | Removedor / Cleaner | Penetrante / Penetrant | Revelador / Developer | Modo de Limpeza / Cleaning | Norma de Referência / Reference standard |
|---|---|---|---|---|---|
| Metal-Chek | Thinner Audi 2800 | VP 30 | D701-NF | Pano/Água | A 89. Asme Sec-VIII-Div. 1 - Ap. 8 |

**REGISTRO DOS RESULTADOS**
**RECORD OF RESULTS**

Realizado ensaio em 100% da sol-da dos testes de números 01 e 02, não sendo de-tectado indicação de descontinuidade em desacordo com a Norma.

**CONCLUSÃO**
**CONCLUSION** Aprovado.

| Elaboração (Data/Nome) / Report by (Date/Name) | Sigla / Dept. | Aprovado (Data/Visto) / Approved by (Date/Sign) | Aprovado p/Cliente (Data/Visto/Carimbo) / Client or Authorized Inspector (Date/Sign/Stamp) |
|---|---|---|---|
| Control 20/08/93 Roberto G. Proença Data | PG/PPA | 25/10/93 | |

BR. 1269

| ABB ASEA BROWN BOVERI | RELATÓRIO DE CONTROLE<br>CONTROL REPORT | Data<br>Date<br>20-08-93 | Nº Fls.<br>Nr Pgs.<br>01 | Fl. Nº<br>Pg. Nr<br>01 | Nº RC – |
|---|---|---|---|---|---|

| Denominação / Denomination | Desenho Nº / Drawing Nr | Mod. |
|---|---|---|
| Qualificação de Soldador e Processo. | | |

| Cliente / Client | Ordem de Fabricação / Fabrication Order | Nº de Série ou de Fabricação / Product Serial Number | Pedido Interno / Internal Order |
|---|---|---|---|
| | | | |

**ENSAIO POR LÍQUIDO PENETRANTE**
**LIQUID PENETRANT EXAMINATION**

| Material / Material | Trat. Térmico / Heat Treatment | Instrução Interna/Procedimento / Procedure | Estado da Superfície / Surface conditions/preparations |
|---|---|---|---|
| A 304-L | ☐ Antes - Before<br>☐ Depois - After | BBQL 01078-Rev. H | ESCOVADA |

| Local Ensaiado / Equipment/Part | Técnica Utilizada / Technique |
|---|---|
| 100% da solda. (CP 04 e 05) | B-3 |

| Produto Tipo / Type of material | Removedor. / Cleaner | Penetrante / Penetrant | Revelador / Developer | Modo de Limpeza / Cleaning | Norma de Referência / Reference standard |
|---|---|---|---|---|---|
| METAL-CHEK | THINNER AUDI 2800 | VP 31 | D 70 | PANO/THINNER | A 89. ASME SEC VIII-DIV. 1-APB |

**REGISTRO DOS RESULTADOS**
**RECORD OF RESULTS**

Realizado ensaio em 100% da solda dos testes de números 04 e 05, não sendo detectado indicação de descontinuidade em desacordo com a Norma.

**CONCLUSÃO**
**CONCLUSION** Aprovado.

| Elaboração (Data/Nome) / Report by (Date/Name) | Sigla / Dept | Aprovado (Data/Visto) / Approved by (Date/Sign) | Aprovado p/Cliente (Data/Visto/Carimbo) / Client or Authorized Inspector (Date/Sign/Stamp) |
|---|---|---|---|
| Quality Control<br>20.08.93<br>Roberto G. Proença | PG/PPA | 25/10/93 CL III | |

BR. 12

**Exame Visual:**

A foto a seguir mostra o procedimento para o ensaio.

ABB
ASEA BROWN BOVERI

**RELATORIO DE CONTROLE**
***CONTROL REPORT***

| Data / *Date* | Nº Fls. / *Nr. Pgs.* | Fl. Nº / *Pg. Nr.* | Nº RCC - |
|---|---|---|---|
| 20-08-93 | 01 | 01 | |

| | |
|---|---|
| Denominação / *Denomination* | Qualificação de Soldador e Processo. |
| Desenho Nº / *Drawing Nr.* | |
| Mod. / *Mod.* | |

| Cliente / *Client* | Ordem de Fabricação / *Fabrication Order* | Nº de Série ou de Fabricação / *Product Serial Number* | Pedido Interno / *Internal Order* |
|---|---|---|---|
| | | | |

**INSPEÇÃO VISUAL**
***VISUAL INSPECTION***

| Instrução Interna / *Procedure* | Revisão / *Revision* | Código de Referência / *Reference Code* | Norma de Aceitação / *Acceptance Standard* |
|---|---|---|---|
| BBLC 30210 | | ASME SEC V - A 89 | A 89. ASME Sec. VIII - Div. 1 - UN 31 A 37 |

| Metal Base / *Base Metal* | Espessura / *Thickness* | Trat. Térmico / *Heat Treatment* | Estado da Superfície / *Surface Condition* |
|---|---|---|---|
| RRST 44,3 | 25mm | ☐ Antes/*Before* ☐ Depois/*After* | ESCOVADA |

| Metal de Adição / *Filler Metal* | Procedimento de Soldagem / *WPS* | Tipo de Junta / *Joint Type* |
|---|---|---|
| ER-70-S-6 | 20130 | "V" |

| Técnica Empregada / *Used Technique* | Identificação/Instrumentos Utilizados / *Identification/Used Instruments* |
|---|---|
| VISUAL DIRETO | GABARITOS |

Observações / *Remarks* TESTE Nº: 01

**RESULTADO DA INSPEÇÃO**
*INSPECTION RESULTS*

| Nº / *Nr.* | LOCALIZAÇÃO / *LOCALIZATION* | DEFEITO / TIPO / *DEFECT/ TYPE* | DIMENSÃO / *SIZE* | RESULTADO / *FINDINGS* |
|---|---|---|---|---|
| — | — | — | — | — |

CROQUIS / *SKETCH*

CONCLUSÃO:
*CONCLUSION*

APROVADO.

| Elaboração (Data/Nome) / *Report by (Date/Name)* | Sigla / *Dept.* | Aprovado (Data/Visto) / *Approved by (Date/Sign)* | Aprovado p/Cliente (Data/Visto/Carimbo) / *Client or Authorized Inspector (Date/Sign/Stamp)* |
|---|---|---|---|
| ABB Quality Control 20.08.93 | PG/PPA | 20/8/93 LEVEL III | |

BR. 1544 Data

**1- DEFEITOS / TIPO**
*Defects / Type*

| | |
|---|---|
| **TL** | TRINCA LONGITUDINAL<br>*Longitudinal Crack* |
| **TT** | TRINCA TRANSVERSAL<br>*Transversal Crack* |
| **IA** | INDICAÇÃO ARREDONDADA<br>*Arouded Indication* |
| **FP** | FALTA DE PENETRAÇÃO<br>*Lack of Penetration* |
| **MO** | MORDEDURA<br>*Undercut* |
| **FF** | FALTA DE FUSÃO<br>*Lack of Fusion* |
| **IL** | INDICAÇÃO EM LINHA<br>*Aligned Indication* |
| **IE** | INDICAÇÃO ALONGADA<br>*Elongated Indication* |

**2 - RESULTADOS**
*Findings*

| | |
|---|---|
| **A** | APROVADO<br>*Approved* |
| **NC** | NÃO CONFORME<br>*No* |

ABB
ASEA BROWN BOVERI

**RELATORIO DE CONTROLE**
***CONTROL REPORT***

| Data / *Date* | Nº Fls. / *Nr. Pgs.* | Fl. Nº / *Pg. Nr.* | Nº RCC - |
|---|---|---|---|
| 20.08.93 | 01 | 01 | |

| Denominação / *Denomination* | Desenho Nº / *Drawing Nr.* | Mod. / *Mod.* |
|---|---|---|
| QUALIFICAÇÃO DE SOLDADOR E PROCESSO | | |

| Cliente / *Client* | Ordem de Fabricação / *Fabrication Order* | Nº de Série ou de Fabricação / *Product Serial Number* | Pedido Interno / *Internal Order* |
|---|---|---|---|
| | | | |

**INSPEÇÃO VISUAL**
***VISUAL INSPECTION***

| Instrução Interna / *Procedure* | Revisão / *Revision* | Código de Referência / *Reference Code* | Norma de Aceitação / *Acceptance Standard* |
|---|---|---|---|
| BBLC 30210 | — | ASME SEC I A 89 | A 89 ASME SEC VIII - DIV. 1 UW 51 A 37 |

| Metal Base / *Base Metal* | Espessura / *Thickness* | Trat. Térmico / *Heat Treatment* | Estado da Superfície / *Surface Condition* |
|---|---|---|---|
| RRST 44.3 | 25 mm | ☐ Antes/*Before* ☐ Depois/*After* | ESCOVADO |

| Metal de Adição / *Filler Metal* | Procedimento de Soldagem / *WPS* | Tipo de Junta / *Joint Type* |
|---|---|---|
| ER 80S2D2/E 7018-1 | 20163 | "V" |

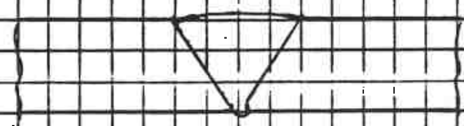
| Técnica Empregada / *Used Technique* | Identificação/Instrumentos Utilizados / *Identification/Used Instruments* |
|---|---|
| VISUAL DIRETO | GABARITOS |

Observações
*Remarks* TESTE Nº 02

**RESULTADO DA INSPEÇÃO**
*INSPECTION RESULTS*

| Nº / *Nr.* | LOCALIZAÇÃO / *LOCALIZATION* | DEFEITO / TIPO / *DEFECT/ TYPE* | DIMENSÃO / *SIZE* | RESULTADO / *FINDINGS* |
|---|---|---|---|---|
| — | — | — | — | — |

CROQUIS
*SKETCH*



CONCLUSÃO:
*CONCLUSION* APROVADO

| Elaboração (Data/Nome) / *Report by (Date/Name)* | Sigla / *Dept.* | Aprovado (Data Visto) / *Approved by (Date/Sign)* | Aprovado p. Cliente (Data Visto Carimbo) / *Client or Authorized Inspector (Date Sign/Stamp)* |
|---|---|---|---|
| ABB Quality Control 20.08.93 Roberto G. Proença | PG/PPA | 20/8/93 LEVEL III | |

BR. 1544 Data

ABB

# RELATORIO DE CONTROLE — INSPEÇÃO VISUAL
*CONTROL REPORT — VISUAL INSPECTION*

## 1- DEFEITOS / TIPO
*Defects/Type*

| | |
|---|---|
| TL | TRINCA LONGITUDINAL<br>*Longitudinal Crack* |
| TT | TRINCA TRANSVERSAL<br>*Transversal Crack* |
| IA | INDICAÇÃO ARREDONDADA<br>*Arouded Indication* |
| FP | FALTA DE PENETRAÇÃO<br>*Lack of Penetration* |
| MO | MORDEDURA<br>*Undercut* |
| FF | FALTA DE FUSÃO<br>*Lack of Fusion* |
| IL | INDICAÇÃO EM LINHA<br>*Aligned Indication* |
| IE | INDICAÇÃO ALONGADA<br>*Elongated Indication* |

## 2 - RESULTADOS
*Findings*

| | |
|---|---|
| A | APROVADO<br>*Approved* |
| NC | NÃO CONFORME<br>*No* |

| ABB | **RELATORIO DE CONTROLE** *CONTROL REPORT* | Data / *Date* 20.08.93 | Nº Fls. / *Nr. Pgs.* 01 | Fl. Nº / *Pg. Nr.* 01 | Nº RCC - |
|---|---|---|---|---|---|

| Denominação / *Denomination* | Desenho Nº / *Drawing Nr.* | Mod. / *Mod.* |
|---|---|---|
| QUALIFICAÇÃO DE SOLDADOR E PROCESSO | | |

| Cliente / *Client* | Ordem de Fabricação / *Fabrication Order* | Nº de Série ou de Fabricação / *Product Serial Number* | Pedido Interno / *Internal Order* |
|---|---|---|---|
| | | | |

## INSPEÇÃO VISUAL
## *VISUAL INSPECTION*

| Instrução Interna / *Procedure* | Revisão / *Revision* | Código de Referência / *Reference Code* | Norma de Aceitação / *Acceptance Standard* |
|---|---|---|---|
| BBLC 30210 | — | ASME SEC. V A.89 | A.89 ASME VIII DIV. 1 UNS 31437 |

| Metal Base / *Base Metal* | Espessura / *Thickness* | Trat. Térmico / *Heat Treatment* | Estado da Superfície / *Surface Condition* |
|---|---|---|---|
| A 304L | 25 mm | ☐ Antes/*Before* ☐ Depois/*After* | ESCOVADA |

| Metal de Adição / *Filler Metal* | Procedimento de Soldagem / *WPS* | Tipo de Junta / *Joint Type* |
|---|---|---|
| ER 308L / E 308 L16 | 20169 | "V" |

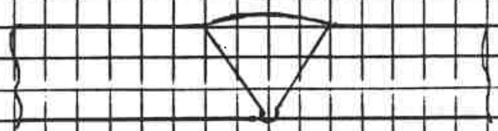
| Técnica Empregada / *Used Technique* | Identificação/Instrumentos Utilizados / *Identification/Used Instruments* |
|---|---|
| VISUAL DIRETO | GABARITOS |

Observações / *Remarks*: TESTE DE Nº 05

## RESULTADO DA INSPEÇÃO
## *INSPECTION RESULTS*

| Nº / *Nr.* | LOCALIZAÇÃO / *LOCALIZATION* | DEFEITO / TIPO / *DEFECT/ TYPE* | DIMENSÃO / *SIZE* | RESULTADO / *FINDINGS* |
|---|---|---|---|---|
| — | — | — | — | — |

CROQUIS / *SKETCH*



CONCLUSÃO:
*CONCLUSION*

APROVADO.

| Elaborado por (Data/Visto) / *Report by (Date/Sign)* | Setor / *Dept.* | Aprovado (Data/Visto) / *Approved by (Date/Sign)* | Aprovado p/Cliente (Data/Visto Carimbo) / *Client or Authorized Inspector (Date/Sign/Stamp)* |
|---|---|---|---|
| ABB Quality Control — 20/08/93 | PG/PPA | 20/8/93 | |

BR. 1584

ABB
ASEA BROWN BOVERI

# RELATORIO DE CONTROLE – INSPEÇÃO VISUAL
## *CONTROL REPORT – VISUAL INSPECTION*

**1- DEFEITOS / TIPO**
***Defects/Type***

| | |
|---|---|
| **TL** | TRINCA LONGITUDINAL<br>*Longitudinal Crack* |
| **TT** | TRINCA TRANSVERSAL<br>*Transversal Crack* |
| **IA** | INDICAÇÃO ARREDONDADA<br>*Arouded Indication* |
| **FP** | FALTA DE PENETRAÇÃO<br>*Lack of Penetration* |
| **MO** | MORDEDURA<br>*Undercut* |
| **FF** | FALTA DE FUSÃO<br>*Lack of Fusion* |
| **IL** | INDICAÇÃO EM LINHA<br>*Aligned Indication* |
| **IE** | INDICAÇÃO ALONGADA<br>*Elongated Indication* |

**2 - RESULTADOS**
***Findings***

| | |
|---|---|
| **A** | APROVADO<br>*Approved* |
| **NC** | NÃO CONFORME<br>*No* |

| ABB ASEA BROWN BOVERI | **RELATORIO DE CONTROLE** *CONTROL REPORT* | Data *Date* 20.08.93 | Nº Fls. *Nr. Pgs.* 01 | Fl. Nº *Pg. Nr.* 01 | Nº RCC - |
|---|---|---|---|---|---|

| Denominação *Denomination* | Desenho Nº *Drawing Nr.* | Mod. *Mod.* |
|---|---|---|
| QUALIFICAÇÃO DE SOLDADOR E PROCESSO | | |

| Cliente *Client* | Ordem de Fabricação *Fabrication Order* | Nº de Série ou de Fabricação *Product Serial Number* | Pedido Interno *Internal Order* |
|---|---|---|---|
| | | | |

## INSPEÇÃO VISUAL
## *VISUAL INSPECTION*

| Instrução Interna *Procedure* | Revisão *Revision* | Código de Referência *Reference Code* | Norma de Aceitação *Acceptance Standard* |
|---|---|---|---|
| BBLC 30210 | — | ASME SEC V A89 | ASME VIII DIV. 1 UNS A.89 31.437 |

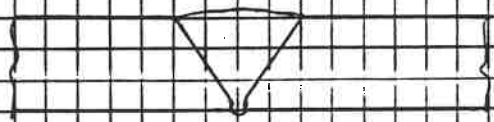
| Metal Base *Base Metal* | Espessura *Thickness* | Trat. Térmico *Heat Treatment* | Estado da Superfície *Surface Condition* |
|---|---|---|---|
| A 304 L | 25 mm | ☐ Antes/*Before* ☐ Depois/*After* | ESCOVADA |

| Metal de Adição *Filler Metal* | Procedimento de Soldagem *WPS* | Tipo de Junta *Joint Type* |
|---|---|---|
| E 308 L 16 | 20164 | "V" |

| Técnica Empregada *Used Technique* | Identificação/Instrumentos Utilizados *Identification/Used Instruments* |
|---|---|
| VISUAL DIRETO | GABARITOS |

Observações *Remarks* TESTE Nº 04

## RESULTADO DA INSPEÇÃO
## *INSPECTION RESULTS*

| Nº *Nr.* | LOCALIZAÇÃO *LOCALIZATION* | DEFEITO / TIPO *DEFECT/ TYPE* | DIMENSÃO *SIZE* | RESULTADO *FINDINGS* | CROQUIS *SKETCH* |
|---|---|---|---|---|---|
| — | — | — | — | — |  |

CONCLUSÃO:
*CONCLUSION* APROVADO.

| Elaboração (Data/Nome) *Report by* (Date/Name) | Sigla *Dept.* | Aprovado (Data/Visto) *Approved by* (Date/Sign) | Aprovado p/Cliente (Data/Visto/Carimbo) *Client or Authorized Inspector (Date/Sign/Stamp)* |
|---|---|---|---|
| ABB Quality Control 20.08.93 Roberto G. Proença Data | PG/PPA | 20/8/93 LEVEL III | |

BR. 154

ABB

# RELATORIO DE CONTROLE – INSPEÇÃO VISUAL
## *CONTROL REPORT – VISUAL INSPECTION*

**1- DEFEITOS / TIPO**
***Defects/ Type***

| | |
|---|---|
| **TL** | **TRINCA LONGITUDINAL**<br>***Longitudinal Crack*** |
| **TT** | **TRINCA TRANSVERSAL**<br>***Transversal Crack*** |
| **IA** | **INDICAÇÃO ARREDONDADA**<br>***Arouded Indication*** |
| **FP** | FALTA DE PENETRAÇÃO<br>*Lack of Penetration* |
| **MO** | MORDEDURA<br>*Undercut* |
| **FF** | FALTA DE FUSÃO<br>*Lack of Fusion* |
| **IL** | INDICAÇÃO EM LINHA<br>*Aligned Indication* |
| **IE** | INDICAÇÃO ALONGADA<br>*Elongated Indication* |

**2 - RESULTADOS**
***Findings***

| | |
|---|---|
| **A** | APROVADO<br>*Approved* |
| **NC** | NÃO CONFORME<br>*No* |

| ABB ASEA BROWN BOVERI | RELATÓRIO DE CONTROLE<br>CONTROL REPORT | Data<br>*Date*<br>23.08.93 | Nº Fls.<br>*Nr Pgs.*<br>01 | Fl. Nº<br>*Pg. Nr*<br>01 | Nº RC – |
|---|---|---|---|---|---|

| Denominação<br>*Denomination* | Desenho Nº<br>*Drawing Nr* | Mod. |
|---|---|---|
| Qualificação de Soldador e Processo | | |

| Cliente<br>*Client* | Ordem de Fabricação<br>*Fabrication Order* | Nº de Série ou de Fabricação<br>*Product Serial Number* | Pedido Interno<br>*Internal Order* |
|---|---|---|---|
| | | | |

## ENSAIO ULTRA-SONICO EM SOLDAS
## ULTRASONIC EXAMINATION OF WELDS

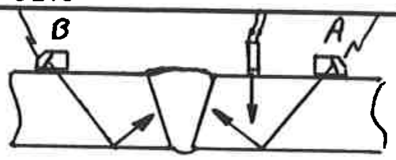
| Material<br>*Material* | Espessura<br>*Thickness* | Trat. Termico<br>*Heat Treatment* | Acoplante<br>*Coupling* | Estado da Superfície<br>*Surface condition* | Aparelho<br>*Equipment* |
|---|---|---|---|---|---|
| A 304 L<br>RRST 44.3 | 25 MM | ☐ Antes - *Before*<br>☐ Depois - *After* | METIL | ESCOVADO | USK 7 |

| Instrução Interna<br>*Procedure* | Técnica Utilizada<br>*Technique* | Bloco de Referência<br>*Calibration block* |
|---|---|---|
| BBQL 01080- REV. G | PULSO - ECO | ASME 20MM - IIW |

## REGISTRO DOS RESULTADOS
## RECORD OF RESULTS

Croqui:
*Sketch*

REALIZADO ENSAIO EM 100% DAS SOLDAS DOS TESTES DE NÚMEROS 01, 02, 04 e 05, NÃO SENDO DETECTADO INDICAÇÃO DE DESCONTINUIDADE.




| Transdutor<br>*Transducer* | Nº Descontinuidade<br>*Nr Discontinuity* | dB<br>Nível Primário<br>*Primary Reference Level* | dB<br>Transferência<br>*Transfer* | dB<br>Nível de Inspeção<br>*Scanning Sensitivity Level* | DESCONTINUIDADE – *Discontinuity*<br>Amplitude<br>*Amplitude*<br>dB | Local mm<br>*Local mm* | Profundidade mm<br>*Depth* | Comprimento mm<br>*Length* | Percurso Sônico<br>*Path Beam* | Projeção do Percurso<br>*Path Projected* | Superfície de Inspeção<br>*Surface of Examination* | Laudo<br>*Disposition* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MSEB 4 H | — | 40 | +2 | 48 | — | — | — | — | — | — | A + B | APROVADO |
| MWB 45 N4 | — | 28 | +2 | 36 | — | — | — | — | — | — | A + B | APROVADO |
| MWB 60 N4 | — | 32 | +2 | 40 | — | — | — | — | — | — | A + B | APROVADO |

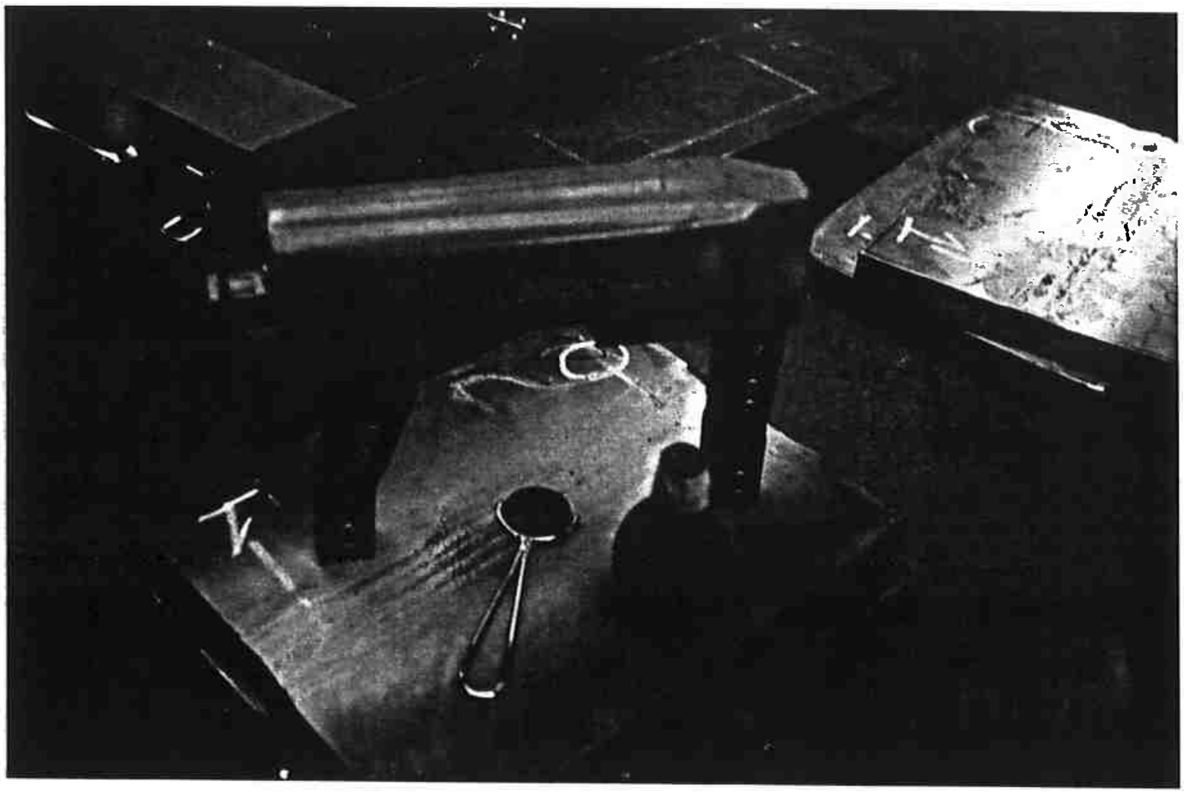
CONCLUSÃO
CONCLUSION
APROVADO

| Elaborado (Data/Visto)<br>*Report by (Date/Name) Level* | Sigla<br>*Dept.* | Aprovado (Data/Visto)<br>*Approved by (Date/Sign)* | Aprovado p/Cliente (Data/Visto/Carimbo)<br>*Client or Authorized Inspector (Date/Sign/Stamp)* |
|---|---|---|---|
| ABB Quality Control<br>23.08.93<br>Roberto G. Proença Data | PG/APA | 25/10/93 LEVEL III | |

BR. 12

## Ensaio por Partícula Magnética:

A foto a seguir ilustra o procedimento do ensaio por partículas magnéticas:



| ABB ASEA BROWN BOVERI | RELATÓRIO DE CONTROLE<br>CONTROL REPORT | Data<br>*Date*<br>20.08.93 | Nº Fls.<br>*Nr Pgs.*<br>01 | Fl Nº<br>*Pg. Nr*<br>01 | Nº RC – |
|---|---|---|---|---|---|

| Denominação<br>*Denomination* | Desenho Nº<br>*Drawing Nr* | Mod. |
|---|---|---|
| QUALIFICAÇÃO DE SOLDADOR E PROCESSO | | |

| Cliente<br>*Client* | Ordem de Fabricação<br>*Fabrication Order* | Nº de Série ou de Fabricação<br>*Product Serial Number* | Pedido Interno<br>*Internal Order* |
|---|---|---|---|
| | | | |

## ENSAIO POR PARTÍCULAS MAGNÉTICAS
## MAGNETIC PARTICLE EXAMINATION

| Material<br>*Material* | Trat. Térmico<br>*Heat Treatment* | ☐ Antes - *Before*<br>☐ Depois - After | Instrução Interna/Procedimento<br>*Procedure* | Estado da Superfície<br>*Surface conditions/preparations* |
|---|---|---|---|---|
| RRST 44.3 | | | BBQL 00966 | ESCOVADA |

| Local Ensaiado<br>*Equipment/Part* | Técnica Utilizada<br>*Technique* |
|---|---|
| EM 100% DAS SOLDAS | YOKE |

| Produto Tipo<br>*Type of material* | Meio líquido<br>*Liquid Medium* | Concentração<br>*Concentration* | Cor<br>*Color* | Modo de Limpeza<br>*Cleaning* | Norma de Referência<br>*Reference standard* |
|---|---|---|---|---|---|
| METAL-CHECK | QUEROSENE | 12 gr/l | PRETA | ISO 10/PANO | ASME VIII DIV.1 AP.6 (89) |

## REGISTRO DOS RESULTADOS
## RECORD OF RESULTS

REALIZADO ENSAIO EM 100% DAS SOLDAS DOS TESTES DE NÚMEROS 01 E 02, NÃO SENDO DETECTADO INDICAÇÃO DE DESCONTINUIDADE.

**CONCLUSÃO**
**CONCLUSION**

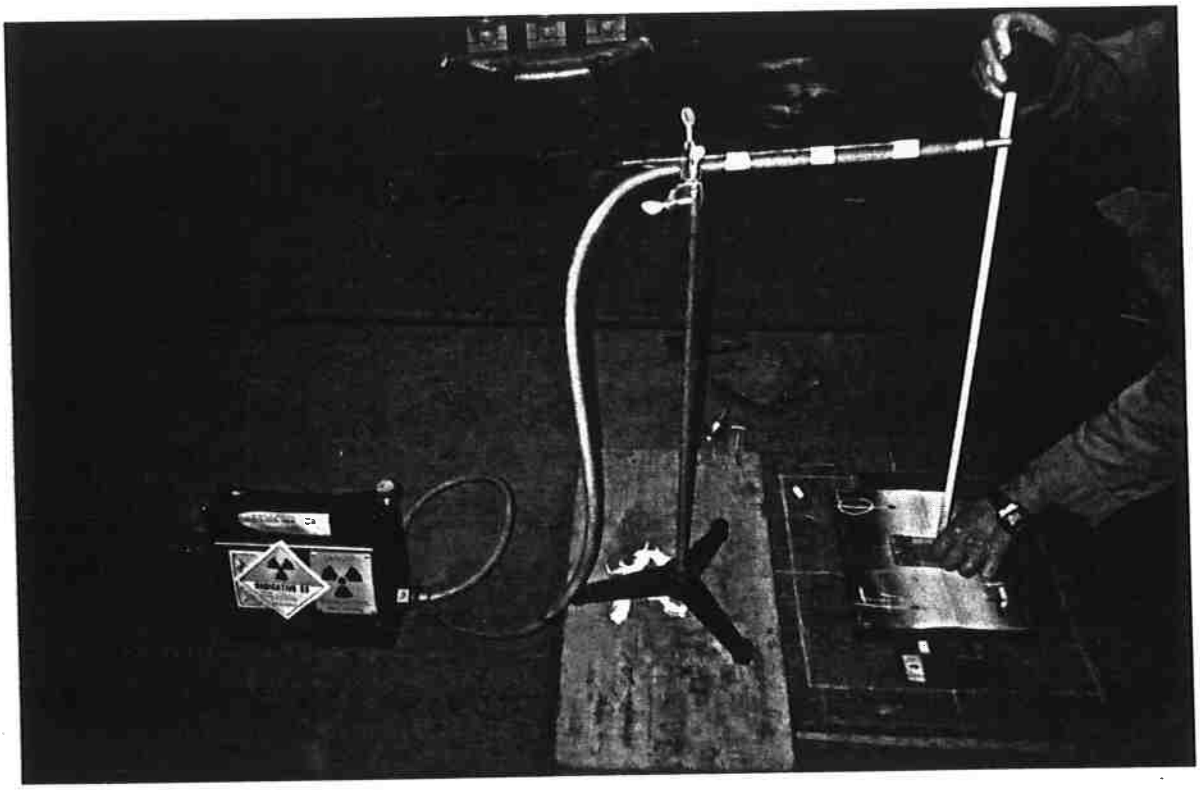
APROVADO

| Elaboração (Data/Nome)<br>*Report* Quality Control | Sigla<br>*Dept.* | Aprovado (Data/Visto)<br>*Approved by (Date/Sign)* LEVEL III | Aprovado p/Cliente (Data/Visto/Carimbo)<br>*Client or Authorized Inspector (Date/Sign/Stamp)* |
|---|---|---|---|
| 23/08/93<br>Roberto G. Proença Data | PG/PPA | 25/10/93 | |

BR.177

**Ensaio por Radiografia Industrial:**

A foto a seguir ilustra o procedimento de preparo para o ensaio de gamagrafia:



| ABB ASEA BROWN BOVERI | RELATORIO DE CONTROLE<br>CONTROL REPORT | Data<br>*Date*<br>20-08-93 | Nº Fls.<br>*Nr Pgs.*<br>01 | Fl. Nº<br>*Pg. Nr*<br>01 | NºRC – |
|---|---|---|---|---|---|

| | |
|---|---|
| Denominação<br>*Denomination* Qualificação de Soldador e Proces. | Desenho Nº<br>*Drawing Nr* |

| | | | |
|---|---|---|---|
| Cliente<br>*Client* | Ordem de Fabricação<br>*Fabrication Order* | Nº de Série ou de Fabricação<br>*Product Serial Number* | Pedido Interno<br>*Internal Order* |

**ENSAIO RADIOGRÁFICO**
**RADIOGRAPHIC EXAMINATION**

| | | | |
|---|---|---|---|
| Material<br>*Material* A 304-L | Nº Procedimento e Revisão<br>*Procedure/Revision* BBQL 01077- REV. I | Tipo de Fonte/Dimensões<br>*Isotope used/source size* Ir 192- 2,7 x 3,0MM | Técnica Radiográfica<br>*Radiographic Technique* PSVS |
| Normas de Referência<br>*Reference standard* ASME SEC-IX-ART.I-QW191-API-A 89 | | KV/mA | Tipo de Ecrans/*Screens used:* Pb<br>Esp. frente / *Front.thick:* 0,005"<br>Esp. traseira / *Back thick:* 0,010" |
| Local Examinado<br>*Equipment/Part* SOLDA - CP 04 e 05 | | DFF/SFD<br>700MM | Marca do Filme<br>*Film brand* KODAK AA5- 4½" x 17" |

**REGISTRO DOS RESULTADOS**
**RECORD OF RESULTS**

Realizado ensaio em 100% da solda dos testes de números 04 e 05, não sendo detectado indicação de descontinuidade.

**CONCLUSÃO**
**CONCLUSION**

Aprovado.

| Elaboração (Data/Nome)<br>*Report by (Date/Name)* | Sigla<br>*Dept.* | Aprovado (Data/Visto)<br>*Approved by (Date/Sign)* | Aprovado p/Cliente (Data/Visto/Carimbo)<br>*Client or Authorized Inspector (Date/Sign/Stamp)* |
|---|---|---|---|
| Quality Control 23.08.93<br>[signature] Data | PG/APA | 23/8/93 [signature] LEVEL III | |

BR. 1250

| ABB ASEA BROWN BOVERI | RELATORIO DE CONTROLE<br>CONTROL REPORT | Data<br>Date<br>20/08/93 | Nº Fls.<br>Nr Pgs.<br>01 | Fl. Nº<br>Pg. Nr<br>01 | NºRC – |
|---|---|---|---|---|---|

| Denominação<br>Denomination | Desenho Nº<br>Drawing Nr | Mod. |
|---|---|---|
| Qualificação de Soldador e Proces. | | |

| Cliente<br>Client | Ordem de Fabricação<br>Fabrication Order | Nº de Série ou de Fabricação<br>Product Serial Number | Pedido Interno<br>Internal Order |
|---|---|---|---|
| | | | |

## ENSAIO RADIOGRÁFICO
## RADIOGRAPHIC EXAMINATION

| Material<br>Material | Nº Procedimento e Revisão<br>Procedure/Revision | Tipo de Fonte/Dimensões<br>Isotope used/source size | Técnica Radiográfica<br>Radiographic Technique |
|---|---|---|---|
| RRST 44.3 | BQQL 01077 - REV. I | Ir 192 - 2,7 x 3,0 mm | PSVS |
| **Normas de Referência**<br>Reference standard<br>ASME SEC. IX - ART. I - QW191 - APT-A89 | | **KV/mA** | **Tipo de Ecrans/Screens used:** Pb<br>Esp. frente / Front thick: 0,005"<br>Esp. traseira / Back thick: 0,010" |
| **Local Examinado**<br>Equipment/Part<br>SOLDA - CP 01 e 02 | | **DFF/SFD**<br>700 mm | **Marca do Filme**<br>Film brand<br>KODAK AA5 - 4½" x 17" |

## REGISTRO DOS RESULTADOS
## RECORD OF RESULTS

Realizado ensaio em 100% da solda dos testes de números 01 e 02, não sendo detectado indicação de descontinuidade.

**CONCLUSÃO**
**CONCLUSION**

Aprovado.

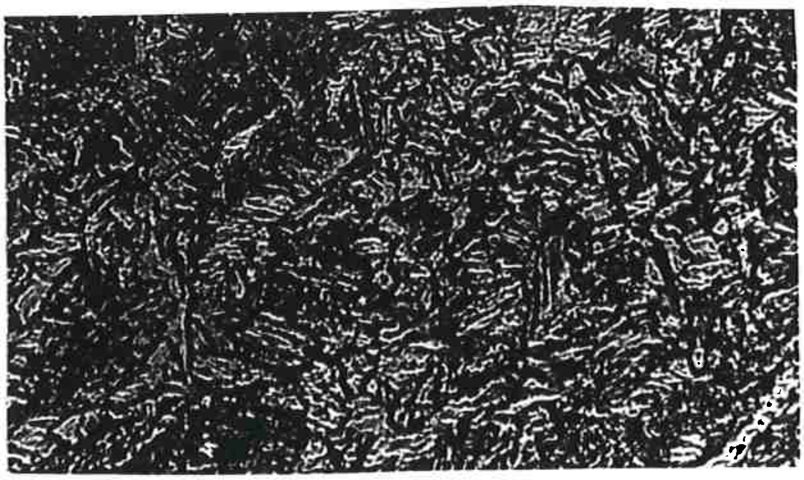
| Elaboração (Data/Nome)<br>Report by ... Control | Sigla<br>Dept. | Aprovado (Data/Visto)<br>Approved by (Date/Sign) | Aprovado p/Cliente (Data/Visto/Carimbo)<br>Client or Authorized Inspector (Date/Sign/Stamp) |
|---|---|---|---|
| 23.08.93 | PG/PPA | 23/8/93 ... LEVEL III | |

BR. 125 Roberto G. Proença Data

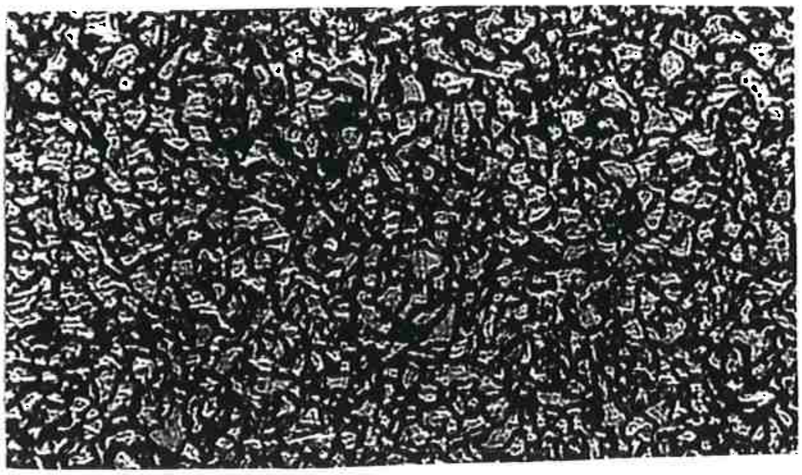
## Ensaio Metalográfico:

Corpo de prova No. 1:

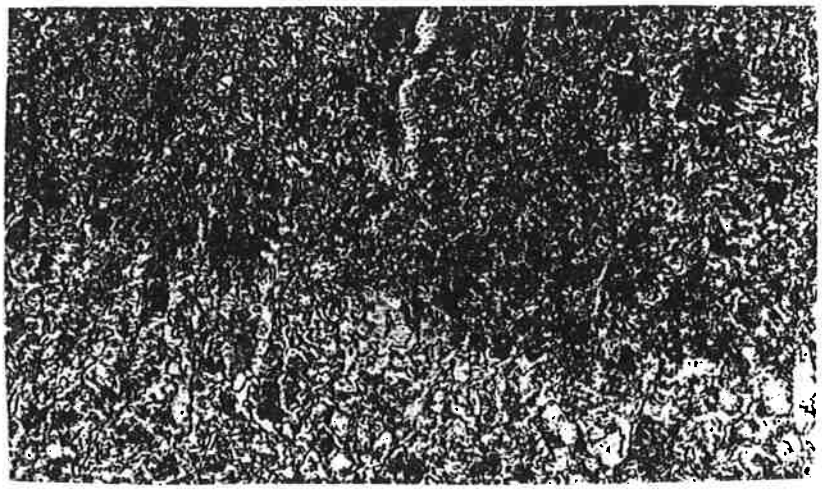
A estrutura consiste de uma zona bruta de fusão, caracterizada por grãos colunares dendríticos localizada no metal de adição. Aumento 600X.



A estrutura apresenta grãos recozidos de PERLITA E FERRITA localizada no metal de adição. Aumento de 600X.

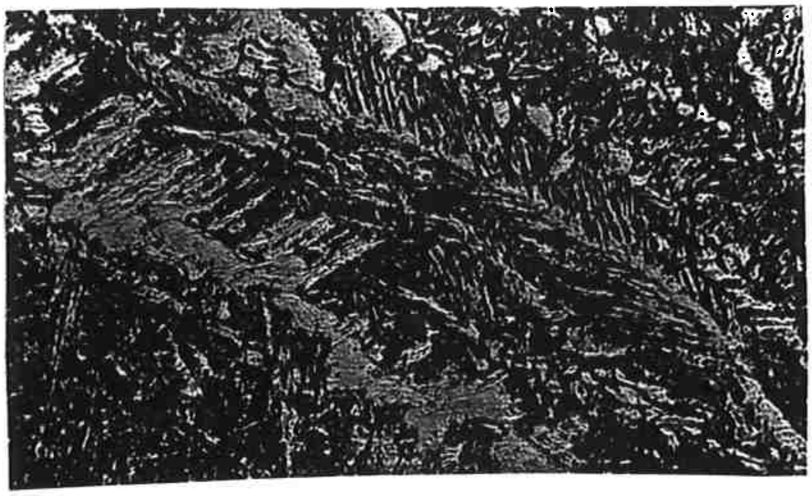


A estrutura é composta por perlita e ferrita alinhadas, localizada no metal de base. Aumento 600X.



A estrutura demonstra o início da recuperação cristalina, localizada no zona de metal de adição. Aumento 300X.

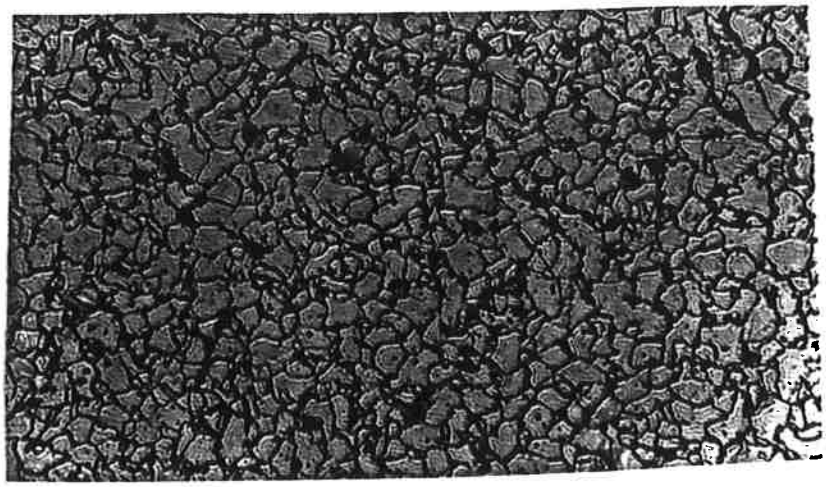
A estrutura mostra a linha de transição entre metal base e metal de adição. Aumento 150X.



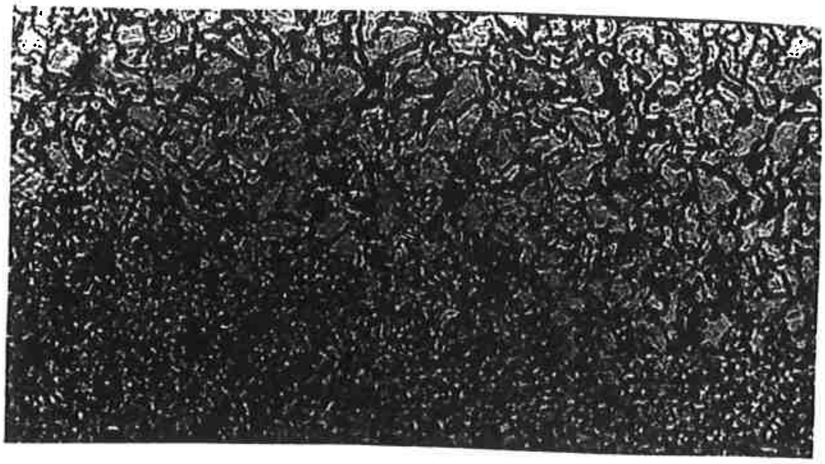
A estrutura mostra a zona bruta de fusão, localizada no metal de adição. Aumento 600X.

Corpo de Prova No.2:

A estrutura mostra a zona bruta de fusão, tendo grãos colunares de PERLITA E ferrita, localizada no metal de adição. Aumento 150X.

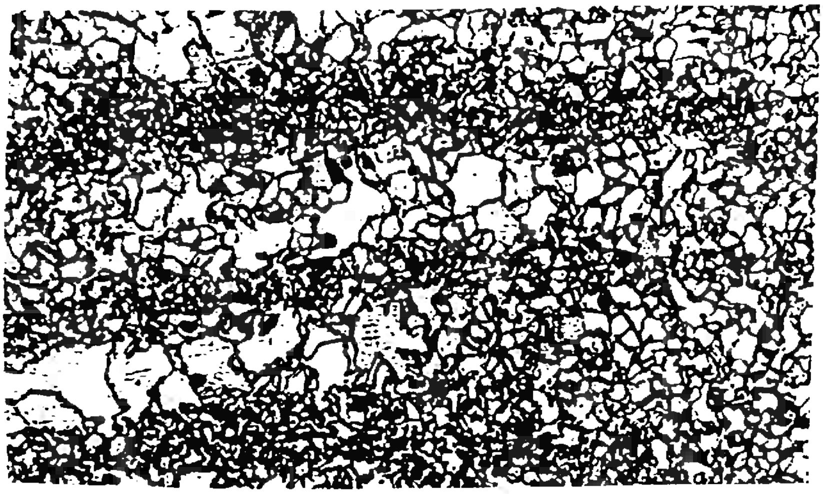


A estrutura mostra grãos recozidos de PERLITA, e ferrita, localizada no metal de adição. Aumento 600X.

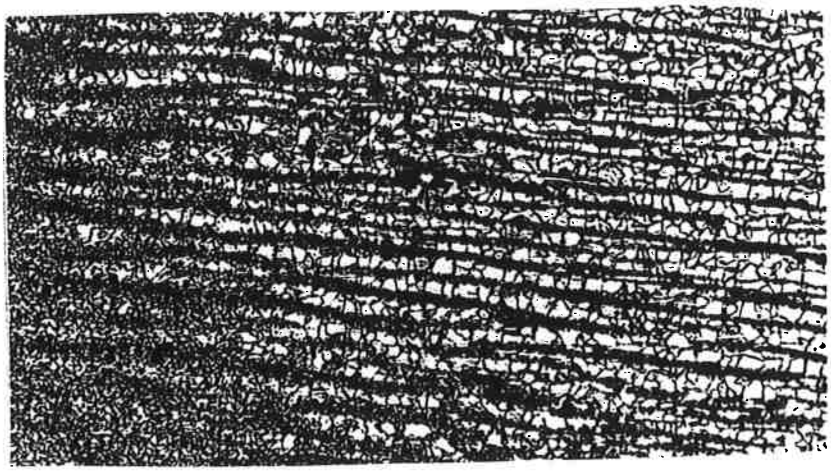


A estrutura mostra o início da recuperação cristalinana zona do metal de adição. Aumento 150X.

A estrutura mostra ferrita e perlita alinhadas, localizada no metal de Base. Aumento 600X.

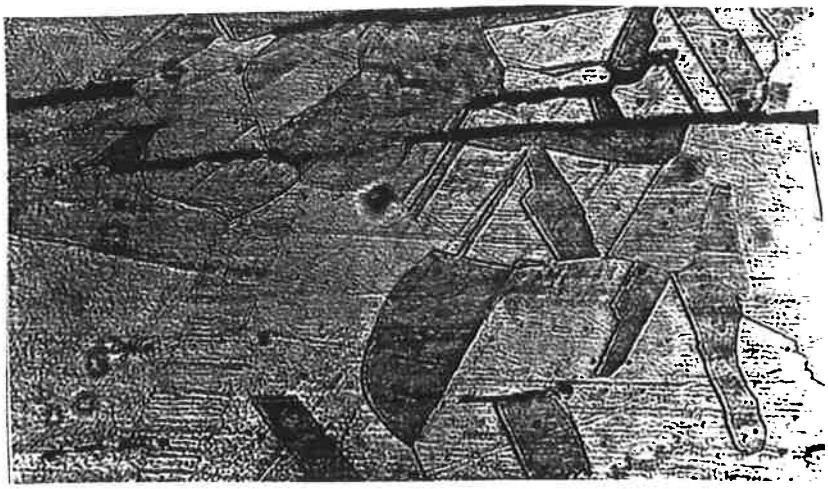


A estrutura mostra ferrita e perlita esboroada, localizada na Zona Afetada Termicamente. Aumento 600X.



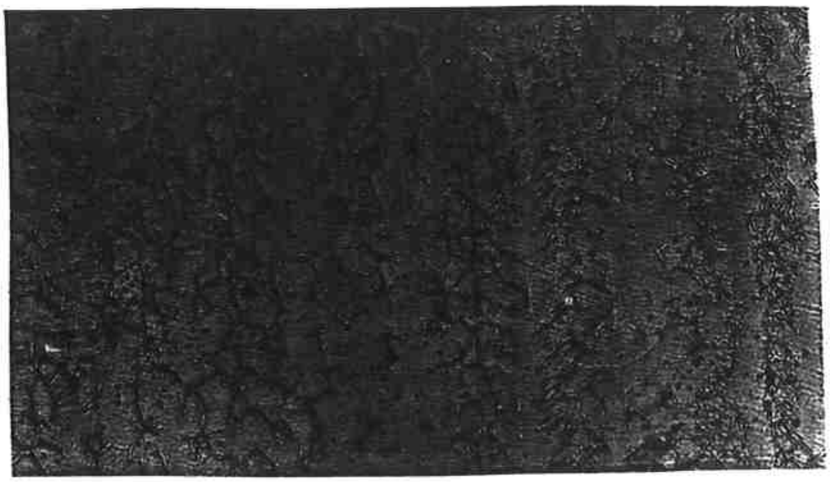
A estrutura mostra perlita esboroada e ferrita, localizada na zona afetada termicamente. Aumento 150X.

Corpo de prova No. 4:



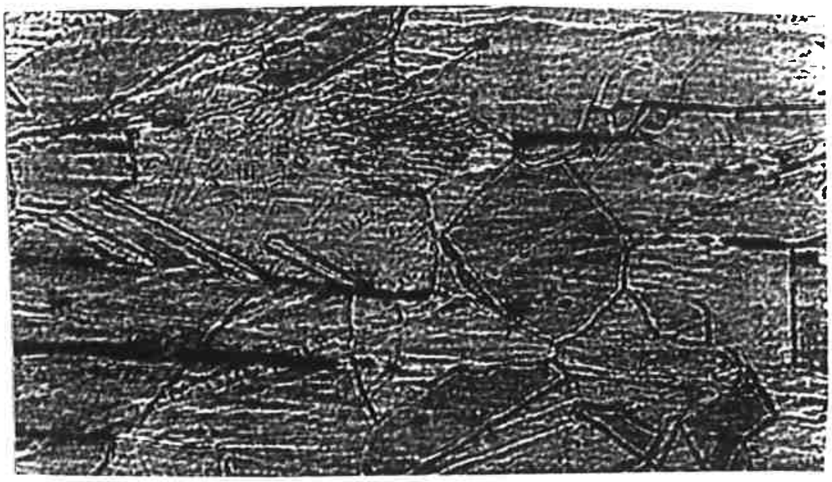
A estrutura mostra grãos equiaxiais de austenita maclada, localizada no metal base. Aumento 600X.

A estrutura mostra a zona de transição austenita maclada / estrutura bruta de fusão, localizada na zona termicamente afetada. Aumento 300X.

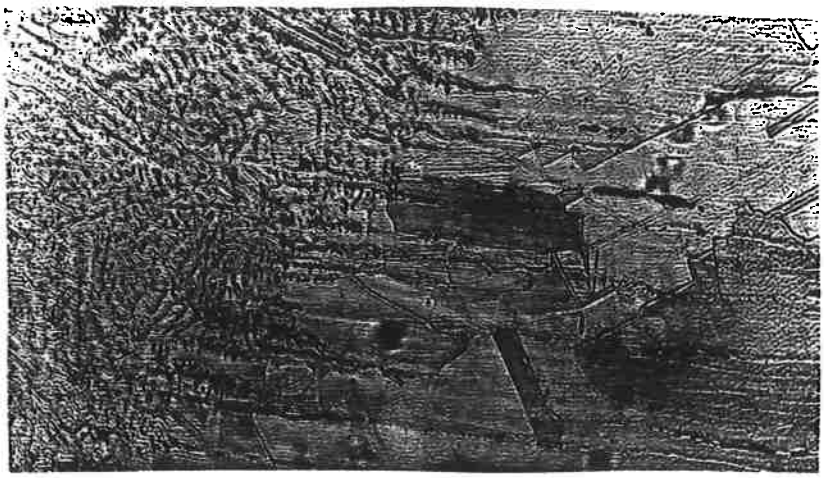


A estrutura é uma zona bruta de fusão, localizada no metal de adição. Aumento 600X.

<u>Corpo de prova No.5:</u>



A estrutura apresenta austenita maclada, localizada no metal base. Aumento 600X.



A estrutura mostra a interface austenita maclada / zona bruta de fusão, localizada na zona termicamente afetada. Aumento 600X.

A estrutura mostra a zona bruta de fusão, localizada no metal de adição. Aumento 300X.

## 4. DISCUSSÃO E CONCLUSÃO:

Dada a espessura das chapas, a soldagem foi realizada por meio de vários passes consecutivos, dando origem a estruturas recuperadas no metal de adição, dado que os passes superiores provocavam uma recuperação cristalina do metal de adição dos passes anteriores devido a temperatura de trabalho na soldagem.

Através de ensaios metalográficos, não pudemos ter uma distinção clara nas microestruturas entre processos distintos para um mesmo metal de base. Somente com o auxílio de um ferritoscópio, pudemos observar uma distinção entre os processos, apresentando um teor de ferrita, médio, maior para o processo GMAW em comparação ao processo GTAW + SMAW.

Através do ferritoscópio notou-se também a presença de uma fase magnética de ferrita delta no metal de adição para os aços inoxidáveis austeníticos, sendo o teor relativamente maior para o processo GTAW + SMAW, quando comparado ao processo SMAW.

Através dos ensaios não destrutivos, nada foi observado para que o processo não fosse aprovado.

Através do ensaio de dobramento, para que o processo seja qualificado, é neccessário que não ocorram trincas na região dobrada, região de solda.

Através do ensaio de tração, a ruptura deve se dar na região do metal de base, ou ainda no metal de adição, desde que atinja um limite de ruptura caima do esperado para o metal de base. Dados estes requisitos, todos os processos foram aprovados.

Através dos parâmetros acima discutidos, pode-se considerar estes processos de soldagem aprovados para vasos de pressão, segundo código ASME Seção IX de 1992.

## 5. REFERÊNCIAS BIBLIOGRÁFICAS: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2. Universidade de São Paulo. Escola Politécnica. Serviço de Bibliotecas. Diretrizes para apresentações de dissertações e teses. Editoração de MGC Reis. Sào Paulo. 1987.

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4. Wainer, E. .Soldagem, Processos e Metalurgia. Edgard Blucher. São Paulo. 1992.

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8. ASME Section IX. Part QW Welding. 1992.

9. ASME Section V. Part of Non Desctructive Tests. 1989. Article 3,5,6,7,9.

10. Normenasschuss Eisen und Stahl. DIN 1711. Numberg. 1980.

# ANEXO A - PROCEDIMENTOS DE SOLDAGEM

**Ensaio por Ultra Som:**

A foto a seguir ilustra o procedimento do ensaio por Ultra Som:

| ABB ASEA BROWN BOVERI | ESPECIFICAÇÃO DO PROCEDIMENTO DE SOLDAGEM (EPS)<br>WELDING PROCEDURE SPECIFICATION (WPS) | Nº EPS<br>Nr WPS 20164<br>Revisão/Data<br>Revision/Date 15.05.93 |
|---|---|---|

Elaborado por:
By: FERNANDO

data:
date: 02.03.93

Nº QPS
Nr PQR 20164

PROCESSO DE SOLDAGEM:
WELDING PROCESS SMAW

Tipo:
Type MANUAL

Juntas (QW 402)
Joints

Detalhe
Details

Tipo de Chanfro EM "V."
Joint Type

Mata-Junta ☒ Sim Yes ☐ Não No
Backing

Material da Mata-Junta WELD METAL
Backing Material

Para outros detalhes de juntas ver desenho de fabricação
For others joints details refer to fabrication drawings

METAIS DE BASE (QW 403)
BASE METALS

P Nº 8 Grupo Nº 1 com P Nº 8 Grupo Nº 1
P Nr Group Nr with P Nr Group Nr

ou Especificação do Tipo e Grau SA 240 tp 304L. SA 312 tp 304
or Specification Type and Grade

com Especificação do Tipo e Grau SA 240 tp 304L. SA 312 tp 304
to Specification Type and Grade

ou Análises Química e Propriedade Mecânica N.U.
or Chemical Analysis and Mechanical Property

com Análises Química e Propriedade Mecânica N.U.
to Chemical Analysis and Mechanical Property

Faixa de Espessura
Thickness Range

Metal de Base: Chanfro 3/16" - 2" Filete QUALQUER
Base Metal: Groove Fillet

Metal de Solda Depositado: Chanfro MÁX - 2" Filete QUALQUER
Deposited Weld Metal: Groove Fillet

Faixa de Diâmetro do Tubo: Chanfro QUALQUER Filete QUALQUER
Pipe Diameter Range Groove Fillet

Outros
Others

METAIS DE ADIÇÃO (QW 404)
Filler Metals

F Nº 5 Outros N.U.
F Nr Others

A Nº 8 Outros N.U.
A Nr Others

Especificação Nº SFA 5.4 Classificação Nº AWS E 308 L16
Specification Nr SFA Classification Nr AWS

Bitolas: Eletrodo 3/32" - 1/8" - 5/32"
Size of Filler Metals Electrode

Arame N.U.
Electrode

Classificação Fluxo-Arame N.U. Marca N.U.
Electrode - Flux (Class) Flux trade made

Insert Consumível N.U.
Consumable Insert

Outros N.U.
Others

POSIÇÕES (QW 405)
Positions

Posição (ões) do Chanfro TODAS
Position (s) of Groove

Progressão de Soldagem: ASC. ☒ 3G Desc. ☐
Welding Progression: Up Down

Posição (ões) do Filete TODAS
Position of Fillet

PRÉ-AQUECIMENTO (QW 406)
Preheat

Temp. Pré-aquecimento (mín.) 10°C
Preheat temperature

Temperatura Interpasse (máx.) 260°C
Interpass Temperature

Outros N.U.
Others

**TRATAMENTO TÉRMICO PÓS-SOLDA**
**POSTWELD HEAT TREATMENT** **(QW 407)**

**Faixa de Temperatura** N.J.
Temperature range

**Tempo de Permanência** N.J.
Maintenance Time

**GÁS**
**GAS** **(QW 408)**

**Gás de Proteção** N.J.
Shielding Gas

**Composição da Mistura** N.J.
Composition Mixture

**Vazão: Tocha** N.J.
Flow rate: Torch

**Raiz** N.J.
Backing

**Backing do Gás** N.J.
Gas Backing

**CARACTERÍSTICAS ELÉTRICAS**
**ELECTRICAL CHARACTERISTICS** **(QW 409)**

**Tipo e Diâmetro do Eletrodo de Tungstênio** N.J.
Tungsten Electrode Size and Type

**Modo de Transferência de Metal para GMAW** N.J.
Mode of Metal transfer for GMAW

**Faixa de Velocidade de Alimentação do Arame** N.J
Electrode wire feed Speed Range

| Processo Process | Camadas Layers | Material de Adição Filler Metal AWS | Ø IN | Intensidade Corrente Current (A) | Polaridade Polarity | Tensão Tension (V) | Velocidade Speed range |
|---|---|---|---|---|---|---|---|
| SMAW | 1-8 | E308L16 | 3/32 | 55-80 | CC+ | 20-24 | 3-10 |
| SMAW | ANY | E308L16 | 1/8 | 80-130 | CC+ | 20-25 | 3-13 |

**Outros** N. J.
**Others**

**TÉCNICA**
**TECHINIQUE** **(QW 410)**

**Filetado ou Trançado** FILETADO
String or Weave Bead

**Orifício ou Tamanho do Furo para Saída de Gás** N.J.
Orifice or Gas Cup Size

**Limpeza Inicial e Final** ESMERILHAR/ESCOVAR
Initial and Interpass Cleaning

**Método de Goivagem** ESMERILHAR/ESCOVAR
Method of Back Gouging

**Oscilação** N.J.
Oscilation

**Distância Tubo x Peça** N.J.
Stickout

**Um ou Múltiplos Passes por lado** MULTIPLOS
Multiple or Single Pass per side

**Eletrodos simples ou múltiplos** SIMPLES
Multiple or single electrode

| FABRICANTE MANUFACTURER | VISTO IMQ SIGN | CLIENTE E/OU INSPETOR CLIENT AND/OR INSPECTOR |
|---|---|---|
| DATA DATE | DATA DATE | DATA DATE |

ABB
ASEA BROWN BOVERI

# ESPECIFICAÇÃO DO PROCEDIMENTO DE SOLDAGEM (EPS)
# WELDING PROCEDURE SPECIFICATION (WPS)

Nº EPS
Nr WPS 20169

Revisão/Data
Revision/Date 15.05.93

Elaborado por:
By: FERNANDO

data:
date: 02.03.93

Nº QPS
Nr PQR 20169

PROCESSO DE SOLDAGEM:
WELDING PROCESS GTAW + SMAW

Tipo:
Type

**Juntas (QW 402)**
**Joints**

Detalhe
Details

Tipo de Chanfro
Joint Type: EM "V"

Mata-Junta
Backing: SMAW ☒ Sim / Yes  GTAW ☒ Não / No

Material da Mata-Junta
Backing Material: GTAW : N.U.
SMAW: WELD METAL

Para outros detalhes de juntas ver desenho de fabricação
For others joints details refer to fabrication drawings

**METAIS DE BASE (QW 403)**
**BASE METALS**

P Nº / P Nr: 8  Grupo Nº / Group Nr: 1  com P Nº / with P Nr: 8  Grupo Nº / Group Nr: 1

ou Especificação do Tipo e Grau
or Specification Type and Grade: SA 240 tp 304L, SA 312 tp 304

com Especificação do Tipo e Grau
to Specification Type and Grade: SA 240 tp 304L, SA 312 tp 304

ou Análises Química e Propriedade Mecânica
or Chemical Analysis and Mechanical Property: N.U.

com Análises Química e Propriedade Mecânica
to Chemical Analysis and Mechanical Property: N.U.

Faixa de Espessura
Thickness Range

| | Chanfro / Groove | Filete / Fillet |
|---|---|---|
| Metal de Base: / Base Metal: | 3/16 - 2" | QUALQUER |
| Metal de Solda Depositado: / Deposited Weld Metal: | GTAW = MÁX 1/2"<br>SMAW = MÁX 1 1/2" | QUALQUER |
| Faixa de Diâmetro do Tubo: / Pipe Diameter Range | QUALQUER | QUALQUER |

Outros
Others: N.U.

**METAIS DE ADIÇÃO (QW 404)**
**Filler Metals**

F Nº / F Nr: GTAW: 6/SMAW: 5  Outros / Others:

A Nº / A Nr: 8/8  Outros / Others:

Especificação Nº SFA
Specification Nr SFA: 5,9/5,4

Classificação Nº AWS
Classification Nr AWS: ER308L/E308L-16

Bitolas:
Size of Filler Metals

Eletrodo
Electrode: 3/32" - 1/8" - 5/32"

Arame
Electrode: 1/16" - 5/64" - 3/32"

Classificação Fluxo-Arame
Electrode - Flux (Class): N.U.

Marca
Flux trade made: N.U.

Insert Consumível
Consumable Insert: N.U.

Outros
Others: N.U.

**POSIÇÕES (QW 405)**
**Positions**

Posição (ões) do Chanfro
Position (s) of Groove: TODAS

Progressão de Soldagem:
Welding Progression: ASC. / Up ☒ 3G  Desc. / Down ☐

Posição (ões) do Filete
Position of Fillet: TODAS

**PRÉ-AQUECIMENTO (QW 406)**
**Preheat**

Temp. Pré-aquecimento
Preheat temperature (mín.): 18ºC

Temperatura Interpasse
Interpass Temperature (máx.): 260ºC

Outros
Others

**TRATAMENTO TÉRMICO PÓS-SOLDA**
**POSTWELD HEAT TREATMENT** (QW 407)

Faixa de Temperatura / Temperature range: N.V.
Tempo de Permanência / Maintenance Time: N.V.

**GÁS**
**GAS** (QW 408)

Gás de Proteção / Shielding Gas: ARGÔNIO
Composição da Mistura / Composition Mixture: N.V.
Vazão: Tocha / Flow rate: Torch: 8-12 l/min
Raiz / Backing: 1-2 l/min
Backing de Gás / Gas Backing: N.V.

**CARACTERÍSTICAS ELÉTRICAS**
**ELECTRICAL CHARACTERISTICS** (QW 409)

Tipo e Diâmetro do Eletrodo de Tungstênio / Tungsten Electrode Size and Type: 1% Tor. - 1/16" ou 3/32"
Modo de Transferência de Metal para GMAW / Mode of Metal transfer for GMAW: N.V.
Faixa de Velocidade de Alimentação do Arame / Electrode wire feed Speed Range: N.V.

| Processo Process | Camadas Layers | Material de Adição Filler Metal | | Intensidade Corrente Current | Polaridade Polarity | Tensão Tension (V) | Velocidade Speed range |
|---|---|---|---|---|---|---|---|
| | | AWS | Ø IN | (A) | | | IN/MIN |
| GTAW | 1-2 | ER 308L | 1/16 | 80-140 | CC- | 8-13 | 0,5-2 |
| SMAW | ANY | ER 308L16 | 5/32 | 130-170 | CC+ | 21-26 | 4-14 |

Outros / Others: N.V.

**TÉCNICA**
**TECHINIQUE** (QW 410)

Filetado ou Trançado / String or Weave Bead: FILETADO
Orifício ou Tamanho do Furo para Saída de Gás / Orifice or Gas Cup Size: N.V.
Limpeza Inicial e Final / Initial and Interpass Cleaning: ESMERILHAR E ESCOVAR
Método de Goivagem / Method of Back Gouging: N.V.
Oscilação / Oscilation: N.V.
Distância Tubo x Peça / Stickout: N.V.
Um ou Múltiplos Passes por lado / Multiple or Single Pass pér side: MÚLTIPLOS
Eletrodos simples ou múltiplos / Multiple or single electrode: SIMPLES

| FABRICANTE MANUFACTURER | VISTO IMQ SIGN | CLIENTE E/OU INSPETOR CLIENT AND/OR INSPECTOR |
|---|---|---|
| DATA DATE | DATA DATE | DATA DATE |

| ABB ASEA BROWN BOVERI | ESPECIFICAÇÃO DO PROCEDIMENTO DE SOLDAGEM (EPS)<br>WELDING PROCEDURE SPECIFICATION (WPS) | Nº EPS<br>Nr WPS 20163<br>Revisão/Data<br>Revision/Date 15.05.93 |
|---|---|---|

Elaborado por:
By: FERNANDO

data:
date: 02.03.93

Nº QPS
Nr PQR 20163

PROCESSO DE SOLDAGEM:
WELDING PROCESS GTAW + SMAW

Tipo:
Type MANUAL

Juntas (QW 402)
Joints

Detalhe
Details

Tipo de Chanfro EM "V"
Joint Type

Mata-Junta SMAW ☒ Sim / Yes ☒ Não / No
Backing

Material da Mata-Junta N.U. (GTAW)
Backing Material WELD METAL (SMAW)

Para outros detalhes de juntas ver desenho de fabricação
For others joints details refer to fabrication drawings

METAIS DE BASE (QW 403)
BASE METALS

P Nº N.U. Grupo Nº N.U. com P Nº N.U. Grupo Nº N.U.
P Nr Group Nr with P Nr Group Nr

ou Especificação do Tipo e Grau DIN RRSt 44.3
or Specification Type and Grade

com Especificação do Tipo e Grau DIN RRSt 44.3
to Specification Type and Grade

ou Análises Química e Propriedade Mecânica C=0,23% Mn=1,6% Si=0,55% P=0,05% S=0,05%
or Chemical Analysis and Mechanical Property

com Análises Química e Propriedade Mecânica N.U.
to Chemical Analysis and Mechanical Property

Faixa de Espessura
Thickness Range

Metal de Base: Chanfro 3/16" – 2" Filete QUALQUER
Base Metal: Groove Fillet

Metal de Solda Depositado: Chanfro GTAW MÁX. 1/2" SMAW MÁX. 11/2" Filete QUALQUER
Deposited Weld Metal: Groove Fillet

Faixa de Diâmetro do Tubo: Chanfro QUALQUER Filete QUALQUER
Pipe Diameter Range Groove Fillet

Outros
Others

METAIS DE ADIÇÃO (QW 404)
Filler Metals

F Nº GTAW: 6/SMAW: 4 Outros
F Nr Others

A Nº ER 80S D2/1 Outros
A Nr Others

Especificação Nº SFA 5.28/5.1 Classificação Nº AWS ER 80S D2/E 7018-1
Specification Nr SFA Classification Nr AWS

Bitolas: Eletrodo 3/32" – 1/8" – 5/32" – 3/16"
Size of Filler Metals Electrode

Arame 1/16" – 5/64" – 3/32"
Electrode

Classificação Fluxo-Arame N.U. Marca N.U.
Electrode - Flux (Class) Flux trade made

Insert Consumível N.U.
Consumable Insert

Outros N.U.
Others

POSIÇÕES (QW 405)
Positions

Posição (ões) do Chanfro TODAS
Position (s) of Groove

Progressão da Soldagem: ASC. ☒ (3G) Desc. ☐
Welding Progression: Up Down

Posição (ões) do Filete TODAS
Position of Fillet

PRÉ-AQUECIMENTO (QW 406)
Preheat

Temp. Pré-aquecimento (mín.) 18°C
Preheat temperature

Temperatura Interpasse (máx.) 260°C
Interpass Temperature

Outros
Others

## TRATAMENTO TÉRMICO PÓS-SOLDA (QW 407)
## POSTWELD HEAT TREATMENT

Faixa de Temperatura / Temperature range: N.U.

Tempo de Permanência / Maintenance Time: N.U.

## GÁS (QW 408)
## GAS

Gás de Proteção / Shielding Gas: ARGÔNIO

Composição da Mistura / Composition Mixture: 99,9% ARGÔNIO

Vazão: Tocha / Flow rate: Torch: 08-12 l/min

Raiz / Backing: 1-2 l/min

Backing de Gás / Gas Backing: N.U.

## CARACTERÍSTICAS ELÉTRICAS (QW 409)
## ELECTRICAL CHARACTERISTICS

Tipo e Diâmetro do Eletrodo de Tungstênio / Tungsten Electrode Size and Type: 1% Tor. - 1/16" ou 3/32"

Modo de Transferência de Metal para GMAW / Mode of Metal transfer for GMAW: N.U.

Faixa de Velocidade de Alimentação do Arame / Electrode wire feed Speed Range: N.U.

| Processo Process | Camadas Layers | Material de Adição Filler Metal | | Intensidade Corrente Current | Polaridade Polarity | Tensão Tension (V) | Velocidade Speed range |
|---|---|---|---|---|---|---|---|
| | | AWS | Ø IN | (A) | | | IN/MIN |
| GTAW | 1-2 | ER 80S02 | | 90-150 | CC- | 08-13 | 0,3-2 |
| SMAW | 3 ANO | E7018-1 | 3/32 | 60-90 | CC+ | 20-25 | 2,5-8 |

Outros / Others: N.U.

## TÉCNICA (QW 410)
## TECHINIQUE

Filetado ou Trançado / String or Weave Bead: FILETADO

Orifício ou Tamanho do Furo para Saída de Gás / Orifice or Gas Cup Size: N.U.

Limpeza Inicial e Final / Initial and Interpass Cleaning: ESMERILHAR - ESCOVAR

Método de Goivagem / Method of Back Gouging: N.U.

Oscilação / Oscillation: N.U.

Distância Tubo x Peça / Stickout: N.U.

Um ou Múltiplos Passes por lado / Multiple or Single Pass per side: MÚLTIPLOS PASSES

Eletrodos simples ou múltiplos / Multiple or single electrode: ELETRODO SIMPLES

| FABRICANTE MANUFACTURER | VISTO IMQ SIGN | CLIENTE E/OU INSPETOR CLIENT AND/OR INSPECTOR |
|---|---|---|
| DATA DATE | DATA DATE | DATA DATE |

ABB
ASEA BROWN BOVERI

# ESPECIFICAÇÃO DO PROCEDIMENTO DE SOLDAGEM (EPS)
# WELDING PROCEDURE SPECIFICATION (WPS)

Nr WPS 20130

Revisão/Data
Revision/Date 15.05.93

Elaborado por:
By: FERNANDO

data:
date: 02.03.93

Nº QPS
Nr PQR 108/83

PROCESSO DE SOLDAGEM:
WELDING PROCESS GMAW

Tipo:
Type SEMI-AUTOMÁTICO

**Juntas (QW 402)**
**Joints**

Detalhe
Details

Tipo de Chanfro / Joint Type: EM "V"

Mata-Junta / Backing: ☐ Sim / Yes ☒ Não / No

Material da Mata-Junta / Backing Material: N.U.

Para outros detalhes de juntas ver desenho de fabricação
For others joints details refer to fabrication drawings

**METAIS DE BASE (QW 403)**
**BASE METALS**

P Nº / P Nr: N.U. — Grupo Nº / Group Nr: N.U. — com P Nº / with P Nr: N.U. — Grupo Nº / Group Nr: N.U.

ou Especificação do Tipo e Grau / or Specification Type and Grade: DIN RRSt 44.3

com Especificação do Tipo e Grau / to Specification Type and Grade: DIN RRSt 44.3

ou Análises Química e Propriedade Mecânica / or Chemical Analysis and Mechanical Property: C = 0,23% Mn = 1,6% Si = 0,55% P = 0,05% S = 0,05%

com Análises Química e Propriedade Mecânica / to Chemical Analysis and Mechanical Property: N.U.

Faixa de Espessura
Thickness Range

| | Chanfro / Groove | Filete / Fillet |
|---|---|---|
| Metal de Base: / Base Metal: | 3/16" - 2" | QUALQUER |
| Metal de Solda Depositado: / Deposited Weld Metal: | MÁX. 2" | QUALQUER |
| Faixa de Diâmetro do Tubo: / Pipe Diameter Range | QUALQUER | QUALQUER |

Outros / Others: N.U.

**METAIS DE ADIÇÃO (QW 404)**
**Filler Metals**

F Nº / F Nr: 6 — Outros / Others: N.U.

A Nº / A Nr: 1 — Outros / Others: N.U.

Especificação Nº SFA / Specification Nr SFA: 5.18 — Classificação Nº AWS / Classification Nr AWS: ER 70 S6

Bitolas: / Size of Filler Metals: Eletrodo / Electrode: N.U.
Arame / Electrode: 1,2 mm

Classificação Fluxo-Arame / Electrode - Flux (Class): N.U. — Marca / Flux trade made: N.U.

Insert Consumível / Consumable Insert: N.U.

Outros / Others: N.U.

**POSIÇÕES (QW 405)**
**Positions**

Posição (ões) do Chanfro / Position (s) of Groove: TODAS / ALL

Progressão de Soldagem: / Welding Progression: ASC. / Up ☒ (3G) — Desc. / Down ☐

Posição (ões) do Filete / Position of Fillet: TODAS

**PRÉ-AQUECIMENTO (QW 406)**
**Preheat**

Temp. Pré-aquecimento / Preheat temperature (mín.): 20°C

Temperatura Interpasse / Interpass Temperature (máx.): 250°C

Outros / Others: N.U.

**TRATAMENTO TÉRMICO PÓS-SOLDA**
**POSTWELD HEAT TREATMENT** **(QW 407)**

**Faixa de Temperatura** N.U.
Temperature range

**Tempo de Permanência** N.U.
Maintenance Time

**GÁS**
**GAS** **(QW 408)**

**Gás de Proteção** CORGON C-25
Shielding Gas

**Composição da Mistura** 75% Ar + 25% $CO_2$
Composition Mixture

**Vazão: Tocha** 10 a 15 L/min
Flow rate: Torch

**Raiz** N.U.
Backing

**Backing de Gás** N.U.
Gas Backing

**CARACTERÍSTICAS ELÉTRICAS**
**ELECTRICAL CHARACTERISTICS** **(QW 409)**

**Tipo e Diâmetro do Eletrodo de Tungstênio** N.U.
Tungsten Electrode Size and Type

**Modo de Transferência de Metal para GMAW** GLOBULAR
Mode of Metal transfer for GMAW

**Faixa de Velocidade de Alimentação do Arame** N.U.
Electrode wire feed Speed Range

| Processo Process | Camadas Layers | Material de Adição Filler Metal AWS | Material de Adição Filler Metal Ø (mm) | Intensidade Corrente Current (A) | Polaridade Polarity | Tensão Tension (V) | Velocidade Speed range |
|---|---|---|---|---|---|---|---|
| GMAW | 1º | ER 70 S 6 | 1,2 | 70 - 110 | CC+ | 17-21 | |
| GMAW | - | ER 70 S 6 | 1,2 | 120 - 180 | CC+ | 17-21 | |

**Outros** N.U.
Others

**TÉCNICA**
**TECHINIQUE** **(QW 410)**

**Filetado ou Trançado** TRANÇADO
String or Weave Bead

**Orifício ou Tamanho do Furo para Saída de Gás** N.U.
Orifice or Gas Cup Size

**Limpeza Inicial e Final** ESMERILHAR E ESCOVAR
Initial and Interpass Cleaning

**Método de Goivagem** N.U.
Method of Back Gouging

**Oscilação** MÁX 5/8"
Oscilation

**Distância Tubo x Peça** MÁX. 1"
Stickout

**Um ou Múltiplos Passos por lado** MULTIPLOS
Multiple or Single Pass per side

**Eletrodos simples ou múltiplos** SIMPLES
Multiple or single electrode

| FABRICANTE MANUFACTURER | VISTO IMQ SIGN | CLIENTE E/OU INSPETOR CLIENT AND/OR INSPECTOR |
|---|---|---|
| DATA DATE | DATA DATE | DATA DATE |

# ANEXO B - CÓDIGO ASME SEÇÃO IX

# PART QW WELDING

## ARTICLE I
## WELDING GENERAL REQUIREMENTS

### QW-100 GENERAL

Section IX of the ASME Boiler and Pressure Vessel Code relates to the qualification of welders, welding operators, brazers, and brazing operators, and the procedures that they employ in welding and brazing according to the ASME Boiler and Pressure Vessel Code and the ASME B31 Code for Pressure Piping. It is divided into two parts: Part QW gives requirements for welding and Part QB contains requirements for brazing.

**QW-100.1** The purpose of the Welding Procedure Specification (WPS) and Procedure Qualification Record (PQR) is to determine that the weldment proposed for construction is capable of providing the required properties for its intended application. It is presupposed that the welder or welding operator performing the welding procedure qualification test is a skilled workman. That is, the welding procedure qualification test establishes the properties of the weldment, not the skill of the welder or welding operator. In addition to this general requirement, special considerations for notch toughness are required by other Sections of the Code. Briefly, a WPS lists the variables, both essential and nonessential, and the acceptable ranges of these variables when using the WPS. The WPS is intended to provide direction for the welder/welding operator. The PQR lists what was used in qualifying the WPS and the test results.

**QW-100.2** In performance qualification, the basic criterion established for welder qualification is to determine the welder's ability to deposit sound weld metal. The purpose of the performance qualification test for the welding operator is to determine the welding operator's mechanical ability to operate the welding equipment.

**QW-100.3** Welding Procedure Specifications (WPS) written and qualified in accordance with the rules of this Section, and welders and welding operators of automatic and machine welding equipment also qualified in accordance with these rules may be used in any construction built to the requirements of the ASME Boiler and Pressure Vessel Code or the ASME B31 Code for Pressure Piping.

However, other Sections of the Code state the conditions under which Section IX requirements are mandatory, in whole or in part, and give additional requirements. The reader is advised to take these provisions into consideration when using this Section.

Welding Procedure Specifications, Procedure Qualification Records, and Welder/Welding Operator Performance Qualification made in accordance with the requirements of the 1962 Edition or any later Edition of Section IX may be used in any construction built to the ASME Boiler and Pressure Vessel Code or the ASME B31 Code for Pressure Piping.

Welding Procedure Specifications, Procedure Qualification Records, and Welder/Welding Operator Performance Qualification made in accordance with the requirements of the Editions of Section IX prior to 1962, in which all of the requirements of the 1962 Edition or later Editions are met, may also be used.

Welding Procedure Specifications meeting the above requirements do not need to be amended to include any variables required by later Editions and Addenda.

Qualification of new Welding Procedure Specifications and requalification of existing Welding Procedure Specifications shall be in accordance with the current Edition (see Foreword) and Addenda of Section IX.

### QW-101 Scope

The rules in this Section apply to the preparation of Welding Procedure Specifications and the qualification of welding procedures, welders, and welding operators for all types of manual and machine welding processes permitted in this Section. These rules may also be applied, insofar as they are applicable, to other manual or machine welding processes permitted in other Sections.

### QW-102 Terms and Definitions

Some of the more common terms relating to welding are defined in QW-492. These are in substantial agreement with the definitions of the American Welding Society given in its document, A3.0-80, Terms and Definitions.

Wherever the word pipe is designated, tube shall also be applicable.

### QW-103 Responsibility

**QW-103.1 Welding.** Each manufacturer[1] or contractor[1] is responsible for the welding done by his organization and shall conduct the tests required in this Section to qualify the welding procedures he uses in the construction of the weldments built under this Code, and the performance of welders and welding operators who apply these procedures.

**QW-103.2 Records.** Each manufacturer or contractor shall maintain a record of the results obtained in welding procedure and welder and welding operator performance qualifications. These records shall be certified by the manufacturer or contractor and shall be accessible to the Authorized Inspector. Refer to recommended Forms in Nonmandatory Appendix A.

## QW-110 WELD ORIENTATION

The orientations of welds are illustrated in QW-461.1 or QW-461.2.

## QW-120 TEST POSITIONS FOR GROOVE WELDS

Groove welds may be made in test coupons oriented in any of the positions in QW-461.3 or QW-461.4 and as described in the following paragraphs, except that an angular deviation of ±15 deg. from the specified horizontal and vertical planes, and an angular deviation of ±5 deg. from the specified inclined plane are permitted during welding.

### QW-121 Plate Positions

**QW-121.1 Flat Position 1G.** Plate in a horizontal plane with the weld metal deposited from above. Refer to QW-461.3(a).

**QW-121.2 Horizontal Position 2G.** Plate in a vertical plane with the axis of the weld horizontal. Refer to QW-461.3(b).

**QW-121.3 Vertical Position 3G.** Plate in a vertical plane with the axis of the weld vertical. Refer to QW-461.3(c).

**QW-121.4 Overhead Position 4G.** Plate in a horizontal plane with the weld metal deposited from underneath. Refer to QW-461.3(d).

### QW-122 Pipe Positions

**QW-122.1 Flat Position 1G.** Pipe with its axis horizontal and rolled during welding so that the weld metal is deposited from above. Refer to QW-461.4(a).

**QW-122.2 Horizontal Position 2G.** Pipe with its axis vertical and the axis of the weld in a horizontal plane. Pipe shall not be rotated during welding. Refer to QW-461.4(b).

**QW-122.3 Multiple Position 5G.** Pipe with its axis horizontal and with the welding groove in a vertical plane. Welding shall be done without rotating the pipe. Refer to QW-461.4(c).

**QW-122.4 Multiple Position 6G.** Pipe with its axis inclined at 45 deg. to horizontal. Welding shall be done without rotating the pipe. Refer to QW-461.4(d).

### QW-123 Test Positions for Stud Welds

**QW-123.1 Stud Welding.** Stud welds may be made in test coupons oriented in any of the positions as described in QW-121 for plate and QW-122 for pipe (excluding QW-122.1). In all cases, the stud shall be perpendicular to the surface of the plate or pipe. See QW-461.7 and QW-461.8.

## QW-130 TEST POSITIONS FOR FILLET WELDS

Fillet welds may be made in test coupons oriented in any of the positions of QW-461.5 or QW-461.6, and as described in the following paragraphs, except

[1]Wherever these words are used in Section IX, they shall include installer or assembler.

that an angular deviation of ±15 deg. from the specified horizontal and vertical planes is permitted during welding.

### QW-131 Plate Positions

**QW-131.1 Flat Position 1F.** Plates so placed that the weld is deposited with its axis horizontal and its throat vertical. Refer to QW-461.5(a).

**QW-131.2 Horizontal Position 2F.** Plates so placed that the weld is deposited with its axis horizontal on the upper side of the horizontal surface and against the vertical surface. Refer to QW-461.5(b).

**QW-131.3 Vertical Position 3F.** Plates so placed that the weld is deposited with its axis vertical. Refer to QW-461.5(c).

**QW-131.4 Overhead Position 4F.** Plates so placed that the weld is deposited with its axis horizontal on the underside of the horizontal surface and against the vertical surface. Refer to QW-461.5(d).

### QW-132 Pipe Positions

**QW-132.1 Flat Position 1F.** Pipe with its axis inclined at 45 deg. to horizontal and rotated during welding so that the weld metal is deposited from above and at the point of deposition the axis of the weld is horizontal and the throat vertical. Refer to QW-461.6(a).

**QW-132.2 Horizontal Positions 2F and 2FR**

*(a) Position 2F.* Pipe with its axis vertical so that the weld is deposited on the upper side of the horizontal surface and against the vertical surface. The axis of the weld will be horizontal and the pipe is not to be rotated during welding. Refer to QW-461.6(b).

*(b) Position 2FR.* Pipe with its axis horizontal and the axis of the deposited weld in the vertical plane. The pipe is rotated during welding. Refer to QW-461.6(c).

**QW-132.3 Overhead Position 4F.** Pipe with its axis vertical so that the weld is deposited on the underside of the horizontal surface and against the vertical surface. The axis of the weld will be horizontal and the pipe is not to be rotated during welding. Refer to QW-461.6(d).

**QW-132.4 Multiple Position 5F.** Pipe with its axis horizontal and the axis of the deposited weld in the vertical plane. The pipe is not to be rotated during welding. Refer to QW-461.6(e).

## QW-140 TYPES AND PURPOSES OF TESTS AND EXAMINATIONS

### QW-141 Mechanical Tests

Mechanical tests used in procedure or performance qualification are as follows.

**QW-141.1 Tension Tests.** Tension tests as described in QW-150 are used to determine the ultimate strength of groove-weld joints.

**QW-141.2 Guided-Bend Tests.** Guided-bend tests as described in QW-160 are used to determine the degree of soundness and ductility of groove-weld joints.

**QW-141.3 Fillet-Weld Tests.** Tests as described in QW-180 are used to determine the size, contour, and degree of soundness of fillet welds.

**QW-141.4 Notch-Toughness Tests.** Tests as described in QW-171 and QW-172 are used to determine the notch toughness of the weldment.

**QW-141.5 Stud-Weld Test.** Deflection bend, hammering, torque, or tension tests as shown in QW-466.4, QW-466.5, and QW-466.6, and a macro-examination performed in accordance with QW-202.5, respectively, are used to determine acceptability of stud welds.

### QW-142 Special Examinations for Welders

Radiographic examination may be substituted for mechanical testing of QW-141 for groove-weld performance qualification as permitted in QW-304 to prove the ability of welders to make sound welds.

### QW-143 Examination for Welding Operators

An examination of a weld by radiography may be substituted for mechanical testing of QW-141 for groove weld performance qualification as permitted in QW-305 to prove the ability of welding operators to make sound welds.

## QW-150 TENSION TESTS

### QW-151 Specimens

Tension test specimens shall conform to one of the types illustrated in QW-462.1 and shall meet the requirements of QW-153.

**QW-151.1 Reduced Section — Plate.** Reduced-section specimens conforming to the requirements given in QW-462.1(a) may be used for tension tests on all thicknesses of plate.

*(a)* For thicknesses up to and including 1 in., a full thickness specimen shall be used for each required tension test.

*(b)* For plate thickness greater than 1 in., full thickness specimens or multiple specimens may be used, provided QW-151.1(c) and QW-151.1(d) are complied with.

*(c)* When multiple specimens are used, in lieu of full thickness specimens, each set shall represent a single tension test of the full plate thickness. Collectively, all of the specimens required to represent the full thickness of the weld at one location shall comprise a set.

*(d)* When multiple specimens are necessary, the entire thickness shall be mechanically cut into a minimum number of approximately equal strips of a size that can be tested in the available equipment. Each specimen of the set shall be tested and meet the requirements of QW-153.

**QW-151.2 Reduced Section — Pipe.** Reduced-section specimens conforming to the requirements given in QW-462.1(b) may be used for tension tests on all thicknesses of pipe having an outside diameter greater than 3 in.

*(a)* For thicknesses up to and including 1 in. a full thickness specimen shall be used for each required tension test.

*(b)* For pipe thicknesses greater than 1 in., full thickness specimens or multiple specimens may be used, provided QW-151.2(c) and QW-151.2(d) are complied with.

*(c)* When multiple specimens are used, in lieu of full thickness specimens, each set shall represent a single tension test of the full pipe thickness. Collectively, all of the specimens required to represent the full thickness of the weld at one location shall comprise a set.

*(d)* When multiple specimens are necessary, the entire thickness shall be mechanically cut into a minimum number of approximately equal strips of a size that can be tested in the available equipment. Each specimen of the set shall be tested and meet the requirements of QW-153.

For pipe having an outside diameter of 3 in. or less, reduced-section specimens conforming to the requirements given in QW-462.1(c) may be used for tension tests.

**QW-151.3 Turned Specimens.** Turned specimens conforming to the requirements given in QW-462.1(d) may be used for tension tests.

*(a)* For thicknesses up to and including 1 in., a single turned specimen may be used for each required tension test, which shall be a specimen of the largest diameter *D* of QW-462.1(d) possible for test coupon thickness [per Note (a) of QW-462.1(d)].

*(b)* For thicknesses over 1 in., multiple specimens shall be cut through the full thickness of the weld with their centers parallel to the metal surface and not over 1 in. apart. The centers of the specimens adjacent to the metal surfaces shall not exceed $^5/_8$ in. from the surface.

*(c)* When multiple specimens are used, each set shall represent a single required tension test. Collectively, all the specimens required to represent the full thickness of the weld at one location shall comprise a set.

*(d)* Each specimen of the set shall be tested and meet the requirements of QW-153.

**QW-151.4 Full-Section Specimens for Pipe.** Tension specimens conforming to the dimensions given in QW-462.1(e) may be used for testing pipe with an outside diameter of 3 in. or less.

## QW-152 Tension Test Procedure

The tension test specimen shall be ruptured under tensile load. The tensile strength shall be computed by dividing the maximum load by the least cross-sectional area of the specimen as calculated from actual measurements made before the load is applied.

## QW-153 Acceptance Criteria — Tension Tests

**QW-153.1 Tensile Strength.** In order to pass the tension test, the specimen shall have a tensile strength that is not less than:

*(a)* the specified minimum tensile strength of the base metal; or

*(b)* the specified minimum tensile strength of the weaker of the two, if base metals of different minimum tensile strengths are used; or

*(c)* the specified minimum tensile strength of the weld metal when the applicable Section provides for the use of weld metal having lower room temperature strength than the base metal;

*(d)* if the specimen breaks in the base metal outside of the weld or fusion line, the test shall be accepted as meeting the requirements, provided the strength is not more than 5% below the specified minimum tensile strength of the base metal.

## QW-160 GUIDED-BEND TESTS

## QW-161 Specimens

Guided-bend test specimens shall be prepared by cutting the test plate or pipe to form specimens of approximately rectangular cross section. The cut surfaces shall be designated the sides of the specimen. The other two surfaces shall be called the face and root surfaces, the face surface having the greater width of weld. The specimen thickness and bend radius are shown in QW-466.1, QW-466.2, and QW-466.3. Guided-bend specimens are of five types, depending on whether the axis of the weld is transverse or parallel to the longitudinal axis of the specimen, and which surface (side, face, or root) is on the convex (outer) side of bent specimen. The five types are defined as follows.

**QW-161.1 Transverse Side Bend.** The weld is transverse to the longitudinal axis of the specimen, which is bent so that one of the side surfaces becomes the convex surface of the bent specimen. Transverse side-bend test specimens shall conform to the dimensions shown in QW-462.2.

Specimens of base metal thickness over $1^1/_2$ in. may be cut into approximately equal strips between $^3/_4$ in. and $1^1/_2$ in. wide for testing, or the specimens may be bent at full width (see requirements on jig width in QW-466). If multiple specimens are used, one complete set shall be made for each required test. Each specimen shall be tested and meet the requirements in QW-163.

**QW-161.2 Transverse Face Bend.** The weld is transverse to the longitudinal axis of the specimen, which is bent so that the face surface becomes the convex surface of the bent specimen. Transverse face-bend test specimens shall conform to the dimensions shown in QW-462.3(a). For subsize transverse face bends, see QW-161.4.

**QW-161.3 Transverse Root Bend.** The weld is transverse to the longitudinal axis of the specimen, which is bent so that the root surface becomes the convex surface of the bent specimen. Transverse root-bend test specimens shall conform to the dimensions shown in QW-462.3(a). For subsize transverse root bends, see QW-161.4.

**QW-161.4 Subsize Transverse Face and Root Bends.** See Note (2) of QW-462.3(a).

**QW-161.5 Longitudinal-Bend Tests.** Longitudinal-bend tests may be used in lieu of the transverse side-, face-, and root-bend tests for testing weld metal or base metal combinations which differ markedly in bending properties between

*(a)* the two base metals; or

*(b)* the weld metal and the base metal.

**QW-161.6 Longitudinal Face Bend.** The weld is parallel to the longitudinal axis of the specimen, which is bent so that the face surface becomes the convex surface of the bent specimen. Longitudinal face-bend test specimens shall conform to the dimensions shown in QW-462.3(b).

**QW-161.7 Longitudinal Root Bend.** The weld is parallel to the longitudinal axis of the specimen, which is bent so that the root surface becomes the convex side of the bent specimen. Longitudinal root-bend test specimens shall conform to the dimensions shown in QW-462.3(b).

## QW-162 Guided-Bend Test Procedure

**QW-162.1 Jigs.** Guided-bend specimens shall be bent in test jigs that are in substantial accordance with QW-466. When using the jigs illustrated in QW-466.1 or QW-466.2, the side of the specimen turned toward the gap of the jig shall be the face for face-bend specimens, the root for root-bend specimens, and the side with the greater defects, if any, for side-bend specimens. The specimen shall be forced into the die by applying load on the plunger until the curvature of the specimen is such that a $^1/_8$ in. diameter wire cannot be inserted between the specimen and the die of QW-466.1, or the specimen is bottom ejected if the roller type of jig (QW-466.2) is used.

When using the wrap around jig (QW-466.3), the side of the specimen turned toward the roller shall be the face for face-bend specimens, the root for root-bend specimens, and the side with the greater defects, if any, for side-bend specimens.

When specimens wider than $1^1/_2$ in. are to be bent as permitted in QW-462.2, the test jig mandrel must be at least $^1/_4$ in. wider than the specimen width.

## QW-163 Acceptance Criteria — Bend Tests

The weld and heat affected zone of a transverse weld-bend specimen shall be completely within the bent portion of the specimen after testing.

The guided-bend specimens shall have no open defects in the weld or heat affected zone exceeding $^1/_8$ in., measured in any direction on the convex surface of the specimen after bending. Cracks occurring on the corners of the specimen during testing shall not be considered unless there is definite evidence that they result from slag inclusions or other internal defects. For corrosion-resistant weld overlay cladding, no open defect exceeding $^1/_{16}$ in., measured in any direction, shall be permitted in the cladding, and no open defects exceeding $^1/_8$ in. shall be permitted in the bond line.

## QW-170 NOTCH-TOUGHNESS TESTS

### QW-171 Notch-Toughness Tests — Charpy V-Notch

**QW-171.1 General.** Charpy V-notch impact tests shall be made when required by other Sections.

Test procedures and apparatus shall conform to the requirements of SA-370.

**QW-171.2 Acceptance.** The acceptance criteria shall be in accordance with that Section specifying impact requirements.

**QW-171.3 Location and Orientation of Test Specimen.** The impact test specimen and notch location and orientation shall be as given in the Section requiring such tests.

When qualifying pipe in the 5G or 6G position, the notch-toughness specimens shall be removed from the shaded portion of QW-463.1(f).

### QW-172 Notch-Toughness Tests — Drop Weight

**QW-172.1 General.** Drop weight tests shall be made when required by other Sections.

Test procedures and apparatus shall conform to the requirements of ASTM Specification E 208.

**QW-172.2 Acceptance.** The acceptance criteria shall be in accordance with that Section requiring drop weight tests.

**QW-172.3 Location and Orientation of Test Specimen.** The drop weight test specimen, the crack starter location, and the orientation shall be as given in the Section requiring such tests.

When qualifying pipe in the 5G or 6G position, the notch-toughness specimens shall be removed from the shaded portion of QW-463.1(f).

## QW-180 FILLET-WELD TESTS

### QW-181 Procedure and Performance Qualification Specimens

**QW-181.1 Procedure.** The dimensions and preparation of the fillet-weld test coupon for procedure qualification as required in QW-202 shall conform to the requirements in QW-462.4(a) or QW-462.4(d). The test coupon for plate-to-plate shall be cut transversely to provide five test specimen sections, each approximately 2 in. long. For pipe-to-plate or pipe-to-pipe, the test coupon shall be cut transversely to provide four approximately equal test specimen sections. The test specimens shall be macro examined to the requirements of QW-183.

**QW-181.2 Performance.** The dimensions and the preparation of the fillet-weld test coupon for performance qualification shall conform to the requirements in QW-462.4(b) or QW-462.4(c). The test coupon for plate-to-plate shall be cut transversely to provide a center section approximately 4 in. long and two end sections, each approximately 1 in. long. For pipe-to-plate or pipe-to-pipe, the test coupon shall be cut to provide two quarter sections test specimens opposite to each other. One of the test specimens shall be fracture tested in accordance with QW-182 and the other macro examined to the requirements of QW-184. When qualifying pipe-to-plate or pipe-to-pipe in the 5F position, the test specimens shall be removed as indicated in QW-463.2(h).

### QW-182 Fracture Tests

The stem of the 4 in. performance specimen center section in QW-462.4(b) or the stem of the quarter section in QW-462.4(c), as applicable, shall be loaded laterally in such a way that the root of the weld is in tension. The load shall be steadily increased until the specimen fractures or bends flat upon itself.

If the specimen fractures, the fractured surface shall show no evidence of cracks or incomplete root fusion, and the sum of the lengths of inclusions and porosity visible on the fractured surface shall not exceed $^3/_8$ in. in QW-462.4(b) or 10% of the quarter section in QW-462.4(c).

### QW-183 Macro-Examination — Procedure Specimens

One face of each cross section of the five test specimens in QW-462.4(a) or four test specimens in QW-462.4(d), as applicable shall be smoothed and etched with a suitable etchant (see QW-470) to give a clear definition to the weld metal and heat affected zone. The examination of the cross sections shall include only one side of the test specimen at the area where the plate or pipe is divided into sections i.e., adjacent faces at the cut shall not be used. In order to pass the test:

Visual examination of the cross sections of the weld metal and heat affected zone shall show complete fusion and freedom from cracks; and

There shall not be more than $^1/_8$ in. difference in the length of the legs of the fillet.

### QW-184 Macro-Examination — Performance Specimens

The cut end of one of the end plate sections, approximately 1 in. long, in QW-462.4(b) or the cut end of one of the pipe quarter sections in QW-462.4(c), as applicable, shall be smoothed and etched with a suitable etchant (see QW-470) to give a clear definition of the weld metal and heat affected zone. In order to pass the test:

Visual examination of the cross section of the weld metal and heat affected zone shall show complete fusion and freedom from cracks, except that linear indications at the root not exceeding $^1/_{32}$ in. shall be acceptable; and

The weld shall not have a concavity or convexity greater than $^1/_{16}$ in.; and

There shall be not more than $^1/_8$ in. difference in the lengths of the legs of the fillet.

## QW-190 OTHER TESTS AND EXAMINATIONS

### QW-191 Radiographic Examination

**QW-191.1** The radiographic examination in QW-142 for welders and in QW-143 for welding operators shall meet the requirements of Article 2, Section V. The acceptance standards of QW-191.2 shall be met.

**QW-191.2 Radiographic Acceptance Criteria**

**QW-191.2.1 Terminology**

*Linear Indications.* Cracks, incomplete fusion, inadequate penetration, and slag are represented on the radiograph as linear indications in which the length is more than three times the width.

*Rounded Indications.* Porosity and inclusions such as slag or tungsten are represented on the radiograph as rounded indications with a length three times the width or less. These indications may be circular, elliptical, or irregular in shape; may have tails; and may vary in density.

**QW-191.2.2 Acceptance Standards.** Welder and welding operator performance tests by radiography of welds in test assemblies shall be judged unacceptable when the radiograph exhibits any imperfections in excess of the limits specified below.

*(a) Linear Indications*

*(1)* any type of crack or zone of incomplete fusion or penetration;

*(2)* any elongated slag inclusion which has a length greater than:

*(a)* $^1/_8$ in. for $t$ up to $^3/_8$ in., inclusive

*(b)* $^1/_3t$ for $t$ over $^3/_8$ to $2^1/_4$ in., inclusive

*(c)* $^3/_4$ in. for $t$ over $2^1/_4$ in.

*(3)* any group of slag inclusions in line that have an aggregate length greater than $t$ in a length of $12t$, except when the distance between the successive imperfections exceeds $6L$ where $L$ is the length of the longest imperfection in the group.

*(b) Rounded Indications*

*(1)* The maximum permissible dimension for rounded indications shall be 20% of $t$ or $^1/_8$ in., whichever is smaller.

*(2)* For welds in material less than $^1/_8$ in. in thickness, the maximum number of acceptable rounded indications shall not exceed 12 in a 6 in. length of weld. A proportionately fewer number of rounded indications shall be permitted in welds less than 6 in. in length.

*(3)* For welds in material $^1/_8$ in. or greater in thickness, the charts in Appendix I represent the maximum acceptable types of rounded indications illustrated in typically clustered, assorted, and randomly dispersed configurations. Rounded indications less than $^1/_{32}$ in. in maximum diameter shall not be considered in the radiographic acceptance tests of welders and welding operators in these ranges of material thicknesses.

**QW-191.2.3 Production Welds.** The acceptance standard for welding operators who qualify on production welds shall be that specified in the referencing Code Section. The acceptance standard for welders who qualify on production welds as permitted by QW-304.1 shall be per QW-191.2.2.

**QW-191.3 Record of Tests.** The results of welder and welding operator performance tests by radiography shall be recorded in accordance with QW-301.4.

### QW-192 Stud-Weld Tests — Procedure Qualification Specimens

**QW-192.1 Required Tests.** Ten stud-weld tests are required to qualify each procedure. The equipment used for stud welding shall be completely automatic except for manual starting.

Every other welding stud (five joints) shall be tested either by hammering over until one-fourth of its length is flat on the test piece, or by bending the stud to an angle of at least 15 deg. and returning it to its original position using a test jig and an adapter location dimension that are in accordance with QW-466.4.

The remaining five welded stud joints shall be tested in torque using a torque testing arrangement that is substantially in accordance with QW-466.5. Alternatively, where torquing is not feasible, tensile testing may be used, and the fixture for tensile testing shall be similar to that shown in QW-466.6 except that studs without heads may be gripped on the unwelded end in the jaws of the tensile testing machine.

**QW-192.2 Acceptance Criteria — Bend and Hammer Tests.** In order to pass the test(s), each of the five stud welds and heat affected zones shall be free of visible separation or fracture after bending and return bending or after hammering.

**QW-192.3 Acceptance Criteria — Torque Tests.** In order to pass the test(s), each of the five stud welds shall be subjected to the required torque shown in the following table before failure occurs.

| | Required Torque for Testing Threaded Carbon Steel Studs | |
|---|---|---|
| Nominal Diameter of Studs, in. | Threads/in. and Series Designated | Testing Torque, ft-lb |
| 1/4 | 28 UNF | 5.0 |
| 1/4 | 20 UNC | 4.2 |
| 5/16 | 24 UNF | 9.5 |
| 5/16 | 18 UNC | 8.6 |
| 3/8 | 24 UNF | 17 |
| 3/8 | 16 UNC | 15 |
| 7/16 | 20 UNF | 27 |
| 7/16 | 14 UNC | 24 |
| 1/2 | 20 UNF | 42 |
| 1/2 | 13 UNC | 37 |
| 9/16 | 18 UNF | 60 |
| 9/16 | 12 UNC | 54 |
| 5/8 | 18 UNF | 84 |
| 5/8 | 11 UNC | 74 |
| 3/4 | 16 UNF | 147 |
| 3/4 | 10 UNC | 132 |
| 7/8 | 14 UNF | 234 |
| 7/8 | 9 UNC | 212 |
| 1 | 12 UNF | 348 |
| 1 | 8 UNC | 318 |

Alternatively, where torquing to destruction is not feasible tensile testing may be used, in which case failure strength in pounds per square inch shall not be less than 35,000. The failure strength shall be based on the minor diameter of the threaded section of externally threaded studs except where the shank diameter is less than the minor diameter, or on the original cross-sectional area where failure occurs in a nonthreaded, internally threaded, or reduced-diameter stud.

**QW-192.4 Acceptance Criteria — Macro-Examination.** In order to pass the macro-examination, each of five sectioned stud welds and the heat affected zone shall be free of cracks when examined at a magnification of ×10, which is required by QW-202.5 when studs are welded to metals other than P-No. 1.

## QW-193 Stud-Weld Tests — Performance Qualification Specimens

**QW-193.1 Required Tests.** Five stud-weld tests are required to qualify each stud-welding operator. The equipment used for stud welding shall be completely automatic except for manual starting. The performance test shall be welded in accordance with a qualified WPS per QW-301.2.

Each stud (five joints) shall be tested either by hammering over until one-fourth of its length is flat on the test piece or by bending the stud to an angle of at least 15 deg. and returning it to its original position using a test jig and an adapter location dimension that are in accordance with QW-466.4.

**QW-193.2 Acceptance Criteria — Bend and Hammer Tests.** In order to pass the test(s), each of the five stud welds and heat affected zones shall be free of visible separation or fracture after bending and return bending or after hammering.

## QW-195 Liquid Penetrant Examination

**QW-195.1** The liquid penetrant examination in QW-214 for corrosion-resistant weld metal overlay shall meet the requirements of Article 6, Section V. The acceptance standards of QW-195.2 shall be met.

**QW-195.2 Liquid Penetrant Acceptance Criteria**

**QW-195.2.1 Terminology**

*(a) relevant indications* — indications with major dimensions greater than $^1/_{16}$ in.

*(b) linear indications* — an indication having a length greater than three times the width

*(c) rounded indications* — an indication of circular or elliptical shape with the length equal to or less than three times the width

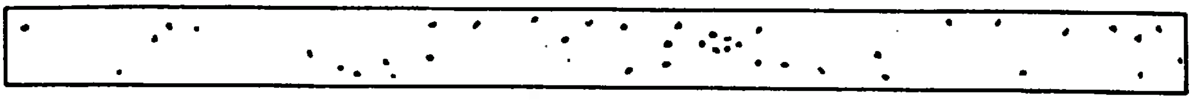
**QW-195.2.2 Acceptance Standards.** Procedure and performance tests examined by liquid penetrant techniques shall be judged unacceptable when the examination exhibits any indication in excess of the limits specified below:

*(a)* relevant linear indications;

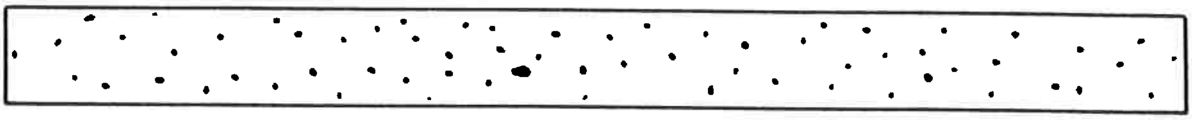
*(b)* relevant rounded indications greater than $^3/_{16}$ in.;

*(c)* four or more relevant rounded indications in a line separated by $^1/_{16}$ in. or less (edge-to-edge).

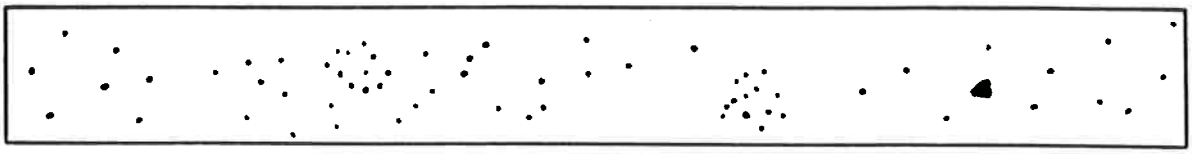
# APPENDIX I
## ROUNDED INDICATION CHARTS
(See QW-191.2)



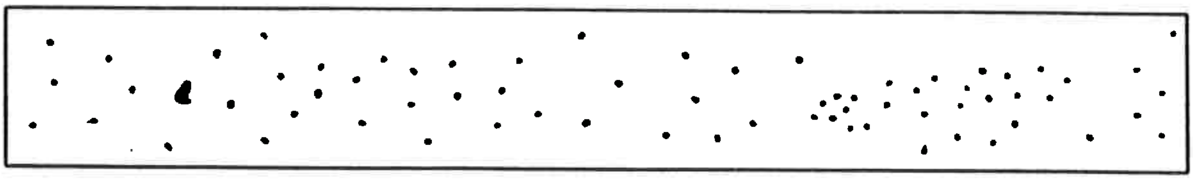
TYPICAL QUANTITY AND SIZE PERMITTED
IN 6 IN. LENGTH OF WELD
1/8 IN. TO 1/4 IN. THICKNESS



TYPICAL QUANTITY AND SIZE PERMITTED
IN 6 IN. LENGTH OF WELD
OVER 1/4 IN. TO 1/2 IN. THICKNESS



TYPICAL QUANTITY AND SIZE PERMITTED
IN 6 IN. LENGTH OF WELD
OVER 1/2 IN. TO 1 IN. THICKNESS



TYPICAL QUANTITY AND SIZE PERMITTED
IN 6 IN. LENGTH OF WELD
OVER 1 IN. THICKNESS

## QW-196 Resistance Weld Testing

### QW-196.1 Metallographic Examination

**QW-196.1.1** Welds shall be cross-sectioned, polished, and etched to reveal the weld metal. The section shall be examined at a magnification of 10 times.

**QW-196.1.2** The weld nugget shall be sound for 1.25 times the thickness of the thinner member.

**QW-196.1.3** For spot welds, the nugget size shall be measured at the interface between the sheets being joined, and it shall equal or exceed $0.9\sqrt{t}$, where $t$ is the thickness of the thinner sheet. For projection welds, the nugget size shall not be less than the initial size of the projection. For seam welds, the width of the fused weld cut transverse to the seam shall be not less than $0.9\sqrt{t}$, where $t$ is the thickness of the thinnest sheet.

### QW-196.2 Mechanical Testing

**QW-196.2.1** Shear test specimens shall be prepared as shown on QW-462.9. For spot and projection welds, each test specimen shall equal or exceed the minimum strength, and the average strength specified in QW-462.10 and QW-462.11 for the appropriate material. Further, for each set, 90% shall have shear strength values between 0.9 and 1.1 times the set average value. The remaining 10% shall lie between 0.8 and 1.2 times the set average value.

**QW-196.2.2** Peel test specimens shall be prepared as shown in Fig. QW-462.8. The specimens shall be peeled or separated mechanically, and fracture shall occur in the base metal by tearing out of the weld in order for the specimen to be acceptable.

# ARTICLE II
# WELDING PROCEDURE QUALIFICATIONS

## QW-200 GENERAL

**QW-200.1** Each manufacturer and contractor shall prepare written Welding Procedure Specifications which are defined as follows.

*(a) Welding Procedure Specification (WPS).* A WPS is a written qualified welding procedure prepared to provide direction for making production welds to Code requirements. The WPS or other documents [see (e) below] may be used to provide direction to the welder or welding operator to assure compliance with the Code requirements.

*(b) Contents of the WPS.* The completed WPS shall describe all of the essential, nonessential, and, when required, supplementary essential variables for each welding process used in the WPS. These variables are listed in QW-250 through QW-280 and are defined in Article IV, Welding Data.

The WPS shall reference the supporting Procedure Qualification Record(s) (PQR) described in QW-200.2. The manufacturer or contractor may include any other information in the WPS that may be helpful in making a Code weldment.

*(c) Changes to the WPS.* Changes may be made in the nonessential variables of a WPS to suit production requirements without requalification provided such changes are documented with respect to the essential, nonessential, and, when required, supplementary essential variables for each process. This may be by amendment to the WPS or by use of a new WPS.

Changes in essential or supplementary essential (when required) variables require requalification of the WPS (new or additional PQRs to support the change in essential or supplementary essential variables).

*(d) Format of the WPS.* The information required to be in the WPS may be in any format, written or tabular, to fit the needs of each manufacturer or contractor, as long as every essential, nonessential, and, when required, supplementary essential variables outlined in QW-250 through QW-280 is included or referenced.

Form QW-482 (see Nonmandatory Appendix A) has been provided as a guide for the WPS. This Form includes the required data for the SMAW, SAW, GMAW, and GTAW processes. It is only a guide and does not list all required data for other processes. It also lists some variables that do not apply to all processes (e.g., listing shielding gas which is not required for SAW). The guide does not easily lend itself to multiple process procedure specification (e.g., GTAW root with SMAW fill).

*(e) Availability of the WPS.* A WPS used for Code production welding shall be available for reference and review by the Authorized Inspector (AI) at the fabrication site.

**QW-200.2** Each manufacturer or contractor shall be required to prepare a procedure qualification record which is defined as follows.

*(a) Procedure Qualification Record (PQR).* A PQR is a record of the welding data used to weld a test coupon. The PQR is a record of variables recorded during the welding of the test coupons. It also contains the test results of the tested specimens. Recorded variables normally fall within a small range of the actual variables that will be used in production welding.

*(b) Contents of the PQR.* The completed PQR shall document all essential and, when required, supplementary essential variables of QW-250 through QW-280 for each welding process used during the welding of the test coupon. Nonessential or other variables used during the welding of the test coupon may be recorded at the manufacturer's or contractor's option. All variables, if recorded, shall be the actual variables (including ranges) used during the welding of the test coupon. If variables are not monitored during welding, they shall not be recorded. It is not intended that the full range or the extreme of a given range of variables to be used in production be used during qualification unless required due to a specific essential or, when required, supplementary essential variable.

The PQR shall be certified accurate by the manufacturer or contractor. The manufacturer or contractor may not subcontract the certification function. This certification is intended to be the manufacturer's or contractor's verification that the information in the PQR is a true record of the variables that were used during the welding of the test coupon and that the resulting tensile, bend, or macro (as required) test results are in compliance with Section IX.

When more than one welding process or filler metal is used to weld a test coupon, the approximate deposit weld metal thickness of each welding process and filler metal shall be recorded.

*(c) Changes to the PQR.* Changes to the PQR are not permitted except as described below. It is a record of what happened during a particular welding test. Editorial corrections or addenda to the PQR are permitted. An example of an editorial correction is an incorrect P-Number, F-Number, or A-Number that was assigned to a particular base metal or filler metal. An example of an addendum would be a change resulting from a Code change. For example, Section IX may assign a new F-Number to a filler metal or adopt a new filler metal under an established F-Number. This may permit, depending on the particular construction Code requirements, a manufacturer or contractor to use other filler metals that fall within that particular F-Number where, prior to the Code revision, the manufacturer or contractor was limited to the particular electrode classification that was used during qualification. Additional information can be incorporated into a PQR at a later date provided the information is substantiated as having been part of the original qualification condition by lab record or similar data.

All changes to a PQR require recertification (including date) by the manufacturer or contractor.

*(d) Format of the PQR.* Form QW-483 (see Nonmandatory Appendix A) has been provided as a guide for the PQR. The information required to be in the PQR may be in any format to fit the needs of each manufacturer or contractor, as long as every essential and, when required, supplementary essential variable, required by QW-250 through QW-280, is included. Also the type of tests, number of tests, and test results shall be listed in the PQR.

The QW-483 guide does not easily lend itself to cover combinations of welding processes or more than one F-Number filler metal in one test coupon. Additional sketches or information may be attached or referenced to record the required variables.

*(e) Availability of the PQR.* PQRs used to support WPSs shall be available, upon request, for review by the Authorized Inspector (AI). The PQR need not be available to the welder or welding operator.

*(f) Multiple WPSs With One PQR/Multiple PQRs With One WPS.* Several WPSs may be prepared from the data on a single PQR (e.g., a 1G plate PQR may support WPSs for the F, V, H, and O positions on plate or pipe within all other essential variables). A single WPS may cover several essential variable changes as long as a supporting PQR exists for each essential and, when required, supplementary essential variable (e.g., a single WPS may cover a thickness range from $^1/_{16}$ in. through $1^1/_4$ in. if PQRs exist for both the $^1/_{16}$ in. through and $^3/_{16}$ in. through $1^1/_4$ in. thickness ranges).

**QW-200.3** To reduce the number of welding procedure qualifications required, P-Numbers are assigned to base metals dependent on characteristics such as composition, weldability, and mechanical properties, where this can logically be done; and for steel and steel alloys (QW-422.1 through QW-422.11) Group Numbers are assigned additionally to P-Numbers. These Group Numbers classify the metals within P-Numbers for the purpose of procedure qualification where notch-toughness requirements are specified. The assignments do not imply that base metals may be indiscriminately substituted for a base metal which was used in the qualification test without consideration of the compatibility from the standpoint of metallurgical properties, postweld heat treatment, design, mechanical properties, and service requirements. Where notch toughness is a consideration, it is presupposed that the base metals meet the specific requirements.

In general, notch-toughness requirements are mandatory for all P-No. 11 quenched and tempered metals, for low temperature applications of other metals as applied to Section VIII, and for various classes of construction required by Section III. Acceptance criteria for the notch-toughness tests are as established in the other Sections of the Code.

For certain materials permitted by the ASME/ANSI B31 Code for Pressure Piping or by selected Code Cases of the ASME Boiler and Pressure Vessel Code but which are not listed in QW-422, S-Number groupings are assigned in Appendix C. These groupings are similar to the P-Number groupings of QW-422. Qualification limits are given in Appendix C.

**QW-200.4 Combination of Welding Procedures**

*(a)* More than one procedure having different essential or nonessential variables may be used in a single production joint. Each procedure may include one or a combination of processes, filler metals, or other variables.

Where two or more procedures involving different processes or other essential variables are used in one joint, QW-451 shall be used to determine the range of base metal thickness qualified and the range of thickness of deposited weld metal qualified for each process or procedure, except for root deposit qualification made in accordance with QW-200.4(b). The deposited weld metal of each process or procedure shall be included in the tension and bend specimens, and in the notch-toughness specimen (when required). One or more processes or procedures may be deleted from a qualified combination procedure. Each such process or procedure may be used separately provided:

*(1)* the remaining essential, nonessential, and supplementary essential variables are applied;

*(2)* the base metal and deposited weld metal thickness limits of QW-451 are applied.

*(b)* When qualifying a separate process or procedure for the root deposit only, the coupon shall be $^1/_2$ in. minimum thickness. The root deposit process shall qualify for $2t$ (for short-circuiting type of GMAW, see QW-404.32) of the qualification deposited weld metal thickness on any maximum thickness of base metal qualified by the other PQRs used to support the WPS, except as otherwise required by Note (1) of QW-451.1 and QW-451.2.

## QW-201 Manufacturer's or Contractor's Responsibility

Each manufacturer or contractor shall list the parameters applicable to welding that he performs in construction of weldments built in accordance with this Code. These parameters shall be listed in a document known as a Welding Procedure Specification (WPS).

Each manufacturer or contractor shall qualify the WPS by the welding of test coupons and the testing of specimens (as required in this Code), and the recording of the welding data and test results in a document known as a Procedure Qualification Record (PQR). The welders or welding operators used to produce weldments to be tested for qualification of procedures shall be under the full supervision and control of the manufacturer or contractor during the production of these test weldments. It is not permissible for the manufacturer or contractor to have the welding of the test weldments performed by another organization. It is permissible, however, to subcontract any or all of the work of preparation of test metal for welding and subsequent work on preparation of test specimens from the completed weldment, performance of nondestructive examination, and mechanical tests, provided the manufacturer or contractor accepts the responsibility for any such work.

The Code recognizes a manufacturer or contractor as the organization which has responsible operational control of the production of the weldments to be made in accordance with this Code. If in an organization effective operational control of welding procedure qualification for two or more companies of different names exists, the companies involved shall describe in their Quality Control system/Quality Assurance Program, the operational control of procedure qualifications. In this case separate welding procedure qualifications are not required, provided all other requirements of Section IX are met.

A WPS may require the support of more than one PQR, while alternatively, one PQR may support a number of WPSs.

The manufacturer or contractor shall certify that he has qualified each Welding Procedure Specification, performed the procedure qualification test, and documented it with the necessary Procedure Qualification Record (PQR).

## QW-202 Type of Tests Required

**QW-202.1 Mechanical Tests.** The type and number of test specimens which shall be tested to qualify a groove weld procedure are given in QW-451, and shall be removed in a manner similar to that shown in QW-463. If any test specimen required by QW-451 fails to meet the applicable acceptance criteria, the test coupon shall be considered as failed, and a new test coupon shall be welded. Where qualification is for fillet welds only, the requirements are given in QW-202.2(c) and (d); and where qualification is for stud welds only, the requirements are given in QW-202.5.

**QW-202.2 Groove and Fillet Welds**

*(a) Qualification for Groove Full Penetration Welds.* Groove-weld test coupons shall qualify the thickness ranges of both base metal and deposited weld metal to be used in production. Limits of qualification shall be in accordance with QW-451. WPS qualification for groove welds shall be made on groove welds using tension and guided-bend specimens. Notch-toughness tests shall be made when required by other Section(s) of the Code. The WPS shall be qualified for use with groove welds within the range of essential variables listed.

*(b) Qualification for Partial Penetration Groove Welds.* Partial penetration groove welds shall be qualified in accordance with the requirements of QW-451 for both base metal and deposited weld metal thickness. Alternatively, partial penetration groove welds qualified using $1^1/_2$ in. thick or thicker base metal qualify the weld metal deposit in accordance with QW-451, with no upper limit on the base metal thickness.

*(c) Qualification for Fillet Welds (Except for P-No. 11 Metals Excluding P-No. 11A Group Nos. 1 and 2).* WPS qualification for fillet welds may be made on groove-weld test coupons using test specimens specified in (a) or (b) above. Fillet-weld procedures so qualified may be used for welding all thicknesses of base metal for all sizes of fillet welds, and all diameters of pipe or tube in accordance with QW-451.4. Nonpressure-retaining fillet welds, as defined in other Sections of the Code, may as an alternate be qualified with fillet welds only. Tests shall be made in accordance with QW-180. Limits of qualification shall be in accordance with QW-451.3.

*(d) Qualification for Fillet Welds in P-No. 11 Metals (Excluding P-No. 11A Group Nos. 1 and 2).* WPS qualification for all fillet welds (including nonpressure-retaining) shall be made on:

*(1)* groove-weld tests in accordance with (a) or (b) above; and

*(2)* fillet-weld tests in accordance with QW-180.

**QW-202.3 Weld Repair and Buildup.** WPS qualified on groove welds shall be applicable for weld repairs to groove and fillet welds and for weld buildup under the following provisions.

*(a)* There is no limitation on the thickness of base metal or deposited weld metal for fillet welds.

*(b)* For other than fillet welds, the upper limit for base metal and deposited weld metal for each welding process shall be in accordance with QW-451, except qualification on $1^1/_2$ in. thick base metal will permit welding on unlimited base metal thickness.

**QW-202.4 Dissimilar Base Metal Thicknesses.** WPS qualified on groove welds shall be applicable for production welds between dissimilar base metal thicknesses provided:

*(a)* the thickness of the thinner member shall be within the range permitted by QW-451;

*(b)* the thickness of the thicker member shall be as follows.

*(1)* For P-No. 8, P-No. 41, P-No. 42, P-No. 43, P-No. 44, P-No. 45, P-No. 46, P-No. 51, P-No. 52, P-No. 61, and P-No. 62 metal in which notch toughness is not a requirement, there shall be no limitation on the maximum thickness of the thicker production member in joints of similar P-Number materials provided qualification was made on base metal having a thickness of $^1/_4$ in. or greater.

*(2)* For all other metal, the thickness of the thicker member shall be within the range permitted by QW-451, except there need be no limitation on the maximum thickness of the thicker production member provided qualification was made on base metal having a thickness of $1^1/_2$ in. or more.

More than one PQR may be required to qualify for some dissimilar thickness combinations.

**QW-202.5 Stud Welding.** Procedure qualification tests for stud welds shall be made in accordance with QW-192. The procedure qualification tests shall qualify the welding procedures for use within the range of the essential variables of QW-261. For studs welded to other than P-No. 1 metals, five additional welds shall be made and subjected to a macro-test, except that this is not required for studs used for extended heating surfaces.

### QW-203 Limits of Qualified Positions for Procedures

Unless specifically required otherwise by the welding variables (QW-250), a qualification in any position qualifies the procedure for all positions. The welding process must be compatible; and the welding rods, electrodes, and filler metals such as defined in the specifications of Section II, Part C must be suitable for their use in specific positions. A welder or welding operator making and passing the WPS qualification test is thereby qualified for the position tested. See QW-301.2.

## QW-210 PREPARATION OF TEST COUPON

### QW-211 Base Metal and Filler Metal

The base metals and filler metals shall be one or more of those listed in the WPS. The dimensions of the test assembly shall be sufficient to provide the required test specimens.

The base metals may consist of either plate, pipe, or other product forms. Qualification in plate also qualifies for pipe welding and vice versa.

### QW-212 Type and Dimensions of Groove Welds

The test coupon shall be welded using a type of welding groove proposed in the WPS for use in construction. Except as otherwise provided in QW-250, the type and dimensions of the welding groove are not essential variables.

### QW-213 P-No. 11 Base Metals

For vessels or parts of vessels constructed with P-No. 11 base metals, weld grooves for thickness less than $^5/_8$ in. shall be prepared by thermal processes, when such processes are to be employed during fabrication. This groove preparation shall also include back gouging, back grooving, or removal of unsound weld metal by thermal processes, when these processes are to be employed during fabrication.

### QW-214 Corrosion-Resistant Weld Metal Overlay

**QW-214.1** The size of test coupons, limits of qualification, required examinations and tests, and test specimens shall be as specified in QW-453.

**QW-214.2** Essential variables shall be as specified in QW-250 for the applicable welding process.

### QW-215 Electron Beam Welding and Laser Beam Welding

The WPS qualification test coupon shall be prepared with the joint geometry duplicating that to be used in production. If the production weld is to include a lapover (completing the weld by rewelding over the starting area of the weld, as for a girth weld), such lapover shall be included in the WPS qualification test coupon.

### QW-216 Hard-Facing Overlay (Wear Resistant)

**QW-216.1** The size of test coupons, limits of qualification, required examinations and tests, and test specimens shall be as specified in QW-453.

**QW-216.2** Essential variables shall be as specified in QW-250 for the applicable welding process.

### QW-217 Joining of Composite (Clad Metals)

The WPS for groove welds in clad metal shall be qualified as provided in (a) below when any part of the cladding thickness, as permitted by the referencing Code Section, is included in the design calculations, and as provided in either (a) or (b) below when the cladding thickness is not included in the design calculations.

*(a)* The essential and nonessential variables of QW-250 shall apply for each welding process used in production. The procedure qualification test coupon shall be made using the same P-Number base metal, cladding, and welding process, and filler metal combination to be used in production welding. For metal not included in QW-422, the metal used in the composite test plate shall be within the range of chemical composition of that to be used in production. The qualified thickness range for the base metal and filler metal(s) shall be based on the actual test coupon thickness for each as applied to QW-451, except that the minimum thickness of filler metal joining the cladding portion of the weldment shall be based on a chemical analysis performed in accordance with QW-453. Tensile and bend tests required in QW-451 for groove welds shall be made, and they shall contain the full thickness of cladding through the reduced section of the specimen. The bond line between the original cladding and the base metal may be disregarded when evaluating side-bend tests if the cladding was applied by a process other than fusion welding.

*(b)* The essential and nonessential variables of QW-250 shall apply for each welding process used in production for joining the base metal portion of the weldment. The PQRs that support this portion of the WPS need not be based on test coupons made with clad metal. The essential and nonessential variables of QW-250 shall apply for the corrosion-resistant overlay portion of the weld, and the test coupon and testing shall be in accordance with QW-453. The WPS shall limit the depth of the groove, which will receive the corrosion-resistant overlay in order to ensure development of the full strength of the underlying weld in the base metal.

### QW-218 Applied Linings

Each welding process to be used in attaching applied linings to base metal shall be qualified on a lining-attachment weld made in the form and arrangement used in the construction, and with materials that are within the range of chemical composition of the metal to be used for the base plate, the linings, and the weld metal. The other welding variables of QW-250 shall also apply. In addition, a qualification test shall be performed for each position that will be used in production. One specimen from each position to be qualified shall be sectioned, polished, and etched to show clearly the demarcation between the fusion zone and the base metal. To be acceptable, the specimen shall show complete fusion in the fusion zone and complete freedom from cracks in the fusion and heat affected zones under visual examination without magnification.

## QW-250 WELDING VARIABLES

### QW-251 General

**QW-251.1 Types of Variables for Welding Procedure Specifications (WPS).** These variables (listed for each welding process in QW-252 through QW-282) are subdivided into essential variables, supplementary essential variables, and nonessential variables (QW-401).

**QW-251.2 Essential Variables.** Essential variables are those in which a change, as described in the specific variables, is considered to affect the mechanical properties of the weldment, and shall require requalification of the WPS.

Supplementary essential variables are required for metals for which other Sections specify notch-toughness tests.

**QW-251.3 Nonessential Variables.** Nonessential variables are those in which a change, as described in the specific variables, may be made in the WPS without requalification.

**QW-251.4 Special Processes**

*(a)* The essential variables for corrosion-resistant and hard-surfacing weld metal overlays are as indicated in the following tables for the specified process. (Exclusive of the variables for groove welding.) A change in the corrosion-resistant or hard-surfacing welding process shall require requalification.

*(b)* WPS qualified for corrosion-resistant and hard-surfacing overlay welding, in accordance with other Sections when such qualification rules were included in those Sections, may be used with the same provisions as provided in QW-100.3.

## QW-252
## WELDING VARIABLES PROCEDURE SPECIFICATIONS (WPS)
### Oxyfuel Gas Welding (OFW)

| Paragraph | | Brief of Variables | Essential | Supplementary Essential | Nonessential | Special Process Essential Variables: Hardfacing Overlay (QW-216) | | Special Process Essential Variables: Corrosion-Resistant Overlay (QW-214) | |
|---|---|---|---|---|---|---|---|---|---|
| QW-402 Joints | .1 | $\phi$ Groove design | | | X | .16 | < finished $t$ | | |
| | .2 | ± Backing | | | X | | | | |
| | .3 | $\phi$ Backing comp. | | | X | | | | |
| | .10 | $\phi$ Root spacing | | | X | | | | |
| QW-403 Base Metals | .1 | $\phi$ P-Number | X | | | .20 | $\phi$ P-Number | | |
| | .2 | Max. $T$ qualified | X | | | | | | |
| | .13 | $\phi$ P-No. 9/10 | X | | | | | | |
| QW-404 Filler Metals | .3 | $\phi$ Size | | | X | .37 | $\phi$ A-Number | | |
| | .4 | $\phi$ F-Number | X | | | | | | |
| | .5 | $\phi$ A-Number | X | | | | | | |
| | .12 | $\phi$ AWS class. | X | | | | | | |
| QW-405 Positions | .1 | + Position | | | X | .4 | + Position | | |
| QW-406 Preheat | .1 | Decrease > 100°F | | | X | .4 | < 100° Preheat > Interpass | | |
| QW-407 PWHT | .1 | $\phi$ PWHT | X | | | .5 | $\phi$ PWHT | | |
| QW-408 Gas | .7 | $\phi$ Type fuel gas | X | | | .7 | $\phi$ Type of fuel gas | | |
| | | | | | | .14 | $\phi$ Fuel gas pressure range | | |
| QW-410 Technique | .1 | $\phi$ String/weave | | | X | .38 | $\phi$ Multi- to single-layer | | |
| | .2 | $\phi$ Flame characteristics | | | X | .39 | $\phi$ Torch type, tip size | | |
| | .4 | $\phi$ ⇄ Technique | | | X | | | | |
| | .5 | $\phi$ Method cleaning | | | X | | | | |
| | .26 | ± Peening | | | X | | | | |

Legend:
+ Addition
− Deletion
> Increase/greater than
< Decrease/less than
↑ Uphill
↓ Downhill
← Forehand
→ Backhand
$\phi$ Change

## QW-253
## WELDING VARIABLES PROCEDURE SPECIFICATIONS (WPS)
### Shielded Metal-Arc (SMAW)

| Paragraph | | Brief of Variables | Essential | Supplementary Essential | Nonessential | Special Process Essential Variables: Hardfacing Overlay (QW-216) | | Special Process Essential Variables: Corrosion-Resistant Overlay (QW-214) | |
|---|---|---|---|---|---|---|---|---|---|
| QW-402 Joints | .1 | $\phi$ Groove design | | | X | .16 | < finished $t$ | .16 | < finished $t$ |
| | .4 | − Backing | | | X | | | | |
| | .10 | $\phi$ Root Spacing | | | X | | | | |
| | .11 | ± Retainers | | | X | | | | |
| QW-403 Base Metals | .5 | $\phi$ Group Number | | X | | .20 | $\phi$ P-Number | .20 | $\phi$ P-Number |
| | .6 | $T$ Limits impact | | X | | | | | |
| | .7 | $T/t$ Limits > 8 in. | X | | | | | | |
| | .8 | $\phi$ $T$ Qualified | X | | | | | | |
| | .9 | $t$ Pass > 1/2 in. | X | | | | | | |
| | .11 | $\phi$ P-No. qualified | X | | | | | | |
| | .13 | $\phi$ P-No. 9/10 | X | | | | | | |
| QW-404 Filler Metals | .4 | $\phi$ F-Number | X | | | .12 | $\phi$ AWS class. | .5 | $\phi$ A-Number |
| | .5 | $\phi$ A-Number | X | | | .38 | $\phi$ Dia. (1st layer) | .38 | $\phi$ Dia. (1st layer) |
| | .6 | $\phi$ Diameter | | | X | | | | |
| | .7 | $\phi$ Diam. > 1/4 in. | | X | | | | | |
| | .12 | $\phi$ AWS class. | | X | | | | | |
| | .30 | $\phi$ $t$ | X | | | | | | |
| | .33 | $\phi$ AWS class. | | | X | | | | |
| QW-405 Positions | .1 | + Position | | | X | .4 | + Position | .4 | + Position |
| | .2 | $\phi$ Position | | X | | | | | |
| | .3 | $\phi$ ↑↓ Vertical welding | | | X | | | | |
| QW-406 Preheat | .1 | Decrease > 100°F | X | | | .4 | Dec. > 100°F preheat > Interpass | .4 | Dec. > 100°F preheat > Interpass |
| | .2 | $\phi$ Preheat maint. | | | X | | | | |
| | .3 | Increase > 100°F (IP) | | X | | | | | |
| QW-407 PWHT | .1 | $\phi$ PWHT | X | | | .1 | $\phi$ PWHT | .1 | $\phi$ PWHT |
| | .2 | $\phi$ PWHT (T & T range) | | X | | | | | |
| | .4 | $T$ Limits | X | | | | | | |
| QW-409 Electrical Characteristics | .1 | $\phi$ I or > heat input | | X | | .4 | $\phi$ Current or polarity | .4 | $\phi$ Current or polarity |
| | .8 | $\phi$ Type I or $\phi$ I & E range | | | X | .25 | Inc. > 10% 1st layer | .25 | Inc. > 10% 1st layer |
| QW-410 Technique | .1 | $\phi$ String/weave | | | X | .38 | $\phi$ Multi- to single-layer | .38 | $\phi$ Multi- to single-layer |
| | .5 | $\phi$ Method cleaning | | | X | | | | |
| | .6 | $\phi$ Method back gouge | | | X | | | | |
| | .25 | $\phi$ Manual or automatic | | | X | | | | |
| | .26 | ± Peening | | | X | | | | |

Legend:
+ Addition
− Deletion
> Increase/greater than
< Decrease/less than
↑ Uphill
↓ Downhill
← Forehand
→ Backhand
$\phi$ Change

## QW-254
## WELDING VARIABLES PROCEDURE SPECIFICATIONS (WPS)
### Submerged-Arc Welding (SAW)

| Paragraph | | Brief of Variables | Essential | Supplementary Essential | Nonessential | Special Process Essential Variables: Hardfacing Overlay (QW-216) | | Corrosion-Resistant Overlay (QW-214) | |
|---|---|---|---|---|---|---|---|---|---|
| QW-402 Joints | .1 | φ Groove design | | | X | .16 | < finished *t* | .16 | < finished *t* |
| | .4 | − Backing | | | X | | | | |
| | .10 | φ Root spacing | | | X | | | | |
| | .11 | ± Retainers | | | X | | | | |
| QW-403 Base Metals | .5 | φ Group Number | | X | | .20 | φ P-Number | .20 | φ P-Number |
| | .6 | *T* Limits | | X | | | | | |
| | .7 | *T*/*t* Limits > 8 in. | X | | | | | | |
| | .8 | φ *T* Qualified | X | | | | | | |
| | .9 | *t* Pass > ½ in. | X | | | | | | |
| | .11 | φ P-No. qualified | X | | | | | | |
| | .13 | φ P-No. 9/10 | X | | | | | | |
| QW-404 Filler Metals | .4 | φ F-Number | X | | | .12 | φ AWS class. | .5 | φ A-Number |
| | .5 | φ A-Number | X | | | .17 | φ Nom. flux comp. | .17 | φ Nom. flux comp. |
| | .6 | φ Diameter | | | X | .24 | ± Sup. filler metal | .24 | ± Sup. filler metal |
| | .9 | φ Flux/wire class. | X | | | .25 | ± Sup. powder | | |
| | .10 | φ Alloy flux | X | | | .26 | > Sup. powder | | |
| | .24 | ± Supplemental | X | | | .27 | φ Alloy elements | | |
| | .25 | ± Sup. powder | X | | | .40 | φ >10% elec. dia. sup. filler | .40 | φ > 10% elec. dia. sup. filler |
| | .26 | > Sup. powder | X | | | | | | |
| | .27 | φ Alloy elements | X | | | | | | |
| | .29 | φ Flux designation | | | X | | | | |
| | .30 | φ *t* | X | | | | | | |
| | .33 | φ AWS class. | | | X | | | | |
| | .34 | φ Flux type | X | | | | | | |
| | .35 | φ Flux/wire class. | | X | X | | | | |
| | .36 | Recrushed slag | X | | | | | | |
| QW-405 Positions | .1 | + Position | | | X | .4 | + Position | .4 | + Position |
| QW-406 Preheat | .1 | Decrease > 100°F | X | | | .4 | Dec. > 100°F preheat > Interpass | .4 | Dec. > 100°F preheat > Interpass |
| | .2 | φ Preheat maint. | | | X | | | | |
| | .3 | Increase > 100°F (IP) | | X | | | | | |
| QW-407 PWHT | .1 | φ PWHT | X | | | .5 | φ PWHT | .5 | φ PWHT |
| | .2 | φ PWHT (T & T range) | | X | | | | | |
| | .4 | *T* Limits | X | | | | | | |
| QW-409 Electrical Characteristics | .1 | φ I or > heat input | | X | | .1 | φ I or > heat input | .1 | φ I or > heat input |
| | .8 | φ Type I or φ I & E range | | | X | .4 | φ Current or polarity | .4 | φ Current or polarity |

## QW-254 (CONT'D) WELDING VARIABLES PROCEDURE SPECIFICATIONS (WPS) Submerged-Arc Welding (SAW)

| Paragraph | | Brief of Variables | Essential | Supplementary Essential | Nonessential | Special Process Essential Variables: Hardfacing Overlay (QW-216) | | Special Process Essential Variables: Corrosion-Resistant Overlay (QW-214) | |
|---|---|---|---|---|---|---|---|---|---|
| QW-410 Technique | .1 | φ String/weave | | | X | .10 | φ No. of elec. | .10 | φ No. of elec. |
| | .5 | φ Method cleaning | | | X | .38 | φ Multi- to single-layer | .38 | φ Multi- to single-layer |
| | .6 | φ Method back gouge | | | X | | | .40 | − Sup. device |
| | .7 | φ Oscillation | | X | X | .42 | ± Oscillation | .42 | ± Oscillation |
| | .8 | φ Tube-work distance | | | X | | | | |
| | .9 | φ Multi to single pass/side | | X | X | | | | |
| | .10 | φ Single to multi electrodes | | X | X | | | | |
| | .15 | φ Electrode spacing | | | X | | | | |
| | .25 | φ Manual or automatic | | | X | | | | |
| | .26 | ± Peening | | | X | | | | |

Legend:
+ Addition
− Deletion
> Increase/greater than
< Decrease/less than
↑ Uphill
↓ Downhill
← Forehand
→ Backhand
φ Change

## QW-255
## WELDING VARIABLES PROCEDURE SPECIFICATIONS (WPS)
### Gas Metal-Arc Welding (GMAW and FCAW)

| Paragraph | | Brief of Variables | Essential | Supplementary Essential | Nonessential | Special Process Essential Variables: Hardfacing Overlay (QW-216) | | Special Process Essential Variables: Corrosion-Resistant Overlay (QW-214) | |
|---|---|---|---|---|---|---|---|---|---|
| QW-402 Joints | .1 | φ Groove design | | | X | .16 | < finished $t$ | .16 | < finished $t$ |
| | .4 | − Backing | | | X | | | | |
| | .10 | φ Root spacing | | | X | | | | |
| | .11 | ± Retainers | | | X | | | | |
| QW-403 Base Metals | .5 | φ Group Number | | X | | .20 | φ P-Number | .20 | φ P-Number |
| | .6 | $T$ Limits | | X | | | | | |
| | .7 | $T/t$ Limits > 8 in. | X | | | | | | |
| | .8 | φ $T$ Qualified | X | | | | | | |
| | .9 | $t$ Pass > ½ in. | X | | | | | | |
| | .10 | $T$ Limits (S. Cir. Arc) | X | | | | | | |
| | .11 | φ P-No. qualified | X | | | | | | |
| | .13 | φ P-No. 9/10 | X | | | | | | |
| QW-404 Filler Metals | .4 | φ F-Number | X | | | .12 | φ AWS class. | .5 | φ A-Number |
| | .5 | φ A-Number | X | | | .24 | ± Sup. filler metal | .24 | ± Sup. filler metal |
| | .6 | φ Diameter | | | X | .25 | ± Sup. powder | | |
| | .12 | φ AWS class. | | X | | .26 | > Sup. powder | | |
| | .23 | φ Solid to tubular | X | | | .27 | φ Alloy elements | | |
| | .24 | ± Supplemental | X | | | | | | |
| | .25 | ± Sup. powder | X | | | | | | |
| | .26 | > Sup. powder | X | | | | | | |
| | .27 | φ Alloy elements | X | | | | | | |
| | .30 | φ $t$ | X | | | | | | |
| | .32 | $t$ Limit (S. Cir. Arc) | X | | | | | | |
| | .33 | φ AWS class. | | | X | | | | |
| QW-405 Positions | .1 | + Position | | | X | .4 | + Position | .4 | + Position |
| | .2 | φ Position | | X | | | | | |
| | .3 | φ ↑↓ Vertical welding | | | X | | | | |
| QW-406 Preheat | .1 | Decrease > 100°F | X | | | .4 | Dec. > 100°F preheat > Interpass | .4 | Dec. > 100°F preheat > Interpass |
| | .2 | φ Preheat maint. | | | X | | | | |
| | .3 | Increase > 100°F (IP) | | X | | | | | |
| QW-407 PWHT | .1 | φ PWHT | X | | | .5 | φ PWHT | .5 | φ PWHT |
| | .2 | φ PWHT (T & T range) | | X | | | | | |
| | .4 | $T$ Limits | X | | | | | | |

## QW-255 (CONT'D)
## WELDING VARIABLES PROCEDURE SPECIFICATIONS (WPS)
### Gas Metal-Arc Welding (GMAW and FCAW)

| Paragraph | | Brief of Variables | Essential | Supplementary Essential | Nonessential | Special Process Essential Variables: Hardfacing Overlay (QW-216) | | Special Process Essential Variables: Corrosion-Resistant Overlay (QW-214) | |
|---|---|---|---|---|---|---|---|---|---|
| QW-408 Gas | .1 | ± Trail or φ comp. | | | X | .15 | φ Type or flow rate | .15 | φ Type or flow rate |
| | .2 | φ Single, mixture, or % | X | | | | | | |
| | .3 | φ Flow rate | | | X | | | | |
| | .5 | ± or φ Backing | | | X | | | | |
| | .9 | ± Backing or < flow rate or φ comp. | X | | | | | | |
| | .10 | φ Shielding or trailing | X | | | | | | |
| QW-409 Electrical Characteristics | .1 | φ I or > heat input | | X | | .1 | φ I or > heat input | .1 | φ I or > heat input |
| | .2 | φ Transfer mode | X | | | .4 | φ Current or polarity | .4 | φ Current or polarity |
| | .8 | φ Type I or φ I & E range | | | X | | | | |
| QW-410 Technique | .1 | φ String/weave | | | X | .10 | φ No. of elec. | .10 | φ No. of elec. |
| | .3 | φ Orifice, cup, or nozzle size | | | X | .38 | φ Multi- to single-layer | .38 | φ Multi- to single-layer |
| | .5 | φ Method cleaning | | | X | .42 | ± Oscillation | .42 | ± Oscillation |
| | .6 | φ Method back gouge | | | X | | | | |
| | .7 | φ Oscillation | | X | X | | | | |
| | .8 | φ Tube-work distance | | | X | | | | |
| | .9 | φ Multi to single pass/side | | X | X | | | | |
| | .10 | φ Single to multi electrodes | | X | X | | | | |
| | .15 | φ Electrode spacing | | | X | | | | |
| | .25 | φ Manual or automatic | | | X | | | | |
| | .26 | ± Peening | | | X | | | | |

Legend:
+ Addition > Increase/greater than ↑ Uphill ← Forehand φ Change
− Deletion < Decrease/less than ↓ Downhill → Backhand

QW-256
WELDING VARIABLES PROCEDURE SPECIFICATIONS (WPS)
Gas Tungsten-Arc Welding (GTAW)

| Paragraph | | Brief of Variables | Essential | Supplementary Essential | Nonessential | Special Process Essential Variables: Hardfacing Overlay (QW-216) | | Special Process Essential Variables: Corrosion-Resistant Overlay (QW-214) | |
|---|---|---|---|---|---|---|---|---|---|
| QW-402 Joints | .1 | $\phi$ Groove design | | | X | .16 | < finished $t$ | .16 | < finished $t$ |
| | .5 | + Backing | | | X | | | | |
| | .10 | $\phi$ Root spacing | | | X | | | | |
| | .11 | ± Retainers | | | X | | | | |
| QW-403 Base Metals | .5 | $\phi$ Group Number | | X | | .20 | $\phi$ P-Number | .20 | $\phi$ P-Number |
| | .6 | $T$ Limits | | X | | | | | |
| | .7 | $T/t$ Limits > 8 in. | X | | | | | | |
| | .8 | $\phi$ $T$ Qualified | X | | | | | | |
| | .11 | $\phi$ P-No. qualified | X | | | | | | |
| | .13 | $\phi$ P-No. 9/10 | X | | | | | | |
| QW-404 Filler Metals | .3 | $\phi$ Size | | | X | .12 | $\phi$ AWS class. | .5 | $\phi$ A-Number |
| | .4 | $\phi$ F-Number | X | | | .24 | ± Sup. filler metal | .24 | ± Sup. filler metal |
| | .5 | $\phi$ A-Number | X | | | | | | |
| | .12 | $\phi$ AWS class. | | X | | | | | |
| | .14 | ± Filler | X | | | | | | |
| | .22 | ± Consum. insert | | | X | | | | |
| | .30 | $\phi$ $t$ | X | | | | | | |
| | .33 | $\phi$ AWS class. | | | X | | | | |
| QW-405 Positions | .1 | + Position | | | X | .4 | + Position | .4 | + Position |
| | .2 | $\phi$ Position | | X | | | | | |
| | .3 | $\phi$ ↑↓ Vertical welding | | | X | | | | |
| QW-406 Preheat | .1 | Decrease > 100°F | X | | | .4 | Dec. > 100°F preheat > Interpass | .4 | Dec. > 100°F preheat > Interpass |
| | .3 | Increase > 100°F (IP) | | X | | | | | |
| QW-407 PWHT | .1 | $\phi$ PWHT | X | | | | | | |
| | .2 | $\phi$ PWHT (T & T range) | | X | | | | | |
| | .4 | $T$ Limits | X | | | | | | |
| QW-408 Gas | .1 | ± Trail or $\phi$ comp. | | | X | .15 | $\phi$ Type or flow rate | .15 | $\phi$ Type or flow rate |
| | .2 | $\phi$ Single, mixture, or % | X | | | | | | |
| | .3 | $\phi$ Flow rate | | | X | | | | |
| | .5 | ± or $\phi$ Backing | | | X | | | | |
| | .9 | ± Backing or < flow rate or $\phi$ comp. | X | | | | | | |
| | .10 | $\phi$ Shielding or trailing | X | | | | | | |

## QW-256 (CONT'D)
## WELDING VARIABLES PROCEDURE SPECIFICATIONS (WPS)
### Gas Tungsten-Arc Welding (GTAW)

| Paragraph | | Brief of Variables | Essential | Supplementary Essential | Nonessential | Special Process Essential Variables: Hardfacing Overlay (QW-216) | | Special Process Essential Variables: Corrosion-Resistant Overlay (QW-214) | |
|---|---|---|---|---|---|---|---|---|---|
| QW-409 Electrical Characteristics | .1 | $\phi$ I or > heat input | | X | | .1 | $\phi$ I or > heat input | .1 | $\phi$ I or > heat input |
| | .3 | ± Pulsing I | | | X | .4 | $\phi$ Current or polarity | .4 | $\phi$ Current or polarity |
| | .8 | $\phi$ Type I or $\phi$ I & E range | | | X | | | | |
| | .12 | $\phi$ Tungsten electrode | | | X | | | | |
| QW-410 Technique | .1 | $\phi$ String/weave | | | X | .10 | $\phi$ No. of elec. | .10 | $\phi$ No. of elec. |
| | .3 | $\phi$ Orifice, cup, or nozzle size | | | X | .38 | $\phi$ Multi- to single-layer | .38 | $\phi$ Multi- to single-layer |
| | .5 | $\phi$ Method cleaning | | | X | .42 | ± Oscillation | .42 | ± Oscillation |
| | .6 | $\phi$ Method back gouge | | | X | | | | |
| | .7 | $\phi$ Oscillation | | X | X | | | | |
| | .9 | $\phi$ Multi to single pass/side | | X | X | | | | |
| | .10 | $\phi$ Single to multi electrodes | | X | X | | | | |
| | .11 | $\phi$ Closed to out chamber | X | | | | | | |
| | .15 | $\phi$ Electrode spacing | | | X | | | | |
| | .25 | $\phi$ Manual or automatic | | | X | | | | |
| | .26 | ± Peening | | | X | | | | |

Legend:
+ Addition
− Deletion
> Increase/greater than
< Decrease/less than
↑ Uphill
↓ Downhill
← Forehand
→ Backhand
$\phi$ Change

## QW-257
## WELDING VARIABLES PROCEDURE SPECIFICATIONS (WPS)
### Plasma-Arc Welding (PAW)

| Paragraph | | Brief of Variables | Essential | Supplementary Essential | Nonessential | Special Process Essential Variables: Hardfacing Overlay (QW-216) | | Special Process Essential Variables: Corrosion-Resistant Overlay (QW-214) | |
|---|---|---|---|---|---|---|---|---|---|
| QW-402 Joints | .1 | φ Groove design | | | X | .16 | < finished $t$ | .16 | < finished $t$ |
| | .5 | + Backing | | | X | | | | |
| | .10 | φ Root spacing | | | X | | | | |
| | .11 | ± Retainers | | | X | | | | |
| QW-403 Base Metals | .5 | φ Group Number | | X | | .20 | φ P-Number | .20 | φ P-Number |
| | .6 | $T$ Limits | | X | | | | | |
| | .8 | φ $T$ Qualified | X | | | | | | |
| | .12 | φ P-Number/melt-in | X | | | | | | |
| | .13 | φ P-No. 9/10 | X | | | | | | |
| QW-404 Filler Metals | .3 | φ Size | | | X | .12 | φ AWS class. | .5 | φ A-Number |
| | .4 | φ F-Number | X | | | .41 | φ >10% powder feed rate | .41 | φ >10% powder feed rate |
| | .5 | φ A-Number | X | | | .43 | φ Particle size | .43 | φ Particle size |
| | .12 | φ AWS class. | | X | | .44 | φ Powder type | .44 | φ Powder type |
| | .14 | ± Filler | X | | | .45 | φ Filler met. form | .45 | φ Filler met. form |
| | .22 | ± Consum. insert | | | X | | | | |
| | .25 | ± Sup. powder | X | | | | | | |
| | .26 | > Sup. powder | X | | | | | | |
| | .27 | φ Alloy elements | X | | | | | | |
| | .30 | φ $t$ | X | | | | | | |
| | .33 | φ AWS class. | | | X | | | | |
| QW-405 Positions | .1 | + Position | | | X | .4 | + Position | .4 | + Position |
| | .2 | φ Position | | X | | | | | |
| | .3 | φ ↑↓ Vertical welding | | | X | | | | |
| QW-406 Preheat | .1 | Decrease > 100°F | X | | | .4 | Dec. > 100°F preheat > Interpass | .4 | Dec. > 100°F preheat > Interpass |
| | .3 | Increase > 100°F (IP) | | X | | | | | |
| QW-407 PWHT | .1 | φ PWHT | X | | | .6 | φ PWHT | .6 | φ PWHT |
| | .2 | φ PWHT ($T$ & $T$ range) | | X | | | | | |
| | .4 | $T$ Limits | X | | | | | | |
| QW-408 Gas | .1 | ± Trail or φ comp. | | | X | .15 | φ Type or mixture | .15 | φ Type or mixture |
| | .4 | φ Comp./flow rate | X | | | .16 | φ >5% Arc or metal feed gas | .16 | φ > 5% Arc or metal feed gas |
| | .5 | ± or φ Backing | | | X | .18 | φ >10% Mix. comp. | .18 | φ > 10% Mix. comp. |
| | .9 | ± Backing or < flow rate or φ comp. | X | | | | | | |
| | .10 | φ Shielding or trailing | X | | | | | | |

## QW-257 (CONT'D)
## WELDING VARIABLES PROCEDURE SPECIFICATIONS (WPS)
### Plasma-Arc Welding (PAW)

| Paragraph | | Brief of Variables | Essential | Supplementary Essential | Nonessential | Special Process Essential Variables: Hardfacing Overlay (QW-216) | | Special Process Essential Variables: Corrosion-Resistant Overlay (QW-214) | |
|---|---|---|---|---|---|---|---|---|---|
| QW-409 Electrical Characteristics | .1 | $\phi$ I or > heat input | | X | | .4 | $\phi$ Current or polarity | .4 | $\phi$ Current or polarity |
| | .8 | $\phi$ Type I or $\phi$ I & E range | | | X | .23 | $\phi$ >10% I & E | .23 | $\phi$ > 10% I & E |
| | .12 | $\phi$ Tungsten electrode | | | X | .24 | $\phi$ >10% filler wire watt. | .24 | $\phi$ >10% filler wire watt. |
| QW-410 Technique | .1 | $\phi$ String/weave | | | X | .38 | $\phi$ Multi- to single-layer | .38 | $\phi$ Multi- to single-layer |
| | .3 | $\phi$ Orifice, cup, or nozzle size | | | X | .39 | $\phi$ Torch dia. | .39 | $\phi$ Torch dia. |
| | .5 | $\phi$ Method cleaning | | | X | .41 | $\phi$ >15% travel speed | .41 | $\phi$ > 15% travel speed |
| | .6 | $\phi$ Method back gouge | | | X | .42 | ± Oscillation | .42 | ± Oscillation |
| | .7 | $\phi$ Oscillation | | X | X | .48 | $\phi$ Transfer mode | .48 | $\phi$ Transfer mode |
| | .9 | $\phi$ Multi to single pass/side | | X | X | .52 | $\phi$ Filler metal del. | .52 | $\phi$ Filler metal del. |
| | .10 | $\phi$ Single to multi electrodes | | X | X | | | | |
| | .11 | $\phi$ Closed to out chamber | X | | | | | | |
| | .12 | $\phi$ Melt-in to keyhole | | X | | | | | |
| | .15 | $\phi$ Electrode spacing | | | X | | | | |
| | .26 | ± Peening | | | X | | | | |

Legend:
+ Addition
− Deletion
> Increase/greater than
< Decrease/less than
↑ Uphill
↓ Downhill
← Forehand
→ Backhand
$\phi$ Change

## QW-258
## WELDING VARIABLES PROCEDURE SPECIFICATIONS (WPS)
### Electroslag Welding (ESW)

| Paragraph | | Brief of Variables | Essential | Supplementary Essential | Nonessential | Special Process Essential Variables: Hardfacing Overlay (QW-216) | | Special Process Essential Variables: Corrosion-Resistant Overlay (QW-214) | |
|---|---|---|---|---|---|---|---|---|---|
| QW-402 Joints | .1 | φ Groove design | | | X | .16 | < finished $t$ | .16 | < finished $t$ |
| | .10 | φ Root spacing | | | X | | | | |
| | .11 | ± Retainers | X | | | | | | |
| QW-403 Base Metals | .1 | φ P-Number | X | | | | | .20 | φ P-Number |
| | .4 | φ Group Number | | X | | | | | |
| | .9 | $t$ Pass > ½ in. | X | | | | | | |
| | .13 | φ P-No. 9/10 | X | | | | | | |
| QW-404 Filler Metals | .4 | φ F-Number | X | | | | | .5 | φ A-Number |
| | .5 | φ A-Number | X | | | | | .24 | ± Sup. filler metal |
| | .6 | φ Diameter | | | X | | | .39 | φ Flux type or comp. |
| | .12 | φ AWS class. | | X | | | | .40 | φ > 10% elec. dia. sup. filler |
| | .17 | φ Flux type or comp. | X | | | | | | |
| | .18 | φ Wire to plate | X | | | | | | |
| | .19 | φ Consum. guide | X | | | | | | |
| | .33 | φ AWS class. | | | X | | | | |
| QW-406 Preheat | | | | | | | | .4 | Dec. > 100°F preheat > Interpass |
| QW-407 PWHT | .1 | φ PWHT | X | | | | | .6 | φ PWHT |
| | .2 | φ PWHT (T & T range) | | X | | | | | |
| | .4 | $T$ Limits | X | | | | | | |
| QW-409 Electrical Characteristics | .5 | φ ±15% I & E range | X | | | | | .1 | φ I or > heat input |
| | | | | | | | | .4 | φ Current or polarity |
| QW-410 Technique | .5 | φ Method cleaning | | | X | | | .38 | φ Multi- to single-layer |
| | .7 | φ Oscillation | X | | | | | .40 | − Sup. device |
| | .10 | φ Single to multi electrodes | X | | | | | .42 | ± Oscillation |
| | .15 | φ Electrode spacing | | | X | | | .50 | φ No. of elec. |
| | .26 | ± Peening | | | X | | | | |

Legend:
+ Addition
− Deletion
> Increase/greater than
< Decrease/less than
↑ Uphill
↓ Downhill
← Forehand
→ Backhand
φ Change

## QW-259
## WELDING VARIABLES PROCEDURE SPECIFICATIONS (WPS)
### Electrogas Welding (EGW)[1]

| Paragraph | | Brief of Variables | Essential | Supplementary Essential | Nonessential |
|---|---|---|---|---|---|
| QW-402 Joints | .1 | φ Groove design | | | X |
| | .10 | φ Root spacing | | | X |
| | .11 | ± Retainers | X | | |
| QW-403 Base Metals | .1 | φ P-Number | X | | |
| | .5 | φ Group Number | | X | |
| | .6 | *T* Limits | | X | |
| | .9 | *t* Pass > ½ in. | X | | |
| | .13 | φ P-No. 9/10 | X | | |
| QW-404 Filler Metals | .4 | φ F-Number | X | | |
| | .5 | φ A-Number | X | | |
| | .6 | φ Diameter | | | X |
| | .12 | φ AWS class. | | X | |
| | .23 | φ Solid to tubular | X | | |
| | .33 | φ AWS class. | | | X |
| QW-406 Preheat | .1 | Decrease > 100°F | | | X |
| QW-407 PWHT | .1 | φ PWHT | X | | |
| | .2 | φ PWHT (T & T range) | | X | |
| | .4 | *T* Limits | X | | |
| QW-408 Gas | .2 | φ Single, mixture, or % | X | | |
| | .3 | φ Flow rate | | | X |
| QW-409 Electrical Characteristics | .1 | φ I or > heat input | | X | |
| | .8 | φ Type I or φ I & E range | | | X |
| QW-410 Technique | .5 | φ Method cleaning | | | X |
| | .7 | φ Oscillation | | | X |
| | .8 | φ Tube-work distance | | | X |
| | .9 | φ Multi to single pass/side | | X | X |
| | .10 | φ Single to multi electrodes | X | | |
| | .15 | φ Electrode spacing | | | X |
| | .26 | ± Peening | | | X |

Legend:

| | | | | |
|---|---|---|---|---|
| + Addition | > Increase/greater than | ↑ Uphill | ← Forehand | φ Change |
| − Deletion | < Decrease/less than | ↓ Downhill | → Backhand | |

NOTE:
(1) Automated vertical gas metal-arc welding for vertical position only.

QW-260
WELDING VARIABLES PROCEDURE SPECIFICATIONS (WPS)
Electron Beam Welding (EBW)

| Paragraph | | Brief of Variables | Essential | Supplementary Essential | Nonessential |
|---|---|---|---|---|---|
| QW-402 Joints | .1 | φ Groove design | X | | |
| | .2 | ± Backing | X | | |
| | .6 | > Fit-up gap | X | | |
| QW-403 Base Metals | .1 | φ P-Number | X | | |
| | .3 | φ Penetration | X | | |
| | .13 | φ P-No. 9/10 | X | | |
| | .15 | φ P-Number | X | | |
| QW-404 Filler Metals | .1 | φ Cross section or speed | X | | |
| | .2 | < *t* or φ comp. | X | | |
| | .8 | ± or φ Chem. comp. | X | | |
| | .14 | ± Filler | X | | |
| | .20 | φ Method of addition | X | | |
| | .21 | φ Analysis | X | | |
| | .33 | φ AWS class. | | | X |
| QW-406 Preheat | .1 | Decrease > 100°F | X | | |
| QW-407 PWHT | .1 | φ PWHT | X | | |
| QW-408 Gas | .6 | φ Environment | X | | |
| QW-409 Electrical Characteristics | .6 | φ I, E, speed, distance, osc. | X | | |
| | .7 | φ Pulsing frequency | X | | |
| QW-410 Technique | .5 | φ Method cleaning | | | X |
| | .7 | φ Oscillation | X | | |
| | .14 | φ Angle of beam axis | X | | |
| | .17 | φ Type & model equip. | X | | |
| | .18 | > Pressure of vacuum | X | | |
| | .19 | φ Filament type, size, etc. | X | | |
| | .20 | + Wash pass | X | | |
| | .21 | 1 vs. 2 side welding | X | | |

Legend:
+ Addition
− Deletion
> Increase/greater than
< Decrease/less than
↑ Uphill
↓ Downhill
← Forehand
→ Backhand
φ Change

## QW-261
## WELDING VARIABLES PROCEDURE SPECIFICATIONS (WPS)
### Stud Welding

| Paragraph | | Brief of Variables | Essential | Supplementary Essential | Nonessential |
|---|---|---|---|---|---|
| QW-402 Joints | .8 | ϕ Stud shape size | X | | |
| | .9 | ϕ Flux or ferrule | X | | |
| QW-403 Base Metal | .17 | ϕ Base metal or stud metal | X | | |
| QW-405 Positions | .1 | + Position | X | | |
| QW-406 Preheat | .1 | Decrease > 100°F | X | | |
| QW-407 PWHT | .1 | ϕ PWHT | X | | |
| QW-408 Gas | .2 | ϕ Single, mixture, or % | X | | |
| QW-409 Electrical Characteristics | .8 | ϕ Type I or ϕ I & E range | | | X |
| | .9 | ϕ Arc timing | X | | |
| | .10 | ϕ Amperage | X | | |
| | .11 | ϕ Power source | X | | |
| QW-410 Technique | .22 | ϕ Gun model or lift | X | | |

Legend:
+ Addition
− Deletion
> Increase/greater than
< Decrease/less than
↑ Uphill
↓ Downhill
← Forehand
→ Backhand
ϕ Change

## QW-262
## WELDING VARIABLES PROCEDURE SPECIFICATIONS (WPS)
### Inertia and Continuous Drive Friction Welding

| Paragraph | | Brief of Variables | Essential | Supplementary Essential | Nonessential |
|---|---|---|---|---|---|
| QW-402 Joints | .12 | $\phi$ > 10 deg. | X | | |
| | | $\phi$ Cross section > 10% | X | | |
| | | $\phi$ O. D. > ±10% | X | | |
| | | $\phi$ Solid-to-tube | X | | |
| QW-403 Base Metal | .19 | $\phi$ Base metal | X | | |
| QW-406 Preheat | .1 | $\phi$ < 100°F | X | | |
| QW-407 PWHT | .1 | $\phi$ PWHT | X | | |
| QW-408 Gas | .6 | $\phi$ Environment | X | | |
| QW-410 Technique | .27 | $\phi$ Spp. > ±10% | X | | |
| | .28 | $\phi$ Load > ±10% | X | | |
| | .29 | $\phi$ Energy > ±10% | X | | |
| | .30 | $\phi$ Upset > ±10% | X | | |

## QW-263
## WELDING VARIABLES PROCEDURE SPECIFICATIONS (WPS)
## RESISTANCE WELDING

| Paragraph | | | Brief of Variables | Essential | Nonessential |
|---|---|---|---|---|---|
| QW-402 Joints | .13 | | Spot, projection, seam | X | |
| | .14 | | Overlap, spacing | X | |
| | .15 | | Projection shape | X | |
| QW-403 Base Metals | .1 | $\phi$ | P-No. | X | |
| | .21 | ± | Coating, plating | X | |
| | .22 | ± | *T* | X | |
| QW-406 Preheat | .6 | $\phi$ | Amplitude, cycles | X | |
| QW-407 PWHT | .5 | $\phi$ | PWHT | X | |
| QW-409 Electrical | .13 | $\phi$ | RWMA class | X | |
| | .14 | ± | Δ Slope | X | |
| | .15 | $\phi$ | Pressure, current, time | X | |
| | .16 | | Timing | X | |
| | .17 | $\phi$ | Power supply | | X |
| | .18 | | Tip cleaning | | X |
| QW-410 Technique | .31 | $\phi$ | Cleaning method | X | |
| | .32 | $\phi$ | Pressure, time | X | |
| | .33 | $\phi$ | Equipment | X | |
| | .34 | $\phi$ | Cooling medium | | X |
| | .35 | $\phi$ | Throat | | X |

## QW-264
## WELDING VARIABLES PROCEDURE SPECIFICATIONS (WPS)
### Laser Beam Welding (LBW)

| Paragraph | | Brief of Variables | Essential | Supplementary Essential | Nonessential |
|---|---|---|---|---|---|
| QW-402 Joints | .1 | φ Groove design | X | | |
| | .2 | ± Backing | X | | |
| | .6 | > Fit-up gap | X | | |
| QW-403 Base Metals | .1 | φ P-Number | X | | |
| | .3 | φ Penetration | X | | |
| | .13 | φ P-No. 9/10 | X | | |
| | .15 | φ P-Number | X | | |
| QW-404 Filler Metals | .1 | φ Cross section or speed | X | | |
| | .2 | < *t* or φ comp. | X | | |
| | .8 | ± or φ Chem. comp. | X | | |
| | .14 | ± Filler | X | | |
| | .20 | φ Method of addition | X | | |
| | .21 | φ Analysis | X | | |
| | .33 | φ AWS class. | | | X |
| QW-406 Preheat | .1 | Decrease > 100°F | X | | |
| QW-407 PWHT | .1 | φ PWHT | X | | |
| QW-408 Gas | .2 | φ Single, mixture, or % | X | | |
| | .6 | φ Environment | X | | |
| | .11 | ± Gases | X | | |
| | .12 | φ % Gases | X | | |
| | .13 | φ Phase jet position | X | | |
| QW-409 Electrical Characteristics | .22 | φ Pulse | X | | |
| | .23 | φ Focal, mode, energy | X | | |
| | .24 | φ Watts, speed, size, dist. | X | | |
| QW-410 Technique | .5 | φ Method cleaning | | | X |
| | .7 | φ Oscillation | X | | |
| | .14 | φ Angle of beam axis | X | | |
| | .17 | φ Type & model equip. | X | | |
| | .20 | + Wash pass | X | | |
| | .21 | 1 vs. 2 side welding | X | | |
| | .37 | φ Single to mult. pass | X | | |

Legend:
+ Addition
− Deletion
> Increase/greater than
< Decrease/less than
↑ Uphill
↓ Downhill
← Forehand
→ Backhand
φ Change

## QW-265
## WELDING VARIABLES PROCEDURE SPECIFICATIONS (WPS)
## HARD-SURFACING: SPRAY FUSE METHOD
[Oxy-fuel Gas or Plasma (non-transferred arc) spraying]

| Paragraph | Special Process Essential Variables | | | |
|---|---|---|---|---|
| | Oxy-fuel Gas Spray | | Plasma (Non-transferred arc) Spray | |
| QW-402 Joints | .16 | > finished *t* | .16 | > finished *t* |
| QW-403 Base Metals | .20 | φ P-Number | .20 | φ P-Number |
| QW-404 Filler Metals | .12 | φ AWS class. | .12 | φ AWS class. |
| | .42 | φ > 5% Particle size range | .42 | φ > 5% Particle size range |
| | .46 | φ Powder feed rate | .46 | φ Powder feed rate |
| QW-405 Positions | .4 | + Positions | .4 | + Positions |
| QW-406 Preheat | .4 | Dec. > 100°F preheat > Interpass | .4 | Dec. > 100°F preheat > Interpass |
| | .5 | φ Preheat maint. | .5 | φ Preheat maint. |
| QW-407 PWHT | .6 | φ PWHT | .6 | φ PWHT |
| | .7 | φ PWHT after fusing | .7 | φ PWHT after fusing |
| QW-408 Gas | .7 | φ Type of fuel gas | | |
| | .16 | φ > 5% Powder feed rate | .16 | φ > 5% Powder feed rate |
| | .17 | φ Feed gas comp. | .17 | φ Feed gas comp. |
| | | | .19 | φ Plasma gas comp. |
| | | | .20 | φ Plasma gas flow rate range |
| QW-409 Electrical | | | .4 | φ Current or polarity |
| | | | .12 | φ Type or size elec. |
| | | | .25 | φ > 10% I & E |
| QW-410 Technique | .38 | φ Multi- single-layer | .38 | φ Multi- single-layer |
| | .44 | φ > 15% torch to work-piece | .41 | φ > 15% travel speed range |
| | .45 | φ Surface prep | .44 | φ > 15% torch to work-piece |
| | .46 | φ Spray torch | .45 | φ Surface prep |
| | .47 | φ > 10% fusing temp. or method | .46 | φ Spray torch |
| | | | .47 | φ > 10% fusing temp. or method |

## QW-283 Welds With Buttering

**QW-283.1 Scope.** This paragraph only applies when the essential variables for the buttering process are different than the essential variables for the process used for subsequent completion of the joint. Common examples are:

*(1)* the buttered member is heat treated and the completed weld is not heat treated after welding; and

*(2)* the filler metal used for buttering has a different F-number from that used for the subsequent completion of the weld.

**QW-283.2 Tests Required.** The procedure shall be qualified by buttering the test coupon (including heat treating of the buttered member when this will be done in production welding) and then making the subsequent weld joining the members. The variables for the buttering and for the subsequent weld shall be in accordance with QW-250, except that QW-409.1 shall be an essential variable for the welding process(es) used to complete the weld when the minimum buttering thickness is less than $^3/_{16}$ in. Mechanical testing of the completed weldment shall be in accordance with QW-202.2(a).

If the buttering is done with filler metal of the same composition as the filler metal used to complete the weld, one weld test coupon may be used to qualify the dissimilar metal joint by welding the first member directly to the second member in accordance with Section IX.

**QW-283.3 Buttering Thickness.** The thickness of buttering which shall remain on the production buttered member after all machining and grinding is completed and before subsequent completion of the joint shall be required by the WPS. When this thickness is less than $^3/_{16}$ in., the thickness of buttering on the test coupon shall be measured before the buttered member is welded to the second member. This thickness shall become the minimum qualified thickness of buttering.

**QW-283.4 Multiple Organizations.** When one organization butters a member and a second organization completes the weld, the second organization shall also qualify the procedure in accordance with QW-283. The buttering thickness shall not be greater, nor the heat input higher than that which was qualified by the first organization. The second organization may substitute any base metal which has an assigned P-Number and a chemical analysis nominally matching the chemical analysis of the buttering weld metal for the buttered base metal of the procedure qualification test coupon.

## QW-284 Resistance Welding Equipment Qualification

Each resistance welding machine shall be tested to determine its ability to make welds consistently and reproducibly. A machine shall be requalified whenever it is rebuilt, moved to a new location requiring a change in power supply, when the power supply is changed, or any other significant change is made to the equipment. Machine qualification testing shall consist of making a set of 100 consecutive welds. Every fifth of these welds shall be subjected to mechanical shear tests. Five welds, which shall include one of the first five and one of the last five of the set shall be metallographically examined. No maintenance or adjustment of the machine shall be permitted during welding of a set of test welds. Qualification testing on any P-2X aluminum alloy shall qualify the machine for all materials. Qualification on P-1 through P-11 iron-base alloys and any P-4X nickel-base alloys shall qualify the machine for all P-1 through P-11 and P-4X metals. Testing and acceptance criteria shall be in accordance with QW-196.

## QW-285 Resistance Spot and Projection Weld Procedure Qualification

Procedure qualification testing for spot or projection welds shall be done following a Welding Procedure Specification, and it shall consist of making a set of 10 consecutive welds. Five of these welds shall be subjected to mechanical shear tests and five to metallographic examination. Examination, testing, and acceptance criteria shall be in accordance with QW-196.

## QW-286 Resistance Seam Weld Procedure Qualification

Plates shall be prepared by welding or brazing a pipe nipple to one of the plates at a hole in one of the plates, and then the plates shall be welded around the edges, sealing the space between the plates as shown in Fig. QW-462.7. The space between the plates shall be pressurized until failure occurs. The procedure qualification is acceptable if failure occurs in the base metal. An additional seam weld at least 6 in. long shall be made between plates of the same thickness as to be used in production welding, and this plate shall be cut into six approximately equal width strips and one cross section of each strip shall be metallographically examined and meet the requirements of QW-196.

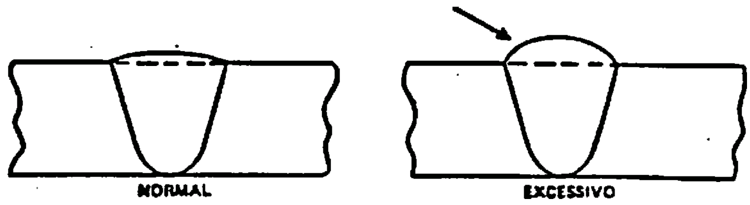



FIGURA 24 - Reforço excessivo.

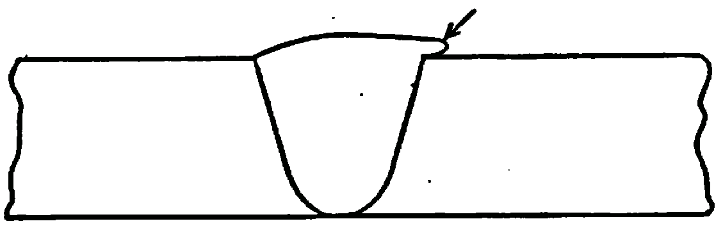


FIGURA 25 - Sobreposição.

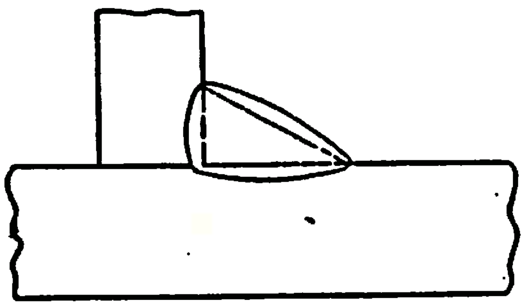


FIGURA 26 - Solda em ângulo assimétrica.

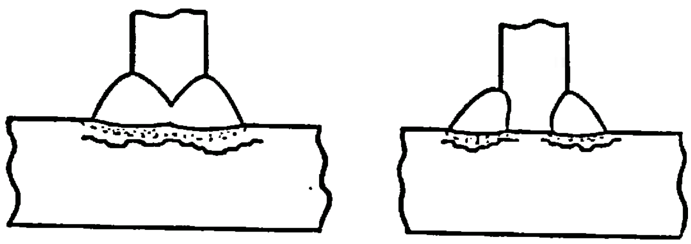


FIGURA 27 - Decoesão lamelar.

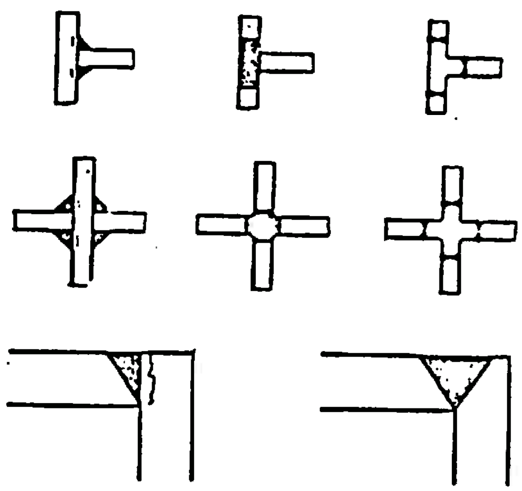


FIGURA 28 - Modificações de projeto para evitar decoesão lamelar.

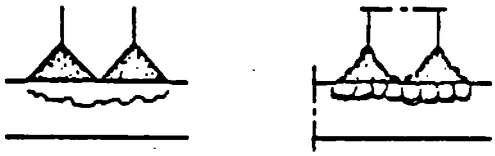


FIGURA 29 - Amanteigamento para evitar decoesão lamelar.

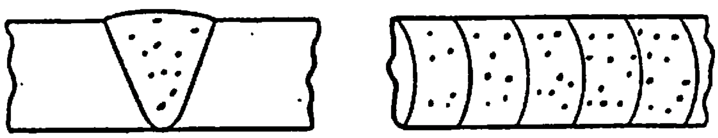


FIGURA 30 - Porosidade.

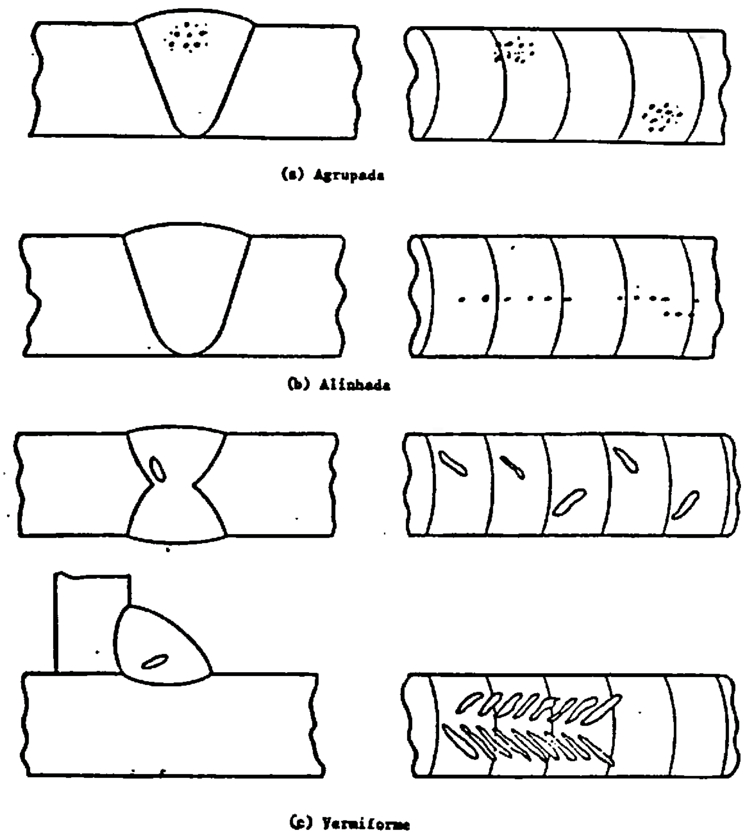



FIGURA 31 - Porosidade.

## 2.5 NORMAS PARA A QUALIFICAÇÃO DOS PROCESSOS DE SOLDAGEM:

As normas para a qualificação de processos de soldagem para vasos de pressão utilizadas para este trabalho são as normas do código ASME, Secção IX, Capítulo QW Welding, edição de 1992.

Estas normas encontram-se no anexo A - Normas ASME / Secção IX explicativo

### 3.2 PROJETOS PARA SOLDAGEM:

#### 3.2.1 AÇO RRSt 44.3:

##### 3.2.1.1 PROCESSO TIG - ELETRODO REVESTIDO:

Este processo de soldagem refere-se a EPS No. 20163, que se encontra no Anexo A - Procedimentos de Soldagem.

##### 3.2.1.2 PROCESSO MAG:

Este processo de soldagem refere-se a EPS No. 20130, que se encontra no Anexo A - Procedimentos de Soldagem.

#### 3.2.2 AÇO INOXIDÁVEL 304L:

##### 3.2.2.1 PROCESSO ELETRODO REVESTIDO:

Este processo de soldagem refere-se a EPS No. 20164, que se encontra no Anexo A - Procedimentos de Soldagem.

##### 3.2.2.1 PROCESSO TIG / ELETRODO REVESTIDO:

Este processo de soldagem refere-se a EPS No. 20169, que se encontra no Anexo A - Procedimentos de Soldagem.

## 3.3 PROCEDIMENTOS PARA ENSAIO:

### 3.3.1 ENSAIO METALOGRÁFICO:

A. Aço RRSt 44.3

Retirar um corpo de prova englobando toda seção longitudinal da solda;

Usinar a superfície por processo de retífica plana;

Fazer o lixamento mecânico com auxílio das lixas 60, 180, 240, 320, 400, 600 e 1000, sendo que obedecendo um ângulo de 90 graus na direção de lixamento entre cada lixa;

Fazer polimento com pasta de alumina 0,05 microns;

Fazer um ataque químico durante 10 a 15 segundos com Nital 2%;

Observar no microscópio ótico.

B Aço Inoxidável 304 L

Retirar um corpo de prova englobando toda seção longitudinal da solda;

Usinar a superfície por processo de retífica plana;

Fazer o lixamento mecânico com auxilio das lixas 60, 180, 240, 320, 400, 600 e 1000, sendo que obedecendo um ângulo de 90 graus na direção de lixamento entre cada lixa;

Fazer polimento com pasta de alumina 0,05 microns;

Fazer um ataque químico durante 50 a 60 segundos com Glicerregia;

Observar no microscópio ótico.

| | | |
|---|---|---|
| Glicerregia: | 10 | ml de $HNO_3$ |
| | 35 | ml de HCl |
| | 30 | ml de Glicerina |

### 3.3.2 ENSAIO DE DOBRAMENTO:

O ensaio de dobramento feito está de acordo com o procedimento recomendado pelo código ASME Seção IX Norma QW160, que encontra-se no anexo B.

### 3.3.3 ENSAIO DE TRAÇÃO:

O ensaio de tração feito está de acordo com o procedimento recomendado pelo código ASME Seção IX Norma QW180, que encontra-se no anexo B.

### 3.3.4 EXAME VISUAL:

O exame foi procedido de acordo com o código ASME Seção V Artigo 9, que encontra-se no anexo C.

### 3.3.5 ENSAIO POR LÍQUIDO PENETRANTE:

O ensaio obedeceu o procedimento recomendado pelo código ASME Seção V Artigo 6, que encontra-se no anexo C.

### 3.3.6 ENSAIO POR PARTÍCULAS MAGNÉTICAS:

Para tal ensaio foi obedecido o procedimento recomendado pelo código ASME Seção V Artigo 7, que encontra-se no anexo C.

### 3.3.7 ENSAIO POR ULTRA-SOM:

Para este ensaio, o procedimento obedeceu ao código ASME Seção V Artigo 5, que encontra-se no anexo C.

### 3.3.8 RADIOGRAFIA INDUSTRIAL:

Foi utlizado o método de gamagrafia, obedecendo ao código ASME Seção V Artigo 3, que encontra-se no anexo C.

## 3.4 RESULTADOS:

| Corpos de Prova | | Processo | | Metal Base |
|---|---|---|---|---|
| 1 | MAG | GMAW | | DIN 17100 RRSt 44.3 |
| 2 | TIG | GTAW + SMAW | Eletrodo revestido | DIN 17100 RRSt 44.3 |
| 4 | | SMAW | | AISI 304 L |
| 5 | | GTAW + SMAW | | AISI 304 L |

**<u>Análise Química:</u>**

Conforme tabela a seguir

**VILLARES**
Aços Villares SA

# ANÁLISE QUÍMICA

Nº LGI-39725/26
DEPTO. CQS | SEÇÃO LQ

REQUISITANTE: IVAN G. S. FALLEIROS
SEÇÃO: DTO
MATERIAL: AÇO
PROCEDÊNCIA:

| AMOSTRA | C | Si | Mn | Cr | Ni | Mo | W | V | Co | Cu | Al | P | S | Pb | | N2 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Nº 1 | 0,153 | 0,23 | 1,00 | 0,08 | 0,01 | 0,01 | — | — | 0,01 | 0,01 | 0,039 | 0,023 | 0,015 | | | | | |
| Nº 2 | 0,021 | 0,50 | 1,45 | 12,40 | 9,60 | 0,04 | 0,05 | 0,04 | 0,04 | 0,01 | | 0,043 | 0,0045 | | | 0,039 | | [illegible] |
| | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | |

OBSERVAÇÕES:

AVSA - USINA
LABORATÓRIO
2? JUN. 1993
QUIMICO
CQS-LQ Nº 02-3045

| EXECUTANTE | | SUPERVISOR | |
|---|---|---|---|
| DATA | ASSINATURA | DATA | ASSINATURA |
| | [signature] | 21/6/93 | [signature] |

AV 03 105 9/87

1ª VIA (BRANCA) - REQUISITANTE • 2ª VIA (ROSA) - ARQUIVO

**Ensaios de Tração e Dobramento:**

Conforme certificados a seguir

| COPIAS : | ASSUNTO: QUALIFICACAO DE PROCEDIMENTO DE SOLDAGEM |
|---|---|
| PG/PPF | |
| Fernando | SOLICITANTE: |

**1. HISTORICO :**

Qualificação de Procedimento de Soldagem , GMAW ,EPS Nº 20130 ,conforme norma ASME IX , parte QW .

Soldador : Aldivino dos R. Anselmo Chapa 15830

**2. ESPECIFICAÇOES :**

Metal de Base : 1 - DIN 17100 RRSt 44.3 1"

Resist. à Tração : 410 - 540 MPa

2 - DIN 17100 RRSt 44.3 1"

Metal de Adição : AWS ER - 70 S-6

**3. TESTE DE TRAÇÃO ( QW 150 ) :**

| Corpo de Prova Nº | Largura (mm) | Espessura (mm) | Carga Máx. (N) | R.Tração ( MPa ) | Local da Ruptura |
|---|---|---|---|---|---|
| 1 | 18.8 | 16.9 | 171500 | 540 | M. Base |
| 2 | 18.9 | 17.0 | 168100 | 523 | M. Base |

Resistência a Tração Especificada : 410 -540 MPa

**4. TESTE DE DOBRAMENTO ( QW 160 ) :**

| Corpo de Prova | Tipo | Resultado |
|---|---|---|
| 1 | Face | Satisfatório |
| 2 | Face | Satisfatório |
| 3 | Raiz | Satisfatório |
| 4 | Raiz | Satisfatório |

| Elaborado: | Sigla | Aprovado: | |
|---|---|---|---|
| J.Batista | PG/PPB | Ricardo Galassi | 24/11/93 |

**6. CONCLUSAO:**

Aprovado conforme norma ASME Seção IX ,ed.89 ,ad.90 .

ASEA BROWN BOVERI

**COPIAS :** PG/PPF Fernando

**ASSUNTO:** QUALIFICACAO DE PROCEDIMENTO DE SOLDAGEM

**SOLICITANTE:**

## 1. HISTORICO :

Qualificação de Procedimento de Soldagem , GTAW + SMAW, EPS Nº 20163 ,conforme norma ASME IX , parte QW .

Soldador : Aldivino dos R. Anselmo Chapa 15830

## 2. ESPECIFICAÇOES :

Metal de Base : 1 - DIN 17100 RRSt 44.3 1"

Resist. à Tração : 410 - 540 MPa

2 - DIN 17100 RRSt 44.3 1"

Metal de Adição : AWS ER - 80 S-D2 e E 7018 - 1

## 3. TESTE DE TRAÇÃO ( QW 150 ) :

| Corpo de Prova Nº | Largura (mm) | Espessura (mm) | Carga Máx. (N) | R.Tração ( MPa ) | Local da Ruptura |
|---|---|---|---|---|---|
| 1 | 19.0 | 17.1 | 167600 | 516 | M. Base |
| 2 | 19.0 | 17.3 | 167600 | 510 | M. Base |

Resistência a Tração Especificada : 410 -540 MPa

## 4. TESTE DE DOBRAMENTO ( QW 160 ) :

| Corpo de Prova | Tipo | Resultado |
|---|---|---|
| 1 | Face | Satisfatório |
| 2 | Face | Satisfatório |
| 3 | Raiz | Satisfatório |
| 4 | Raiz | Satisfatório |

Elaborado: J.Batista | Sigla: PG/PPB | Aprovado: Ricardo Galassi 24/11/93

**6. CONCLUSAO:**

Aprovado conforme norma ASME Seção IX ,ed.89 ,ad.90 .

**COPIAS :** PG/PPF Fernando

**ASSUNTO:** QUALIFICACAO DE PROCEDIMENTO DE SOLDAGEM

**SOLICITANTE:**

## 1. HISTORICO :

Qualificação de Procedimento de Soldagem , SMAW , EPS Nº 20164 ,conforme norma ASME IX , parte QW .

Soldador : Aldivino dos R. Anselmo Chapa 15830

## 2. ESPECIFICAÇOES :

Metal de Base : 1 - AISI 304 L - 1"

Resist. à Tração : 485 MPa , min.

2 - AISI 304 L - 1"

Metal de Adição : AWS E 308 L - 16

## 3. TESTE DE TRAÇÃO ( QW 150 ) :

| Corpo de Prova Nº | Largura (mm) | Espessura (mm) | Carga Máx. (N) | R.Tração ( MPa ) | Local da Ruptura |
|---|---|---|---|---|---|
| 1 | 18.8 | 17.2 | 195020 | 603 | M. Base |
| 2 | 19.0 | 17.0 | 197000 | 610 | M. Base |

Resistência a Tração Especificada : 485 MPa , min.

## 4. TESTE DE DOBRAMENTO ( QW 160 ) :

| Corpo de Prova | Tipo | Resultado |
|---|---|---|
| 1 | Face | Satisfatório |
| 2 | Face | Satisfatório |
| 3 | Raiz | Satisfatório |
| 4 | Raiz | Satisfatório |

| Elaborado: | Sigla | Aprovado: | |
|---|---|---|---|
| J.Batista | PG/PPB | Ricardo Galassi | 24/11/93 |

6. CONCLUSAO:

Aprovado conforme norma ASME Seção IX ,ed.89 ,ad.90 .

| COPIAS : | ASSUNTO: QUALIFICACAO DE PROCEDIMENTO DE SOLDAGEM |
|---|---|
| PG/PPF | |
| Fernando | SOLICITANTE: |

**1. HISTORICO :**

Qualificação de Procedimento de Soldagem , SMAW + GTAW , EPS Nº 20169 ,conforme norma ASME IX , parte QW .

Soldador : Aldivino dos R. Anselmo Chapa 15830

**2. ESPECIFICAÇOES :**

Metal de Base : 1 - AISI 304 L - 1"

Resist. à Tração : 485 MPa , min.

2 - AISI 304 L - 1"

Metal de Adição : AWS E 308 L - 16

**3. TESTE DE TRAÇÃO ( QW 150 ) :**

| Corpo de Prova Nº | Largura (mm) | Espessura (mm) | Carga Máx. (N) | R.Tração ( MPa ) | Local da Ruptura |
|---|---|---|---|---|---|
| 1 | 19.0 | 17.2 | 196000 | 600 | M. Base |
| 2 | 18.8 | 17.0 | 197500 | 618 | M.Adição |

Resistência a Tração Especificada : 485 MPa , min.

**4. TESTE DE DOBRAMENTO ( QW 160 ) :**

| Corpo de Prova | Tipo | Resultado |
|---|---|---|
| 1 | Face | Satisfatório |
| 2 | Face | Satisfatório |
| 3 | Raiz | Satisfatório |
| 4 | Raiz | Satisfatório |

| Elaborado: | Sigla | Aprovado: | |
|---|---|---|---|
| J.Batista | PG/PPB | Ricardo Galassi | 24/11/93 |

# ARTICLE III
# WELDING PERFORMANCE QUALIFICATIONS

## QW-300 GENERAL

**QW-300.1** This Article lists the welding processes separately, with the essential variables which apply to welder and welding operator performance qualifications.

The welder qualification is limited by the essential variables given for each welding process. These variables are listed in QW-350, and are defined in Article IV Welding Data. The welding operator qualification is limited by the essential variables given in QW-360 for each type of weld.

A welder or welding operator may be qualified by radiography of a test coupon, radiography of his initial production welding, or by bend tests taken from a test coupon except as stated in QW-304 and QW-305.

**QW-300.2** The basic premises of responsibility in regard to welding are contained within QW-103 and QW-301.2. These paragraphs require that each manufacturer or contractor (an assembler or an installer is to be included within this premise) shall be responsible for conducting tests to qualify the performance of welders and welding operators in accordance with qualified Welding Procedure Specifications, which his organization employs in the construction of weldments built in accordance with the Code. The purpose of this requirement is to ensure that the manufacturer or contractor has determined that his welders and welding operators using his procedures are capable of developing the minimum requirements specified for an acceptable weldment. This responsibility cannot be delegated to another organization.

The welders or welding operators used to produce such weldments shall be tested under the full supervision and control of the manufacturer, contractor, assembler, or installer during the production of these test weldments. It is not permissible for the manufacturer, contractor, assembler, or installer to have the welding performed by another organization. It is permissible, however, to subcontract any or all of the work of preparation of test materials for welding and subsequent work on the preparation of test specimens from the completed weldments, performance of nondestructive examination and mechanical tests, provided the manufacturer, contractor, assembler, or installer accepts full responsibility for any such work.

The Code recognizes a manufacturer, contractor, assembler, or installer as the organization which has responsible operational control of the production of the weldments to be made in accordance with this Code. If in an organization effective operational control of the welder performance qualification for two or more companies of different names exists, the companies involved shall describe in the Quality Control system, the operational control of performance qualifications. In this case requalification of welders and welding operators within the companies of such an organization will not be required, provided all other requirements of Section IX are met.

## QW-301 Tests

**QW-301.1 Intent of Tests.** The performance qualification tests are intended to determine the ability of welders and welding operators to make sound welds.

**QW-301.2 Qualification Tests.** Each manufacturer or contractor shall qualify each welder or welding operator for each welding process to be used in production welding. The performance qualification test shall be welded in accordance with qualified Welding Procedure Specifications (WPS), except that when performance qualification is done in accordance with a WPS that requires a preheat or postweld heat treatment, these may be omitted. Changes beyond which requalification is required are given in QW-350 for welders and in QW-360 for welding operators. Allowable mechanical and radiographic testing requirements are described in QW-304 and QW-305. Retests and renewal of qualification are given in QW-320.

**QW-303.4 Stud-Weld Positions.** Qualification in the 4S position also qualifies for the 1S position. Qualification in the 4S and 2S positions qualifies for all positions.

## QW-304 Welders

Except for the special requirements of QW-380, each welder who welds under the rules of the Code shall have passed the mechanical tests prescribed in QW-302.1. Alternatively, welders making a groove weld using SMAW, SAW, GTAW, PAW, and GMAW (except short-circuiting mode) or a combination of these processes, may be qualified by radiographic examination, except for P-No. 2X, P-No. 5X, and P-No. 6X metals. Welders making groove welds in P-No. 2X and P-No. 5X metals with the GTAW process may also be qualified by radiographic examination. The radiographic examination shall be in accordance with QW-302.2.

A welder qualified to weld in accordance with one qualified WPS is also qualified to weld in accordance with other qualified WPSs, using the same welding process, within the limits of the essential variables of QW-350.

**QW-304.1 Examination.** Welds made in test coupons for performance qualification may be examined by mechanical tests (QW-302.1) or by radiography (QW-302.2) for the process(es) and mode of arc transfer specified in QW-304. Alternatively, a 6 in. length of the first production weld made by a welder using the process(es) and/or mode of arc transfer specified in QW-304 may be qualified by radiography.

**QW-304.2 Failure to Meet Radiographic Standards.** If a production weld is selected for welder performance qualification and it does not meet the radiographic standards, the welder has failed the test. In this event, the entire production weld made by this welder shall be radiographed and repaired by a qualified welder or welding operator. Alternatively, retests may be made as permitted in QW-320.

## QW-305 Welding Operators

Except for the special requirements of QW-380, each welding operator who welds under the rules of this Code shall have passed the mechanical tests prescribed in QW-302.1. Alternatively, welding operators making a groove weld using SMAW, SAW, GTAW, PAW, EGW, and GMAW (except short-circuiting mode) or a combination of these processes, may be qualified by radiographic examination, except for P-Nos. 2X, 5X, and 6X metals. Welding operators making groove welds in P-No. 2X and P-No. 5X metals with the GTAW process may also be qualified by radiographic examination. The radiographic examination shall be in accordance with QW-302.2.

A welding operator qualified to weld in accordance with one qualified WPS is also qualified to weld in accordance with other qualified WPSs within the limits of the essential variables of QW-360.

**QW-305.1 Examination.** Welds made in test coupons may be examined by radiography (QW-302.2) or by bend tests (QW-302.1). Alternatively, a 3 ft length of the first production weld made entirely by the welding operator in accordance with a qualified WPS may be examined by radiography.

**QW-305.2 Failure to Meet Radiographic Standards.** If a portion of a production weld is selected for welding operator performance qualification, and it does not meet the radiographic standards, the welding operator has failed the test. In this event, the entire production weld made by this welding operator shall be radiographed completely and repaired by a qualified welder or welding operator. Alternatively, retests may be made as permitted in QW-320.

## QW-306 Combination of Welding Processes

Each welder or welding operator shall be qualified within the limits given in QW-301 for the specific welding process(es) he will be required to use in production welding. A welder or welding operator may be qualified by making tests with each individual welding process in separate test coupons, or with a combination of welding processes in a single test coupon. Two or more welders or welding operators, each using the same or a different welding process, may be qualified in combination in a single test coupon. For combination qualifications in a single test coupon, the limits for thicknesses of deposited weld metal, and bend and fillet testing are given in QW-452 and shall be considered individually for each welder or welding operator for each welding process or whenever there is a change in an essential variable. A welder or welding operator qualified in combination on a single test coupon is qualified to weld in production using any of his processes individually or in different combinations, provided he welds within his limits of qualification with each specific process.

Failure of any portion of a combination test in a single test coupon constitutes failure of the entire combination.

*(b)* when there is a specific reason to question his ability to make welds that meet the specification, the qualifications which support the welding he is doing shall be revoked. All other qualifications not questioned remain in effect.

**QW-322.2 Renewal of Qualification**

*(a)* Renewal of qualification expired under QW-322.1(a) above may be made for any process by welding a single test coupon of either plate or pipe, of any material, thickness or diameter, in any position, and by testing of that coupon as required by QW-301 and QW-302. A successful test renews the welder or welding operator's previous qualifications for that process for those materials, thicknesses, diameters, positions, and other variables for which he was previously qualified.

*(b)* Welders and welding operators whose qualifications have been revoked under QW-322.1(b) above shall requalify. Qualification shall utilize a test coupon appropriate to the planned production work. The coupon shall be welded and tested as required by QW-301 and QW-302. Successful test restores the qualification.

## QW-350 WELDING VARIABLES FOR WELDERS

### QW-351 General

A welder shall be requalified whenever a change is made in one or more of the essential variables listed for each welding process.

Where a combination of welding processes is required to make a weldment, each welder shall be qualified for the particular welding process or processes he will be required to use in production welding. A welder may be qualified by making tests with each individual welding process, or with a combination of welding processes in a single test coupon.

The limits of deposited weld metal thickness for which he will be qualified are dependent upon the thickness of the weld he deposits with each welding process, exclusive of any weld reinforcement, this thickness shall be considered the test coupon thickness as given in QW-452.

In any given production weldment, welders may not deposit a thickness greater than that permitted by QW-452 for each welding process in which they are qualified.

**QW-352 OXYFUEL GAS WELDING (OFW)**
**Essential Variables**

| Paragraph | | Brief of Variables | |
|---|---|---|---|
| QW-402 Joints | .7 | + | Backing |
| QW-403 Base Metals | .2 | | Maximum qualified |
| | .18 | φ | P-Number |
| QW-404 Filler Metals | .14 | ± | Filler |
| | .28 | φ | F-Number |
| Filler Metals | .31 | φ | *t* Weld deposit |
| QW-405 Positions | .1 | + | Position |
| QW-408 Gas | .7 | φ | Type fuel gas |

**QW-353 SHIELDED METAL-ARC WELDING (SMAW)**
**Essential Variables**

| Paragraph | | Brief of Variables | |
|---|---|---|---|
| QW-402 Joints | .4 | − | Backing |
| QW-403 Base Metals | .16 | φ | Pipe Diameter |
| | .18 | φ | P-Number |
| QW-404 Filler Metals | .11 | | F-No. 4X limits |
| | .15 | φ | F-Number |
| | .30 | φ | *t* Weld deposit |
| QW-405 Positions | .1 | + | Position |
| | .3 | φ | ↑↓ Vertical welding |

**QW-354 SEMIAUTOMATIC SUBMERGED-ARC WELDING (SAW)**
**Essential Variables**

| Paragraph | | Brief of Variables | |
|---|---|---|---|
| QW-403 Base Metals | .16 | φ | Pipe diameter |
| | .18 | φ | P-Number |
| QW-404 Filler Metals | .30 | φ | *t* Weld deposit |
| QW-405 Positions | .1 | + | Position |

*(f)* The deletion of consumable inserts, except that qualification with consumable inserts shall also qualify for fillet welds and welds with backing.

*(g)* The deletion of backing. Double-welded groove welds are considered welding with backing.

*(h)* A change from single pass per side to multiple passes per side but not the reverse.

### QW-362 Electron Beam Welding (EBW) and Laser Beam Welding (LBW)

The performance qualification of operators shall duplicate the test samples, test specimens, and requirements for the WPS qualification test.

### QW-363 Stud Welding

Stud welding operators shall be performance qualified in accordance with the test requirements of QW-193 and the position requirements of QW-303.4.

### QW-364 Friction Welding

Performance qualification of friction welding operators shall duplicate the test samples, test specimens, and requirements for the WPS qualification test.

## QW-380 SPECIAL PROCESSES

### QW-381 Corrosion-Resistant Weld Metal Overlay

*(a)* The size of test coupons, limits of qualification, required examinations and tests, and test specimens shall be as specified in QW-453.

*(b)* Welders or welding operators who pass the tests for corrosion-resistant weld metal overlay cladding shall only be qualified to apply corrosion-resistant weld metal overlay portion of a groove weld joining composite clad or lined materials.

*(c)* The essential variables of QW-350 and QW-360 shall apply for welders and welding operators, respectively, except welders or welding operators shall be qualified for unlimited maximum deposited thickness and as otherwise specified in QW-453.

*(d)* A welder or welding operator who has qualified on composite welds in clad or lined material, as provided in QW-383(c) is also qualified to deposit corrosion-resistant weld metal overlay.

### QW-382 Hard-Facing Weld Metal Overlay (Wear Resistant)

*(a)* The size of the test coupons, limits of qualification, required examinations and tests, and test specimens shall be as specified in QW-453. Base material test coupons may be as permitted in QW-423.

*(b)* Welders and welding operators who pass the tests for hard-facing weld metal overlay are qualified for hard-facing overlay only.

*(c)* The essential variable, of QW-350 and QW-360, shall apply for welders and welding operators, respectively, except that there is no limit on the maximum thickness of hard-facing overlay that may be applied in production and as otherwise specified in QW-453.

*(d)* Qualification with one AWS classification within an SFA specification qualifies for all other AWS classifications in that SFA specification.

*(e)* A change in welding process shall require welder and welding operator requalification.

### QW-383 Clad Plate or Applied Lining

*(a)* A welder or welding operator who has qualified on composite welds in clad or lined material as provided in (c), below, is qualified for welding the base metal and lining or cladding material separately. A welder or welding operator who has qualified using separate test coupons for both the base material and lining or cladding materials is also qualified to make a composite weld. Qualification on both base material and lining or cladding material is required only of welders or welding operators who weld both materials.

*(b)* The qualification test coupon shall consist of a base material not less than 6 in. long, 3 in. wide, and $^1/_4$ in. thick, to which are clamped or bonded two strips of lining or cladding material separated by a gap left in the lining or a groove cut in the cladding as illustrated in QW-462.6(a); or the test coupon may be a base material not less than 6 in. long, 3 in. wide, and $^3/_8$ in. thick with a $^1/_8$ in. deep groove cut in the cladding as illustrated in QW-462.6(b).

The gap or groove shall run lengthwise of the test coupon approximately midway of the coupon width. The width of the gap shall not be less than twice the nominal thickness of the lining or cladding and not less than the maximum gap to be used in construction, but need not be greater than $^3/_4$ in. The essential variables of QW-350 for welders and QW-360 for welding operators shall apply separately to the base material and the lining or cladding. For material not included in QW-422, the material used in the test coupon shall be within the range of chemical composition of that to be used in construction. The test weld shall be made between the edges of the joint representing lining or cladding material by the technique prescribed in a qualified WPS. Postweld heat treatment may be omitted per QW-301.2. The mechanical test shall be performed on

# ANEXO C - CÓDIGO ASME SEÇÃO V

# ARTICLE 9
# VISUAL EXAMINATION

## T-910 SCOPE

This Article contains methods and requirements for visual examination applicable when specified by a referencing Code Section. The visual examination involved in interpretation of the various nondestructive examination methods is not intended to be included in this Article, since such visual examination is included with the Articles describing the particular nondestructive examination methods. Because there are many places in the Code where visual examination is required, including nondestructive examination, hydrostatic testing, fabrication procedures, leak testing, etc., there may be some duplication.

## T-920 GENERAL REQUIREMENTS

### A89 T-921 Basic Requirements and Terms Used

The requirements of Article 1, General Requirements, and Appendix A, Glossary of Terms in Nondestructive Examination, apply in addition to this Article.

### T-922 Written Procedure Requirements

**T-922.1** Visual examinations to this Article, when required by the referencing Code Sections, shall be done to a written procedure prepared by the Manufacturer and under the conditions described. The manufacturer shall make copies of the written procedure and a list of the examinations to be performed available to the Inspector.

**T-922.2** A written procedure, when required in accordance with T-150, shall include at least the following:

*(a)* how visual examination is to be performed;
*(b)* type of surface condition available;
*(c)* method or tool for surface preparation, if any;
*(d)* whether direct or remote viewing is used;
*(e)* special illumination, instruments, or equipment to be used, if any;
*(f)* sequence of performing examination, when applicable;
*(g)* data to be tabulated, if any;
*(h)* report forms or general statement to be completed.

**T-922.3** In some instances it is preferable to relate the procedure to a specific component or surface such as the internal examination of a weld many feet from the open end of a tube or tubes of several sizes, but procedures may be in a general form applicable without adaptation to a variety of unlisted products or situations, thereby reducing the number of written procedures required.

**T-922.4** The procedure shall contain or reference a report of what was used to demonstrate that the examination procedure was adequate. In general, a fine line $\frac{1}{32}$ in. or less in width, or some other artificial flaw located on the surface or a similar surface to that to be examined, may be considered a test method for this demonstration. The line or artificial flaw should be in the least discernible location on the area examined, to prove the procedure.

**T-922.5** Substituting one equipment manufacturer's equipment for another, or changes in the details of test arrangement, will not require requalification.

## T-940 APPLICATIONS

Visual examination is generally used to determine such things as the surface condition of the part, alignment of mating surfaces, shape, or evidence of leaking. In addition, visual examination is used to determine a composite material's (translucent laminate) subsurface conditions.

### T-941 Direct Visual Examination

Direct visual examination may usually be made when access is sufficient to place the eye within 24 in. of the surface to be examined and at an angle not less than 30 deg. to the surface to be examined. Mirrors may be used to improve the angle of vision, and aids such as a magnifying lens may be used to assist examinations. The specific part, component, vessel, or section thereof, under immediate examination, shall be illuminated, if necessary with flashlight or other auxiliary lighting, to attain a minimum of 15 fc for general examination and a minimum of 50 fc for the detection or study of small anomalies. Visual examination personnel shall have an annual visual examination to assure natural or corrected near distance acuity such that they are capable of reading standard J-1 letters on standard Jaeger test type charts for near vision or equivalent methods.

### T-942 Remote Visual Examination

In some cases, remote visual examination may have to be substituted for direct examination. Remote visual examination may use visual aids such as mirrors, telescopes, borescopes, fiber optics, cameras, or other suitable instruments. Such systems shall have a resolution capability at least equivalent to that obtainable by direct visual observation.

### T-943 Translucent Visual Examination

Translucent visual examination is a supplement of direct visual examination. The method of translucent visual examination uses the aid of artificial lighting which can be contained in an illuminator that produces directional lighting. The illuminator shall provide light of an intensity that will illuminate and diffuse the light evenly through the area or region under examination. The ambient lighting must be so arranged that there are no surface glares or reflections from the surface under examination and shall be less than the light applied through the area or region under examination. The artificial light source shall have sufficient intensity to permit "candling" any translucent laminate thickness variations. Classification of the visual imperfections shall be made as recommended in SD-2563, Article 28.

## T-950 EVALUATION

**T-950.1** All examinations shall be evaluated in terms of the acceptance standards of the referencing Code Section.

**T-950.2** An examination checklist shall be used to plan visual examination and to verify that the required visual observations were performed. This checklist establishes minimum examination and inspection requirements and does not indicate the maximum examination which the Manufacturer may perform in process.

## T-960 REPORTS

When required by the referencing Code Section, a written report shall be provided.

*(a)* The date of the test, examination procedure used, and results shall be certified by the Manufacturer. The illuminators, instruments, equipment, tools, etc., shall be identified in the report to the extent that they or their equivalents can be obtained for future examinations. This may be accomplished by referencing the visual examination procedure number.

*(b)* At the option of the Manufacturer, he may maintain one certification for each product, or several separate signed records based on the area or type of work, or both combined. Where impractical to use specialized visual examination personnel, knowledgeable production workmen may be used to perform the examination and to sign the report forms.

*(c)* Even though dimensions, etc., were recorded in the process of visual examination to aid in the evaluation, there need not be documentation of each viewing or each dimensional check. Documentation shall include all observation and dimensional checks specified by the referencing Code Section.

## T-970 RECORDS

Records shall be maintained as required by the referencing Code Section.

# ARTICLE 3



**Figures**



**Tables**

# ARTICLE 3
# RADIOGRAPHIC EXAMINATION OF METALLIC CASTINGS

## A89 T-310 SCOPE

When this Article is specified by a referencing Code Section, the radiographic method described in this Article for examination of metallic castings shall be used together with Article 1, General Requirements. Definitions of terms used in this Article may be found in Nonmandatory Appendix A, Standard Definition of Terms.

## T-320 GENERAL REQUIREMENTS

### T-321 Procedure Requirements

A89 **T-321.1 Compliance Without a Written Radiographic Procedure.** When Article 3 is required by the referencing Code Section, the density and penetrameter image requirements of this Article on production or technique radiographs shall be considered a satisfactory demonstration of compliance.

**T-321.2 Requirements and Compliance for a Written Radiographic Procedure.** When required by the referencing Code Section, a written procedure shall contain, as a minimum, the following technique variables:

*(a)* material and thickness range
*(b)* isotope used or maximum X-ray voltage
*(c)* minimum source-to-film distance
*(d)* maximum source size
*(e)* film brand and designation
*(f)* screens used

Demonstration of the density and penetrameter image requirements of the written procedure on production or technique radiographs shall be considered satisfactory evidence of compliance with that procedure.

### A89 T-322 Surface Preparation

Surfaces shall satisfy the requirements of the referencing Code Section, with additional conditioning if necessary, by any suitable process to a degree that surface irregularities do not interfere with interpretation.

### T-323 Backscatter Radiation A89 A91

A lead symbol "B", with minimum dimensions of $\frac{1}{2}$ in. in height and $\frac{1}{16}$ in. in thickness, shall be attached to the back of each film holder during each exposure to determine if backscatter radiation is exposing the film.

### T-324 System of Identification A89

A system shall be used to produce permanent identification on the radiograph traceable to the contract, component, or part numbers, as appropriate. In addition, each film of a casting being radiographed shall be plainly and permanently identified with the name or symbol of the Material Manufacturer, Certificate Holder or Subcontractor, job or heat number, date, and, if applicable, repairs (R1, R2, etc.) This identification system does not necessarily require that the information appear as radiographic images. In any case, this information shall not obscure the area of interest.

### T-325 Monitoring Density Limitations of Radiographs A89

Either a densitometer or step wedge comparison film shall be used for judging film density.

### T-326 Extent of Examination A89

The extent of radiographic examination shall be as specified by the referencing Code Section.

A89

TABLE T-333.1
HOLE TYPE IQI DESIGNATION, THICKNESS, AND HOLE DIAMETERS, in.

| IQI Designation | IQI Thickness | 1*T* Hole Diameter | 2*T* Hole Diameter | 4*T* Hole Diameter |
|---|---|---|---|---|
| 5 | 0.005 | 0.010 | 0.020 | 0.040 |
| 7 | 0.007 | 0.010 | 0.020 | 0.040 |
| 10 | 0.010 | 0.010 | 0.020 | 0.040 |
| 12 | 0.012 | 0.012 | 0.025 | 0.050 |
| 15 | 0.015 | 0.015 | 0.030 | 0.060 |
| 17 | 0.017 | 0.017 | 0.035 | 0.070 |
| 20 | 0.020 | 0.020 | 0.040 | 0.080 |
| 25 | 0.025 | 0.025 | 0.050 | 0.100 |
| 30 | 0.030 | 0.030 | 0.060 | 0.120 |
| 35 | 0.035 | 0.035 | 0.070 | 0.140 |
| 40 | 0.040 | 0.040 | 0.080 | 0.160 |
| 45 | 0.045 | 0.045 | 0.090 | 0.180 |
| 50 | 0.050 | 0.050 | 0.100 | 0.200 |
| 60 | 0.060 | 0.060 | 0.120 | 0.240 |
| 80 | 0.080 | 0.080 | 0.160 | 0.320 |
| 100 | 0.100 | 0.100 | 0.200 | 0.400 |
| 120 | 0.120 | 0.120 | 0.240 | 0.480 |
| 160 | 0.160 | 0.160 | 0.320 | 0.640 |
| 200 | 0.200 | 0.200 | 0.400 | . . . |

A8

TABLE T-333.2
WIRE IQI DESIGNATION AND WIRE DIAMETERS, in.

| ASTM Set | Wire Diameter |
|---|---|
| A | 0.0032, 0.004, 0.005, 0.0063, 0.008, 0.010 |
| B | 0.010, 0.013, 0.016, 0.020, 0.025, 0.032 |
| C | 0.032, 0.040, 0.050, 0.063, 0.080, 0.100 |
| D | 0.100, 0.126, 0.160, 0.200, 0.250, 0.320 |

## T-330 EQUIPMENT AND MATERIALS

### T-331 Film

A89 **T-331.1 Selection.** Radiographs shall be made using industrial radiographic film.

A89 A90 **T-331.2 Processing.** Standard Guide for Controlling the Quality of Industrial Radiographic Film Processing, SE-999, or Part III of Standard Guide for Radiographic Testing SE-94 shall be used as a guide for processing film.

### A89 T-332 Intensifying Screens

Except when restricted by the referencing Code Section, intensifying screens may be used.

### A89 T-333 Image Quality Indicator (IQI) Design

Penetrameters shall be either the hole type or the wire type and shall be manufactured and identified in accordance with the requirements or alternates allowed in SE-142 or SE-1025 (for hole type) and SE-747 (for wire type), and Appendices. ASME standard penetrameters shall consist of those in Table T-333.1 for hole type and those in Table T-333.2 for wire type.

### A89 T-334 Facilities for Viewing of Radiographs

Viewing facilities shall provide subdued background lighting of an intensity that will not cause troublesome reflections, shadows, or glare on the radiograph. Equipment used to view radiographs for interpretation shall provide a variable light source sufficient for the essential penetrameter hole or designated wire to be visible for the specified density range. The viewing conditions shall be such that light from around the outer edge of the radiograph or coming through low-density portions of the radiograph does not interfere with interpretation.

## T-360 CALIBRATION

### T-361 Source Size

**T-361.1 Verification of Source Size.** The equipment manufacturer's or supplier's publications, such as technical manuals, decay curves, or written statements documenting the actual or maximum source size or focal spot, shall be acceptable as source size verification.

**T-361.2 Determination of Source Size.** For X-ray machines operating at 320 kV or less, the focal spot size may be determined by the pinhole method.[1] For IR-192 sources, the focal spot size may be determined

[1] *Nondestructive Testing Handbook*, Volume I, First Edition, pp. 14.32–14.33, "Measuring Focal-Spot Size." Also, pp. 20–21 of *Radiography in Modern Industry*, Fourth Edition.

by ASTM E 1114-86, Standard Method for Determining the Focal Size of Iridium-192 Industrial Radiographic Sources.

### T-362 Step Wedge Film and Densitometer

The density of step wedge comparison films and densitometer calibration shall be verified by comparison with a calibrated step wedge film traceable to a national standard. The densitometer shall be calibrated in accordance with paragraph 5 of SE-1079, Calibration of Transmission Densitometers.

## T-370 EXAMINATION

### T-371 Radiographic Technique

A single-wall exposure technique shall be used for radiography whenever practical. When it is not practical to use a single-wall technique, a double-wall technique shall be used. An adequate number of exposures shall be made to demonstrate that the required coverage has been obtained.

**T-371.1 Single-Wall Technique.** In the single-wall technique the radiation passes through only one wall of the casting, which is viewed for acceptance on the radiograph.

**T-371.2 Double-Wall Technique.** When it is not practical to use a single-wall technique, one of the following double-wall techniques shall be used.

*(a) Single-Wall Viewing.* A technique may be used in which the radiation passes through two walls and only the casting on the film-side wall is viewed for acceptance on the radiograph.

*(b) Double-Wall Viewing.* For cylindrical castings 3½ in. or less in O.D. or when the shape of a casting precludes single-wall viewing, a technique may be used in which the radiation passes through two walls (images are superimposed) and the material in both walls is viewed for acceptance on the same radiograph. For double-wall viewing, only a source side penetrameter shall be used.

## T-372 Selection of Radiation Energy

**T-372.1 X-Radiation.** Except as provided in T-372.3, the maximum voltage used in the examination shall not exceed the value shown in Fig. T-372.1(a), (b), or (c), as applicable. For materials other than those shown in the figures, the requirements of T-372.3 shall apply.

A89 **T-372.2 Gamma Radiation.** Except as provided in T-372.3, the recommended minimum thickness for which radioactive isotopes may be used is as follows:

| Material | Minimum Thickness[1] Iridium 192 | Minimum Thickness[1] Cobalt 60 |
|---|---|---|
| Steel | 0.75 in. | 1.50 in. |
| Copper or High Nickel | 0.65 in. | 1.30 in. |
| Aluminum | 2.50 in. | . . . |

NOTE:
(1) Overall radiographic sensitivity is primarily influenced by factors such as:
*(a)* film selection
*(b)* intensifying screen selection
*(c)* geometric unsharpness
*(d)* film density

The maximum thickness for the use of radioactive isotopes is primarily dictated by exposure time, therefore, upper limits are not shown. The minimum recommended thickness limitation may be reduced when the radiographic techniques used demonstrate that the required radiographic sensitivity has been obtained.

**T-372.3 Special Conditions.** When special conditions do not make it practical to perform radiography within the limitations outlined in T-372.1 or T-372.2, the procedure shall be proven satisfactory by actual demonstration of penetrameter resolution on the minimum thickness of the casting radiographed.

## T-373 Direction of Radiation A89

The direction of the central beam of radiation should be centered on the area of interest whenever practical.

## T-374 Geometric Unsharpness

Geometric unsharpness of the radiograph shall be determined in accordance with:

$$Ug = Fd/D$$

where

$Ug$ = geometric unsharpness

$F$ = source size: the maximum projected dimension of the radiating source (or effective focal spot) in the plane perpendicular to the distance $D$ from the casting being radiographed, in.

$d$ = distance from source side of casting being radiographed to the film, in.

$D$ = distance from the source of radiation to casting being radiographed, in.

NOTE: Refer to Standard Guide for Radiographic Testing SE-94 for a method of determining geometric unsharpness. Alternatively, a nomograph as shown in Standard Guide for Radiographic Testing SE-94 may be used. A89 A90

## T-375 Location Markers

Location markers (see Fig. T-375), which are to appear as radiographic images on the film, shall be placed on the part, not on the exposure holder/cassette. Their locations shall be permanently marked on the surface of the part being radiographed when permitted, or on a map, in a manner permitting the area of interest on a radiograph to be accurately traceable to its location on the part, for the required retention period of the radiograph. Evidence shall also be provided on the radiograph that the required coverage of the region being examined has been obtained. Location markers shall be placed as follows.

**T-375.1 Single-Wall Viewing**

*(a) Source Side Markers.* Location markers shall be placed on the source side when radiographing the following:

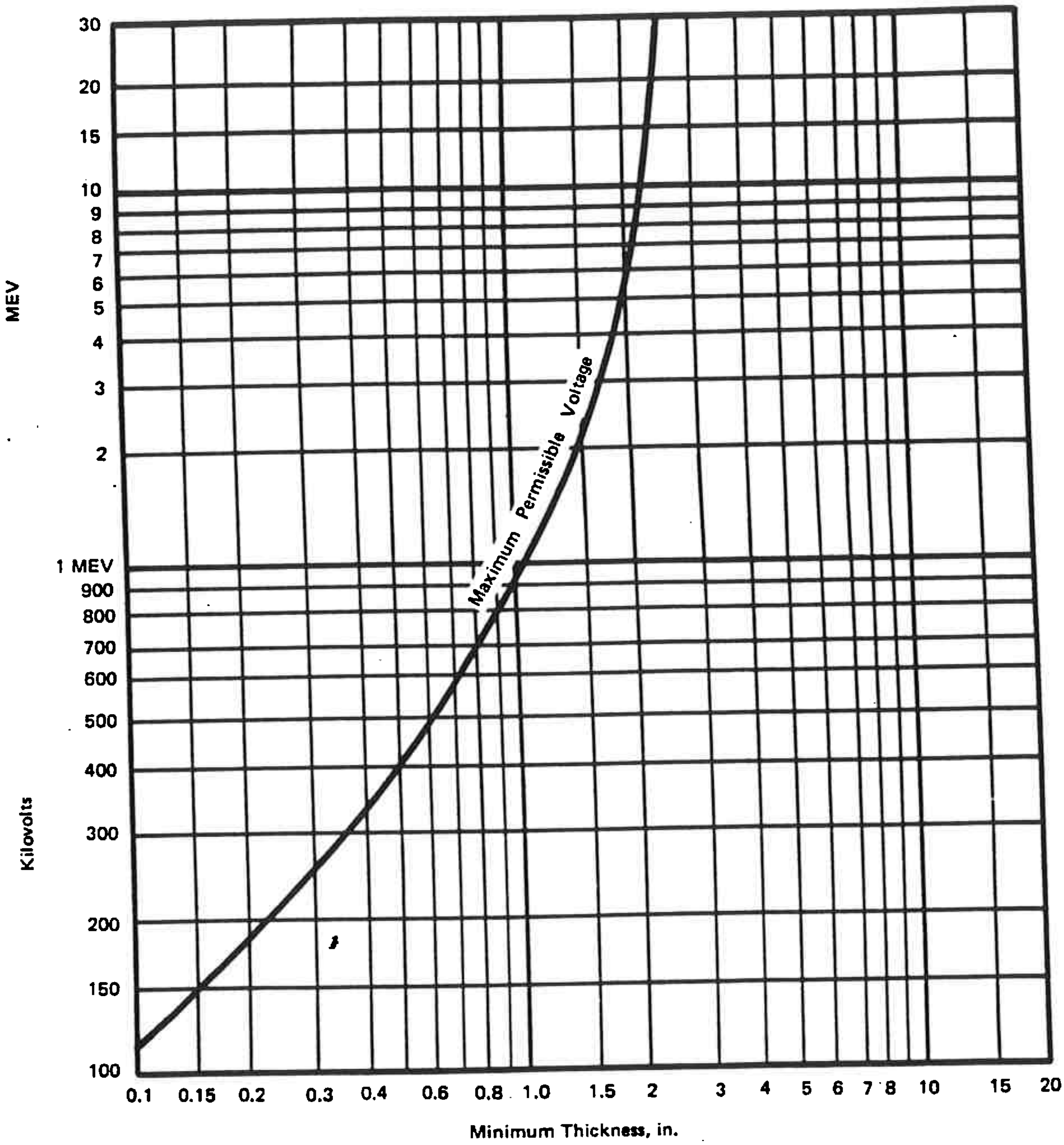



FIG. T-372.1(a) MAXIMUM VOLTAGE FOR STEEL

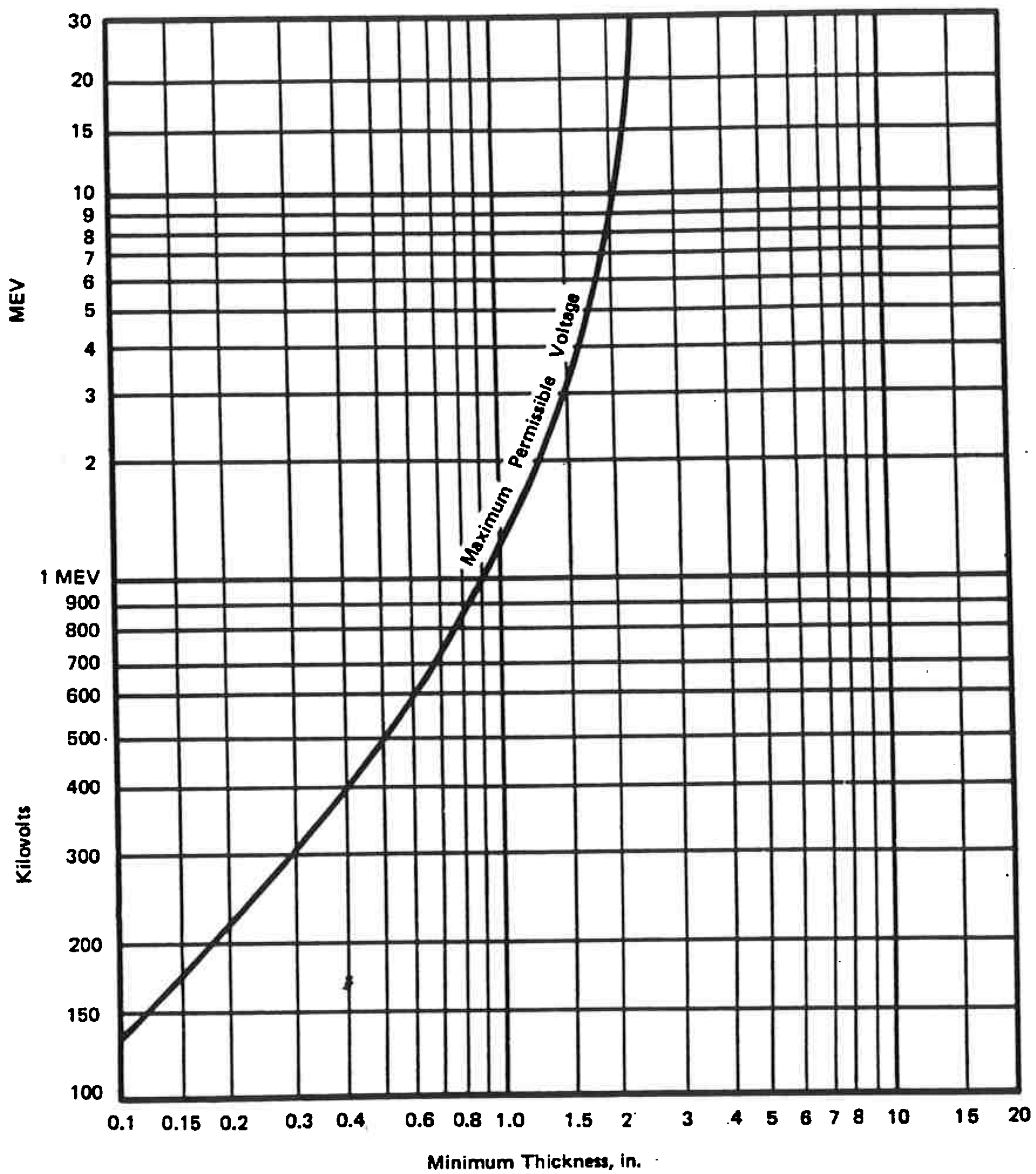



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FIG. T-372.1(b) MAXIMUM VOLTAGE FOR ALLOYS OF COPPER AND/OR HIGH NICKEL

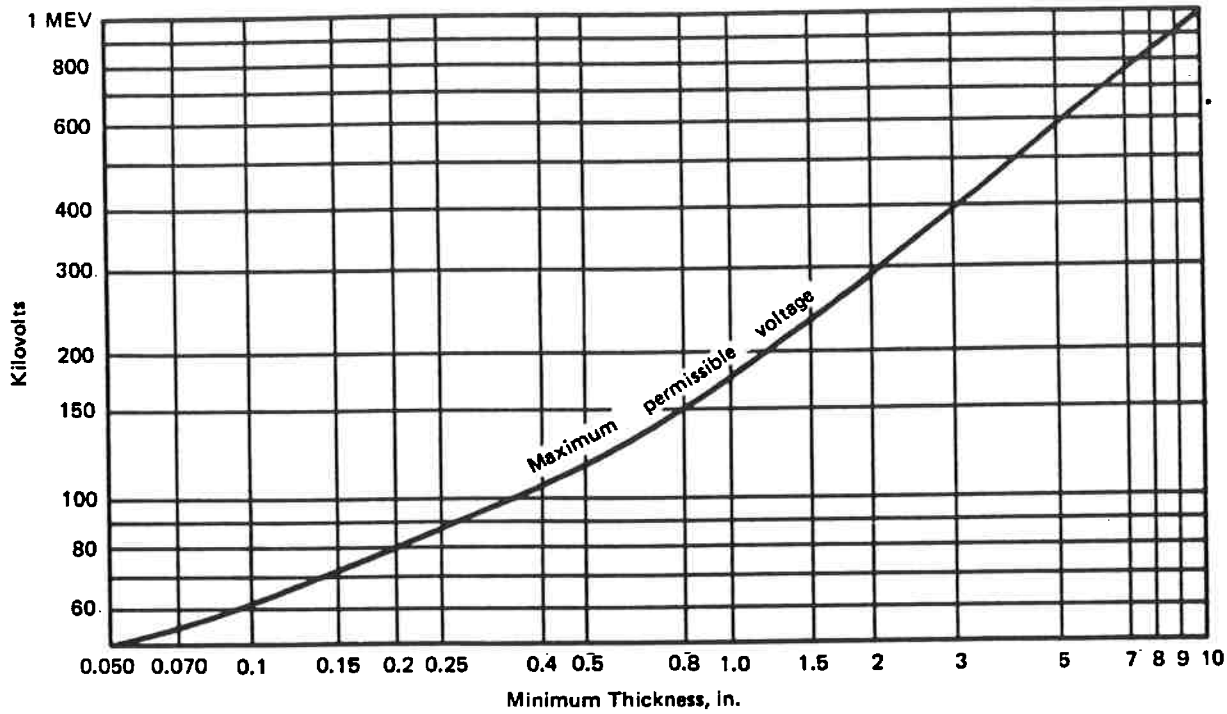



FIG. T-372.1(c) MAXIMUM VOLTAGE PERMITTED FOR ALUMINUM AND ALUMINUM ALLOYS

*(1)* flat or cylindrical castings;

*(2)* curved or spherical castings whose concave side is toward the source and when the source-to-material distance is less than the inside radius of the casting;

*(3)* curved or spherical castings whose convex side is toward the source.

*(b) Film Side Markers*

*(1)* Location markers shall be placed on the film side when radiographing either curved or spherical castings whose concave side is toward the source and when the source-to-material distance is greater than the inside radius.

A89 *(2)* As an alternative to source side placement in T-375.1(a)(1), location markers may be placed on the film side when the radiograph shows coverage beyond the location markers to the extent demonstrated by Fig. T-375, sketch (e), and when this alternate is documented in accordance with T-391.

*(c) Either Side Markers.* Location markers may be placed on either the source side or film side when radiographing either curved or spherical castings whose concave side is toward the source and the source-to-material distance equals the inside radius of the castings.

**T-375.2 Double-Wall Viewing.** For double-wall viewing, at least two location markers shall be placed on the source side surface of the castings for each radiograph.

**T-375.3 Mapping the Placement of Location Markers.** When inaccessibility or other limitations prevent the placement of markers as stipulated in T-375.1 and T-375.2, a dimensioned map of the actual marker placement shall accompany the radiographs to show that full coverage has been obtained. A8

## T-376 IQI Selection A8

The designated hole penetrameter with essential hole or designated wire diameter shall be as specified in Table T-376. A smaller hole in a thicker penetrameter or a larger hole in a thinner penetrameter may be substituted for any section thickness listed in Table T-376, provided equivalent penetrameter sensitivity (EPS) is maintained and all other requirements for radiography are met. Approximate equivalence between hole and wire penetrameters is shown in Table B-220 of Article 2, Nonmandatory Appendix B, and may be used to determine approximate equivalence between hole penetrameters. The thickness on which the penetrameter is based is the single-wall thickness.

**T-376.1 Casting Areas Prior to Finish Machining.** The penetrameter shall be based on a thickness which

A89

TABLE T-376
IQI SELECTION

| Single-Wall Material Thickness Range, in. | Penetrameter | | | | | |
|---|---|---|---|---|---|---|
| | Source Side | | | Film Side | | |
| | Hole Type Designation | Essential Hole | Wire Diameter, in. | Hole Type Designation | Essential Hole | Wire Diameter, in. |
| Up to 0.25, incl. | 12 | 2*T* | 0.008 | 10 | 2*T* | 0.006 |
| Over 0.25 through 0.375 | 15 | 2*T* | 0.010 | 12 | 2*T* | 0.008 |
| Over 0.375 through 0.50 | 17 | 2*T* | 0.013 | 15 | 2*T* | 0.010 |
| Over 0.50 through 0.75 | 20 | 2*T* | 0.016 | 17 | 2*T* | 0.013 |
| Over 0.75 through 1.00 | 25 | 2*T* | 0.020 | 20 | 2*T* | 0.016 |
| Over 1.00 through 1.50 | 30 | 2*T* | 0.025 | 25 | 2*T* | 0.020 |
| Over 1.50 through 2.00 | 35 | 2*T* | 0.032 | 30 | 2*T* | 0.025 |
| Over 2.00 through 2.50 | 40 | 2*T* | 0.040 | 35 | 2*T* | 0.032 |
| Over 2.50 through 4.00 | 50 | 2*T* | 0.050 | 40 | 2*T* | 0.040 |
| Over 4.00 through 6.00 | 60 | 2*T* | 0.063 | 50 | 2*T* | 0.050 |
| Over 6.00 through 8.00 | 80 | 2*T* | 0.100 | 60 | 2*T* | 0.063 |
| Over 8.00 through 10.00 | 100 | 2*T* | 0.126 | 80 | 2*T* | 0.100 |
| Over 10.00 through 12.00 | 120 | 2*T* | 0.160 | 100 | 2*T* | 0.126 |
| Over 12.00 through 16.00 | 160 | 2*T* | 0.250 | 120 | 2*T* | 0.160 |
| Over 16.00 through 20.00 | 200 | 2*T* | 0.320 | 160 | 2*T* | 0.250 |

does not exceed the finished thickness by more than 20% or ¼ in., whichever is greater. In no case shall a penetrameter size be based on a thickness greater than the thickness being radiographed.

**T-376.2 Casting Areas That Will Remain in the As-Cast Condition.** The penetrameter shall be based on the thickness being radiographed.

### T-377 Use of IQI (Penetrameters) to Monitor Radiographic Examination

**T-377.1 Placement of Penetrameters**

A89 A91 *(a) Source Side Penetrameter(s).* The penetrameter(s) shall be placed on the source side of the casting being examined, except for the condition described in T-377.1(b).

When it is not practical to place the penetrameter(s) on the casting, a separate block may be used. Separate blocks shall be made of the same or radiographically similar materials (as defined in SE-142) and may be used to facilitate penetrameter positioning. There is no restriction on the separate block thickness, provided the penetrameter/area-of-interest density tolerance requirements of T-382.2 are met.

*(1)* The penetrameter on the source side of the separate block shall be placed no closer to the film than the source side of the casting being radiographed.

*(2)* The separate block shall be placed as close as possible to the casting being radiographed.

*(3)* The block dimensions shall exceed the penetrameter dimensions such that the outline of at least three sides of the penetrameter image shall be visible on the radiograph.

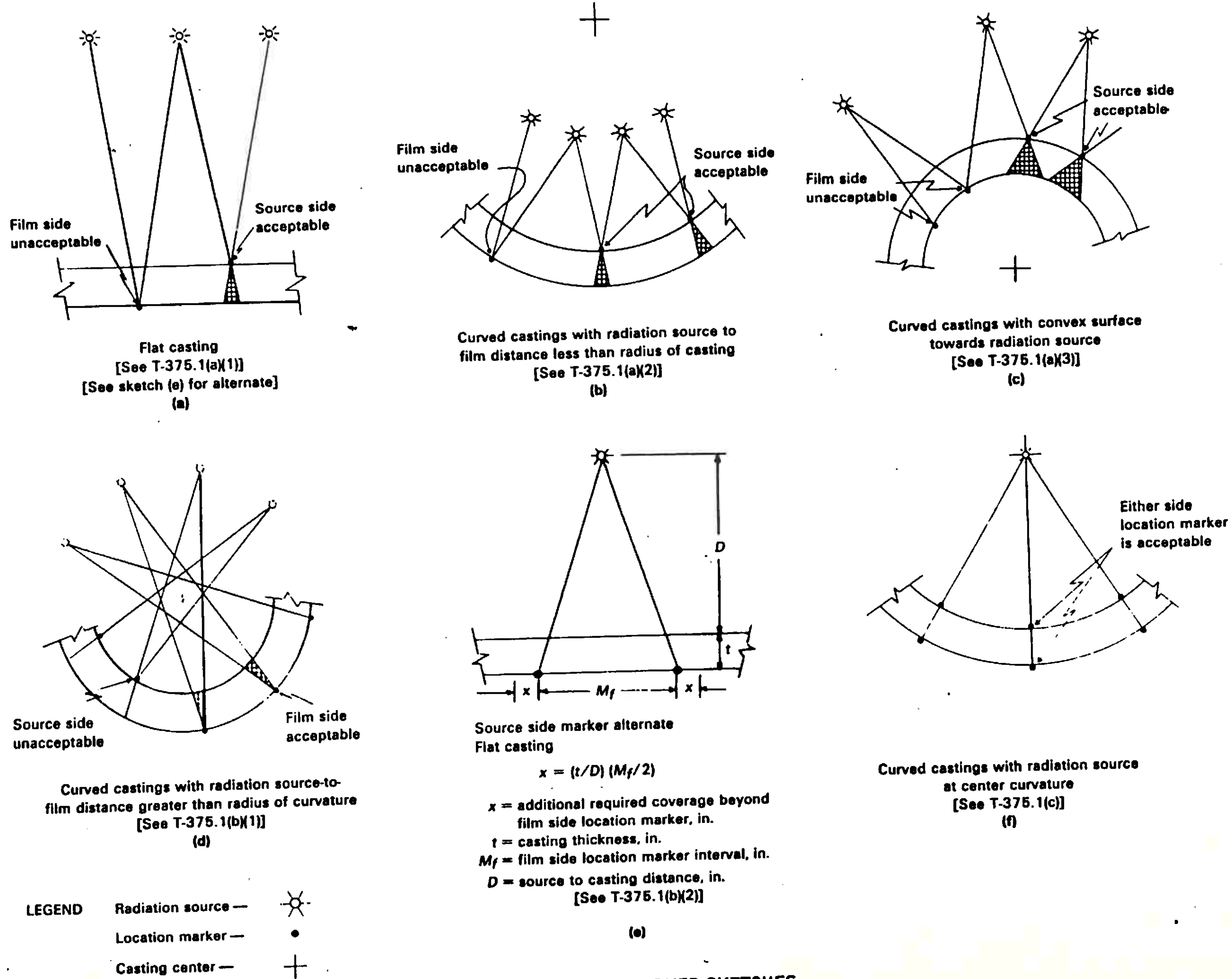
*(b) Film Side Penetrameter(s).* Where inaccessibility prevents hand placing the penetrameter(s) on the source side, the penetrameter(s) shall be placed on the film side in contact with the casting being examined. A lead letter "F", at least as high as the penetrameter identification number(s), shall be placed adjacent to or on the penetrameter(s), but shall not mask the essential hole where hole type penetrameters are used. A89 A91

**T-377.2 Number of Penetrameters.** For castings where one or more film holders are used for an exposure, at least one penetrameter image shall appear on each radiograph except as outlined in T-377.2(b). A89

*(a) Multiple Penetrameters.* If the requirements of T-382 are met by using more than one penetrameter, one shall be representative of the lightest area of interest and the other the darkest area of interest; the intervening densities on the radiograph shall be considered as having acceptable density. A89

*(b) Special Cases*

*(1)* For cylindrical castings where the source is placed on the axis of the object and one or more film holders are used for a single exposure of a complete circumference, at least three penetrameters shall be spaced approximately 120 deg. apart.




Flat casting
[See T-375.1(a)(1)]
[See sketch (e) for alternate]
(a)

Curved castings with radiation source to film distance less than radius of casting
[See T-375.1(a)(2)]
(b)

Curved castings with convex surface towards radiation source
[See T-375.1(a)(3)]
(c)

Curved castings with radiation source-to-film distance greater than radius of curvature
[See T-375.1(b)(1)]
(d)

Source side marker alternate
Flat casting

$x = (t/D)\,(M_f/2)$

$x$ = additional required coverage beyond film side location marker, in.
$t$ = casting thickness, in.
$M_f$ = film side location marker interval, in.
$D$ = source to casting distance, in.
[See T-375.1(b)(2)]

(e)

Curved castings with radiation source at center curvature
[See T-375.1(c)]
(f)

LEGEND
Radiation source —
Location marker —
Casting center —

FIG. T-375 LOCATION MARKER SKETCHES

A89 *(2)* For cylindrical castings where the source is placed on the axis of the object and four or more film holders are used for a single exposure of a section of the circumference, at least three penetrameters shall be used. One penetrameter shall be in the approximate center of the section exposed and one at each end. When the section of the circumference exposed exceeds 240 deg., the rules of T-377.2(b)(1) apply. Additional film locations may be required to obtain necessary penetrameter spacing; otherwise, at least one penetrameter image shall appear on each radiograph.

*(3)* For spherical castings, where the source is located at the center of the component and one or more film holders are used for a single exposure of a complete circumference, at least three penetrameters shall be spaced approximately 120 deg. apart.

A89 *(4)* For segments of spherical castings where the source is located at the center of the component and four or more film holders are used for an exposure of the circumference, at least three penetrameters shall be used. One penetrameter shall be in the approximate center of the portion exposed and one at each end. When the portion exposed exceeds 240 deg., the rules of T-377.2(b)(3) apply. Additional film locations may be required to obtain necessary penetrameter spacing; otherwise, at least one penetrameter image shall appear on each radiograph.

*(5)* When an array of objects in a circle is radiographed, at least one penetrameter shall show on each object image.

A89 *(6)* In order to maintain the continuity of records involving subsequent exposures, all radiographs exhibiting penetrameters which qualify the techniques permitted in accordance with T-377.2(b)(1), (2), (3), or (4) must be retained.

## T-380 EVALUATION

### T-381 Quality of Radiographs

All radiographs shall be free from mechanical, chemical, or other blemishes to the extent that they do not mask and are not confused with the image of any discontinuity in the area of interest of the object being radiographed. Such blemishes include, but are not limited to:

*(a)* fogging;

*(b)* processing defects such as streaks, watermarks, or chemical stains;

*(c)* scratches, finger marks, crimps, dirtiness, static marks, smudges, or tears;

*(d)* false indications due to defective screens.

### T-382 Radiographic Density

**T-382.1 Density Limitations.** The transmitted film density through the radiographic image of the body of the appropriate penetrameter and the area of interest shall be 1.5 minimum for single film viewing. For composite viewing of multiple film exposures, each film of the composite set shall have a minimum density of 1.0. The maximum density shall be 4.0 for either single or composite viewing. A tolerance of 0.05 in density is allowed for variations between densitometer readings. A89

**T-382.2 Density Variation.** If the density of the radiograph anywhere through the area of interest varies by more than minus 15% or plus 30% from the density through the body of the penetrameter, within the minimum/maximum allowable density ranges specified in T-382.1, then an additional penetrameter shall be used for each exceptional area or areas and the radiograph retaken. When calculating the allowable variation in density, the calculation may be rounded to the nearest 0.1 within the range specified in T-382.1. A89

### T-383 IQI Sensitivity A89

Radiography shall be performed with a technique of sufficient sensitivity to display the hole penetrameter image and the specified hole, or the designated wire of a wire penetrameter, which are essential indications of the image quality of the radiograph. The radiographs shall also display the identifying numbers and letters. If the required hole penetrameter image and specified hole, or designated wire, do not show on any film in a multiple film technique, but do show in composite film viewing, interpretation shall be permitted only by composite film viewing.

### T-384 Excessive Scatter A89

If a light image of the "B," as described in T-323, appears on the darker background of the radiograph, protection from backscatter is insufficient and the radiograph shall be considered unacceptable. A dark image of the "B" on a lighter background is not cause for rejection.

### T-385 Geometric Unsharpness Limitations

When required by the referencing Code Section, geometric unsharpness of the radiograph shall not exceed the following:

| Material Thickness, in. | $U_g$ Maximum, in. |
|---|---|
| Under 2 | 0.020 |
| 2 through 3 | 0.030 |
| Over 3 through 4 | 0.040 |
| Greater than 4 | 0.070 |

NOTE: Material thickness is the thickness on which the penetrameter is based.

## T-390 DOCUMENTATION

### T-391 Radiographic Examination Detail Information

To aid in proper interpretation of radiographs, the details of the radiographic examination used shall accompany each group of radiographs.

**T-391.1 Layout Details.**[2] To assure that all castings are radiographed consistently in the same manner, layout details shall be provided. As a minimum the layout details shall include:

*(a)* sketches of the casting, in as many views as necessary, to show the approximate position of each location marker;

*(b)* source angles if not perpendicular to film.

**T-391.2 Technique Details.**[2] As a minimum, technique details information shall include:

*(a)* identification, e.g., job or heat number
*(b)* data specified in T-375.3, when applicable
*(c)* number of exposures
*(d)* isotope or maximum X-ray voltage used
*(e)* effective focal-spot size
*(f)* material type and thickness range
*(g)* single- or double-wall exposure
*(h)* minimum source-to-film distances
*(i)* film brand and designation
*(j)* number of films per cassette
*(k)* single- or double-wall viewing

### T-392 Evaluation by Manufacturer

Prior to being presented to the Inspector for acceptance, the radiographs shall be examined and interpreted by the Manufacturer as complying with the referencing Code Section. The Manufacturer shall record the interpretation of each radiograph and disposition of the material examined on a radiographic interpretation review form accompanying the radiographs.

[2] Sample layout and technique details are illustrated in SE-1030, Appendix (Nonmandatory Information), X1, Radiographic Standard Shooting Sketch (RSS).

# ARTICLE 4



**Figures**



**Mandatory Appendices**



**Figure**



**Nonmandatory Appendices**

**Figures**

# ARTICLE 5

# ARTICLE 5
# ULTRASONIC EXAMINATION METHODS FOR MATERIALS AND FABRICATION

## T-510 SCOPE

This Article describes or references requirements which are to be used in selecting and developing [see T-110(c)] ultrasonic examination procedures for welds, parts, components, materials, and thickness determinations. This Article contains all of the basic technical and methodological requirements for ultrasonic examination. When examination to any part of this Article is a requirement of a referencing Code Section, the referencing Code Section shall be consulted for specific requirements for the following:

Personnel Qualification/Certification Requirements
Procedure Requirements and/or Techniques
Examination System Characteristics
Retention and Control of Calibration Blocks
Acceptance Standards to Be Used for Evaluation
Extent and Retention of Records
Report Requirements
Extent of Examination and/or Volume to be Scanned

## T-520 GENERAL REQUIREMENTS

### T-521 Basic Requirements and Terms Used

Article 1, General Requirements, and Appendix A, Glossary of Terms Used in Nondestructive Examination, apply when the use of this Article is required by a referencing Code Section. When SA, SB, and SE documents are referenced, they are located in Article 23.

### T-522 Written Procedure Requirements

Ultrasonic examination shall be performed in accordance with a written procedure. Each procedure shall include at least the following information, as applicable.

*(a)* weld and/or material types and configurations to be examined, including thickness dimensions, and product form (casting, forging, plate, etc.);
*(b)* the surface or surfaces from which the examination shall be performed;
*(c)* surface condition;
*(d)* couplant, brand name, or types;
*(e)* technique (straight beam, angled beam, contact, and/or immersion);
*(f)* angles and mode(s) of wave propagation in the material;
*(g)* search unit type, frequency(ies), and transducer size(s);
*(h)* special search units, wedges, shoes, or saddles;
*(i)* ultrasonic instrument type(s);
*(j)* description of calibration: blocks and techniques;
*(k)* directions and extent of scanning;
*(l)* data to be recorded and method of recording (manual or mechanized);
*(m)* automatic alarm and recording equipment, or both;
*(n)* rotating, revolving, or scanning mechanisms; and
*(o)* post-examination cleaning.

### T-523 General Examination Requirements for Other Than Thickness Measurements

**T-523.1 Examination Coverage.** The volume shall be examined by moving the search unit over the examination surface so as to scan the entire examination volume. Each pass of the search unit shall overlap a minimum of 10% of the transducer (piezo-electric element) dimension perpendicular to the direction of the scan.

**T-523.2 Rate of Search Unit Movements.** The rate of search unit movement for examination shall not exceed 6 in./sec unless calibration is verified at scanning speed.

**T-523.3 Recording Sensitivity Level.** For both manual and mechanized examinations recording of indications shall be made with respect to the reference level.

## T-530 EQUIPMENT AND SUPPLIES

### T-531 Frequency

This examination shall be conducted with a pulse-echo ultrasonic instrument capable of generating frequencies over the range of at least 1 MHz to 5 MHz. Instruments operating at other frequencies may be used if equal or better sensitivity can be demonstrated and documented.

### T-532 Screen Height Linearity

The ultrasonic instrument shall provide linear vertical presentation within ±5% of the full screen height for 20% to 80% of the calibrated screen height [base line to maximum calibrated screen point(s)]. The procedure for evaluating screen height linearity is provided in Appendix I and shall be performed at the beginning of each period of extended use (or every 3 months, whichever is less).

### T-533 Amplitude Control Linearity

The ultrasonic instrument shall utilize an amplitude control accurate over its useful range to ±20% of the nominal amplitude ratio, to allow measurement of indications beyond the linear range of the vertical display on the screen. The procedure for evaluating amplitude control linearity is given in Appendix II and shall be performed at the beginning of each period of extended use (or every 3 months, whichever is less).

### T-534 Checking and Calibration of Equipment

The proper functioning of the examination equipment shall be checked and the equipment shall be calibrated by the use of the calibration standard at the beginning and end of each examination, when examination personnel are changed, and at any time that malfunctioning is suspected, as a minimum.

If during any check it is determined that the testing equipment is not functioning properly, all of the product that has been tested since the last valid equipment calibration shall be reexamined.

### T-536 Search Units

*(a)* Search units may contain either single or dual transducer elements.

*(b)* Search units with contoured contact wedges may be used to aid ultrasonic coupling. Calibration shall be done with the contact wedges used during the examination.

## T-540 APPLICATIONS

### T-541 Material Product Forms

**T-541.1 Plate.** Procedures used for ultrasonic examination of plate shall conform to the following applicable standards in Article 23, supplemented by T-510 and T-520, as well as T-541.1.1, T-541.1.2, and T-541.1.3:

*(a)* SA-435/SA-435M Specification for Straight-Beam Ultrasonic Examination of Steel Plates

*(b)* SA-577/SA-577M Specification for Ultrasonic Angle-Beam Examination of Steel Plates

*(c)* SA-578/SA-578M Specification for Straight-Beam Ultrasonic Examination of Plain and Clad Steel Plates for Special Applications

*(d)* SB-509 Specification for Supplementary Requirements for Nickel Alloy Plate for Nuclear Applications

*(e)* SB-548 Specification for Standard Method for Ultrasonic Inspection of Aluminum-Alloy Plate for Pressure Vessels

**T-541.1.1 Equipment.** The requirements for equipment shall be in accordance with T-530.

**T-541.1.2 Calibration.** The calibration requirements shall be in accordance with the applicable standard listed in T-541.1, or as supplemented by the referencing Code Section.

**T-541.1.3 Examination.** The requirements for examination shall be in accordance with the applicable standard listed in T-541.1. Examinations for final acceptance shall be performed after the plate rolling to size and after heat treatment.

**T-541.2 Forgings and Bars.** Procedures used for ultrasonic examination of forgings and bars shall conform to the following applicable standards in Article 23, supplemented by T-510 and T-520, as well as T-541.2.1, T-541.2.2, and T-541.2.3:

*(a)* SA-388 Recommended Practice for Ultrasonic Testing and Inspection of Heavy Steel Forgings

*(b)* SA-745 Standard Recommended Practice for Ultrasonic Examination of Austenitic Steel Forgings

*(c)* SB-510 Specifications for Supplementary Requirements for Nickel Alloy Rod and Bar for Nuclear Applications

**T-541.2.1 Equipment.** The requirements for equipment shall be in accordance with T-530.

**T-541.2.2 Calibration.** The calibration requirements shall be in accordance with the applicable standard listed in T-541.2.

**T-541.2.3 Examination.** The requirements for examination shall be selected in accordance with the applicable standard listed in T-541.2, except as listed in (a) through (d) below.

*(a)* All forgings and bars shall be examined by the ultrasonic method, using the straight beam technique.

*(b)* Ring forgings and other hollow forgings shall, in addition, be examined using the angle beam technique in two circumferential directions, unless wall thickness or geometric configuration makes angle beam examinations impractical.

*(c)* In addition to (a) and (b) above, ring forgings made to fine grain melting practices and used for vessel shell sections shall also be examined by angle beam technique in two axial directions.

*(d)* Immersion techniques may be used.

**T-541.3 Tubular Products.** Procedures used for ultrasonic examination of pipe, tubing, and fittings shall conform to the following applicable standards in Article 23, supplemented by T-510 and T-520, as well as T-541.3.1, T-541.3.2, and T-541.3.3.

*(a)* SB-513 Specification for Supplementary Requirements for Nickel Alloy Seamless Pipe and Tube for Nuclear Applications

*(b)* SE-213 Standard Method for Ultrasonic Inspection of Metal Pipe and Tubing for Longitudinal Discontinuities

*(c)* SE-273 Standard Method for Ultrasonic Inspection of Longitudinal and Spiral Welds of Welded Pipe and Tube

**T-541.3.1 Equipment.** The requirements shall be in accordance with T-530.

**T-541.3.2 Calibration.** The calibration requirements shall be selected in accordance with the applicable standard listed in T-541.3, as well as (a) and (b) below.

*(a)* The calibration block shall be of the same nominal diameter and thickness and of the same nominal composition and heat treatment condition as the product that is being examined. The calibration reflectors shall be axial notches or grooves on the outside and the inside surfaces of the calibration block, and shall have a length of approximately 1 in. or less, a width not to exceed $\frac{1}{16}$ in., and a depth not greater than the larger of 0.004 in. or 5% of the nominal wall thickness. The calibration block may be the product being examined.

*(b)* The calibration block shall be long enough to simulate the handling of the product being examined through the examination equipment. When more than one calibration reflector is placed in a calibration block, the reflector shall be located so that indications from each reflector are separate and distinct, without mutual interference or amplification.

**T-541.3.3 Examination.** The requirements for examination shall be selected in accordance with the applicable standard listed in T-541.3.

**T-541.4 Castings.** When ultrasonic examination of ferritic castings is required by the referencing Code Section, all sections, regardless of thickness, shall be examined in accordance with SA-609, supplemented by T-510 and T-520, as well as T-541.4.1, T-541.4.2, and T-541.4.3.

**T-541.4.1 Equipment.** The requirements for equipment shall be in accordance with T-530, supplemented by (a) and (b) below.

*(a)* The transducer shall be 1 or 1 $\frac{1}{8}$ in. in diameter, or 1 sq in., maximum.

*(b)* 1 MHz search units shall be used for examination, although other frequencies may be used for evaluation if equal or better sensitivity can be demonstrated and documented.

**T-541.4.2 Calibration**

**T-541.4.2.1 Calibration Blocks.** The block or blocks required to establish the examination sensitivity across the full thickness of the castings to be examined shall be made of material of the same specification, grade, product form, heat treatment, and thickness ±25% as the castings to be examined. The surface finish of the calibration block shall be representative of the examination surface of the casting to be examined.

*(a) Straight Beam.* Calibration blocks meeting the requirements described in T-541.4.2.1 and in SA-609 shall be used.

*(b) Angle Beam.* The basic calibration block shall be as shown in Fig. T-541.4.1.2(b). Holes of larger or smaller diameters, V- or square notches may also be

placed in the calibration block to provide reference reflectors for evaluation purposes. These additional holes and notches shall be located so as not to interfere with the responses from the basic calibration reflectors.

**T-541.4.2.2 Calibration Method**

*(a) Straight Beam.* The examination sensitivity adjustment shall be established as described in SA-609, exclusive of paragraph 7.3, on the calibration block described in T-541.4.2.1(a).

*(b) Angle Beam.* The examination sensitivity shall be established at 80% of full screen height using the side-drilled hole producing the largest response. The distance amplitude correction (DAC) curve shall be constructed by utilizing the responses from the side drilled hole reflectors in the angle beam calibration block [Fig. T-541.4.1.2(b)] covering the examination distance range in the casting to be examined.

**T-541.4.3 Examination.** The requirements for examination shall be in accordance with SA-609, and supplemented by (a) and (b) below.

*(a)* A supplementary angle beam examination shall be performed on castings or areas of castings where a back reflection cannot be maintained during the straight beam examination, or where the angle between the front and back surfaces of the castings exceeds 15 deg.

*(b)* The requirements for extent of examination and acceptance criteria shall be as required by the referencing Code Section.

**T-541.5 Bolting Material.** Procedures used for ultrasonic examination of bolting material bolts, studs, and nuts shall conform to the requirements of SA-388 as modified by the following subparagraphs. Calibration blocks in accordance with Tables T-541.5.1 and T-541.5.2 shall be used for straight beam calibration. Tables T-541.5.1 and T-541.5.2 show relationships between examined material diameter $d$, length $\ell$, and calibration block diameter $D$, and length $L$. Flat bottom holes shall be as shown in Fig. T-541.5.1 drilled a minimum of $1\frac{1}{2}$ in. deep in the axial direction of the block.

Calibration block material and examination surface finish shall be the same or equivalent to the bolting under examination.

**T-541.5.1 Straight Beam, Radial Scan.** Bolting materials shall be examined radially prior to threading. The examination shall be in accordance with the following.

*(a) Technique.* The examination shall be performed using pulse-echo, straight beam equipment with the contact or immersion technique.

*(b) Calibration.* The sensitivity shall be established using the reflection indication from the side of the hole in calibration block A, at the radial metal paths of $D/4$ and $3D/4$. Select the hole indication at the metal path which gives the greatest amplitude and set the gain control so that this indication is 80% ± 5% of full screen height. Without changing the instrument controls, obtain maximum amplitudes from the other metal path. Mark the indication amplitudes on the cathode ray tube, connect the adjacent points and extend the DAC to cover the range of examination.

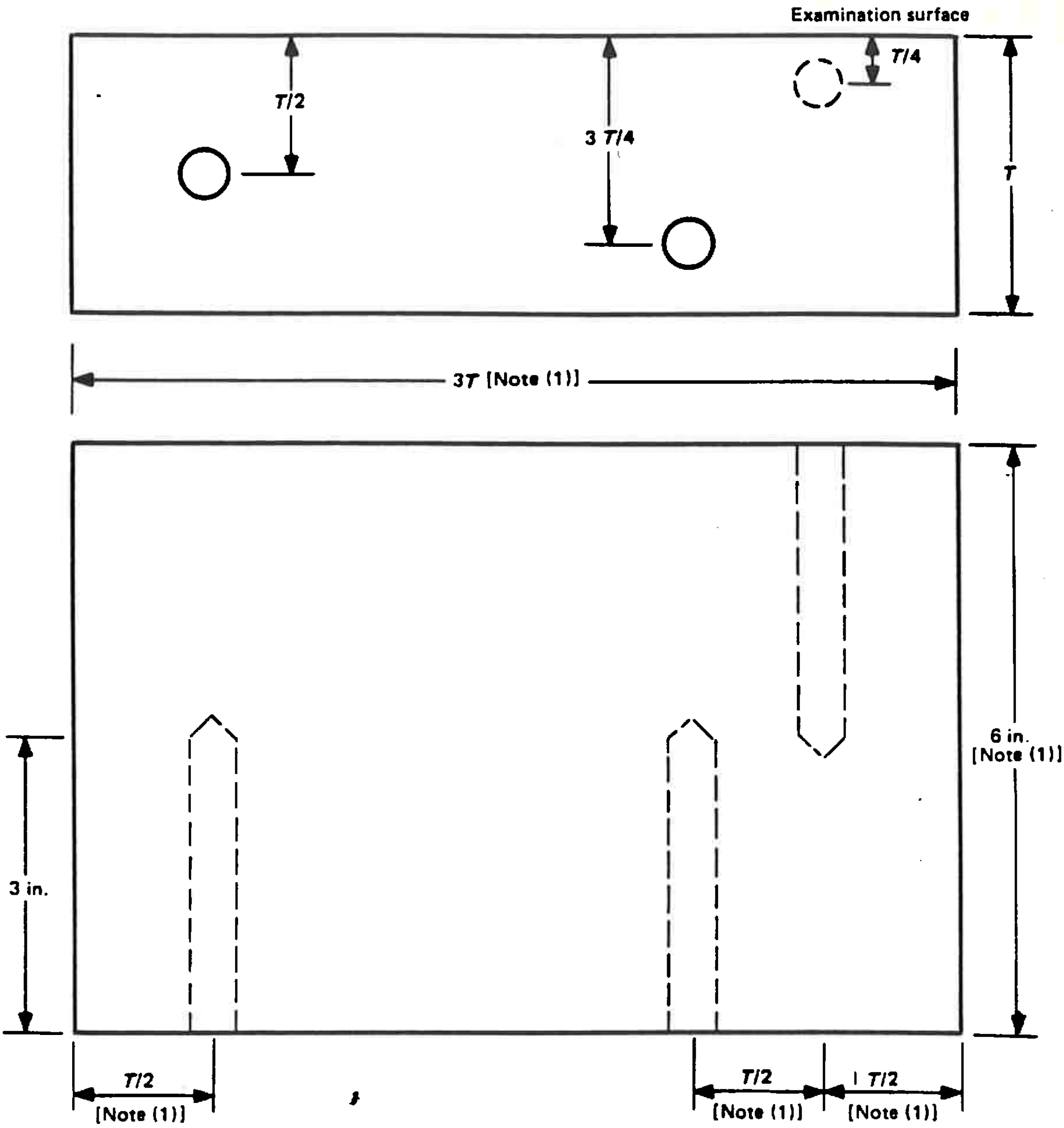
*(c) Examination.* Scanning shall be performed helically or circumferentially in overlapping paths so as to cover the entire accessible cylindrical surface of the bar.

*(d) Evaluation.* Any imperfection which causes an indication in excess of 20% of DAC shall be investigated to the extent that it can be evaluated in terms of the acceptance standards of the referencing Code Section.

**T-541.5.2 Straight Beam, Axial Scan.** Bolting materials shall be examined axially before or after threading. The examination shall be conducted in accordance with the following.

*(a) Technique.* The examination shall be performed from both end surfaces of the material using pulse-echo, straight beam equipment with the contact or immersion technique.

*(b) Calibration.* The sensitivity shall be adjusted to give an 80% of full screen amplitude from the flat bottom hole in the block which gives the highest amplitude. Mark this amplitude and the amplitude of the flat bottom hole in the lower amplitude block on the screen, and connect the two marks with a straight line extending to the entry surface indication. This is the DAC line. If the lower amplitude block gives less than 20% of full screen amplitude, prepare an $\ell/4$ + hole depth block and construct two DAC lines to cover the examination metal path range. This is accomplished by setting the sensitivity to give an 80% of full screen amplitude from the flat bottom hole in the $\ell/8$ or $\ell/4$ block which gives the higher amplitude. Mark this amplitude and the amplitude of the lower amplitude block on the screen and connect the two marks with a straight line extending to the entry surface indication. Record the sensitivity setting which will be used in the examination of the end quarters of length of the bolting material. Next set the sensitivity to give an 80% of full screen amplitude from the flat bottom hole in the $\ell/4$ or $\ell/2$ block which gives the higher amplitude. Mark this amplitude and the amplitude of the lower amplitude block on the screen and connect the two




GENERAL NOTE:

*Holes:* Drilled and reamed essentially parallel to the examination surface. The tolerance on hole diameter shall be ± 1/32 in. The tolerance on location through the thickness shall be ± 1/8 in.

| Material Thickness *T* | Diameter *D* | Holes Required |
|---|---|---|
| 1/2 in. through 2 in. | 1/4 in. | *T*/2 |
| Greater than 2 in. | 3/8 in. | *T*/4, *T*/2, and 3*T*/4 |

NOTE:

(1) Minimum.

FIG. T-541.4.1.2(b) ANGLE BEAM CALIBRATION BLOCK

### TABLE T-541.5.1
### FLAT BOTTOM HOLE REQUIREMENTS

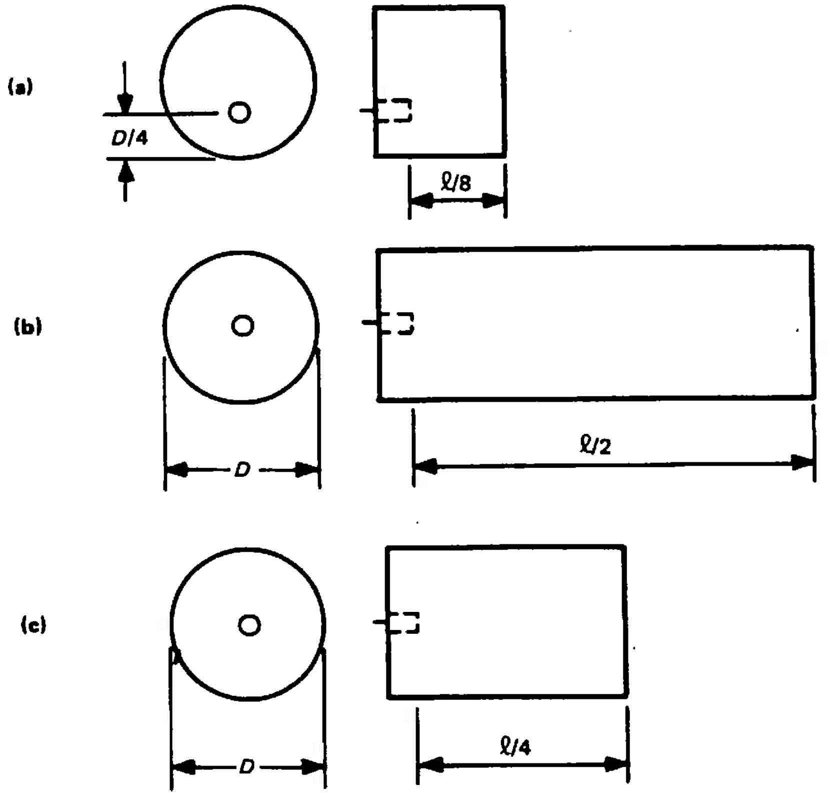
| $D = d \pm 1$ in. | Flat Bottom Hole Diam. $\pm 1/32$ in. |
|---|---|
| Up to 1 in. | 1/16 in. |
| Over 1 to 2 in. | 1/8 in. |
| Over 2 to 3 in. | 3/16 in. |
| Over 3 to 4 in. | 5/16 in. |
| Over 4 in. | 3/8 in. |

GENERAL NOTE:
Flat bottom hole machined to a minimum depth of 1/2 in. parallel to the transducer contact surface.

### TABLE T-541.5.2
### CALIBRATION BLOCK DESIGNATION PER LENGTH AND HOLE LOCATION

| Block Designation | Block Length $L$ | Flat Bottom Hole Location $L$ |
|---|---|---|
| A | $\ell/8$ + hole depth | $D/4$ of block end |
| B | $\ell/2$ + hole depth | Center line of block end |
| C | $\ell/4$ + hole depth | Center line of block end |

GENERAL NOTE: A tolerance of ±5% may be applied.




$D$ = calibration block diameter
$d$ = examination material diameter
$L$ = calibration block length
$\ell$ = examination material length

FIG. T-541.5.1 STRAIGHT BEAM (FBH) CALIBRATION BLOCK marks with a straight line. Record the sensitivity setting which will be used in the examination of the two middle quarters of length of the bolting material.

*(c) Examination.* Surface preparation — both end surfaces of the bolting material shall be flat and normal to the bolt axis. Record all indications exceeding 20% DAC in the quarter of length applicable to the sensitivity setting.

*(d) Evaluation.* Any reflector which causes an indication in excess of 20% of DAC shall be investigated to the extent that it can be evaluated in terms of the acceptance standards of the referencing Code Section.

**T-541.5.3 Inservice Examination of Bolts and Studs**

**T-541.5.3.1** When inservice examination of bolts and studs is specified by the referencing Code Section, the examination shall be performed in accordance with T-541.5.2 or T-541.5.3.2.

**T-541.5.3.2 Straight Beam, Axial Scan.** When bolts and studs of sizes specified by the referencing Code Section are to be ultrasonically examined axially over an entire end surface before or after threading, the examination may be performed in accordance with the following.

*(a) Technique.* Examination shall be performed at a nominal frequency of 2.25 MHz with a circular transducer element not less than ½ in. diameter and not greater than 1⅛ in. diameter.

*(b) Calibration.* Calibration shall be established on a test bar of the same nominal composition and diameter as the production part and a minimum of one-half of the length. A ⅜ in. diameter × 3 in. deep flat bottom hole shall be drilled in one end of the bar and plugged with similar material to full depth. A distance amplitude curve shall be established by scanning from both ends of the test bar.

*(c) Evaluation of Indications.* Any discontinuity which causes an indication in excess of that produced by the calibration hole in the reference specimen as corrected by the distance amplitude curve shall be investigated to the extent that the operator can evaluate the shape, identity, and location of all such reflectors in terms of acceptance–rejection standards of the referencing Code Section.

## T-542 Welds

These paragraphs describe the requirements for ultrasonic examination of full penetration welds in wrought (rolled, drawn, forged, or extruded) and cast materials.

These requirements are established for the ultrasonic detection, location, and evaluation of ultrasonic reflectors within the weld, heat affected zone, and adjacent material. The two general examination classifications are:

*(a)* welds in ferritic product forms other than pipe;

*(b)* ferritic welds in ferritic pipe.

For austenitic and high nickel alloy welds, see T-542.8.5.

**T-542.1 Equipment.** The requirements for equipment shall be in accordance with T-530.

**T-542.2 Calibration**

**T-542.2.1 Basic Calibration Block(s).** The basic calibration reflectors shall be used to establish a primary reference response of the equipment. The basic calibration reflectors may be located either in the component material or in a basic calibration block. Where the block thickness ±1 in. spans two of the weld thickness ranges shown in Fig. T-542.2.1, the block's use shall be acceptable in those portions of each thickness range covered by 1 in.

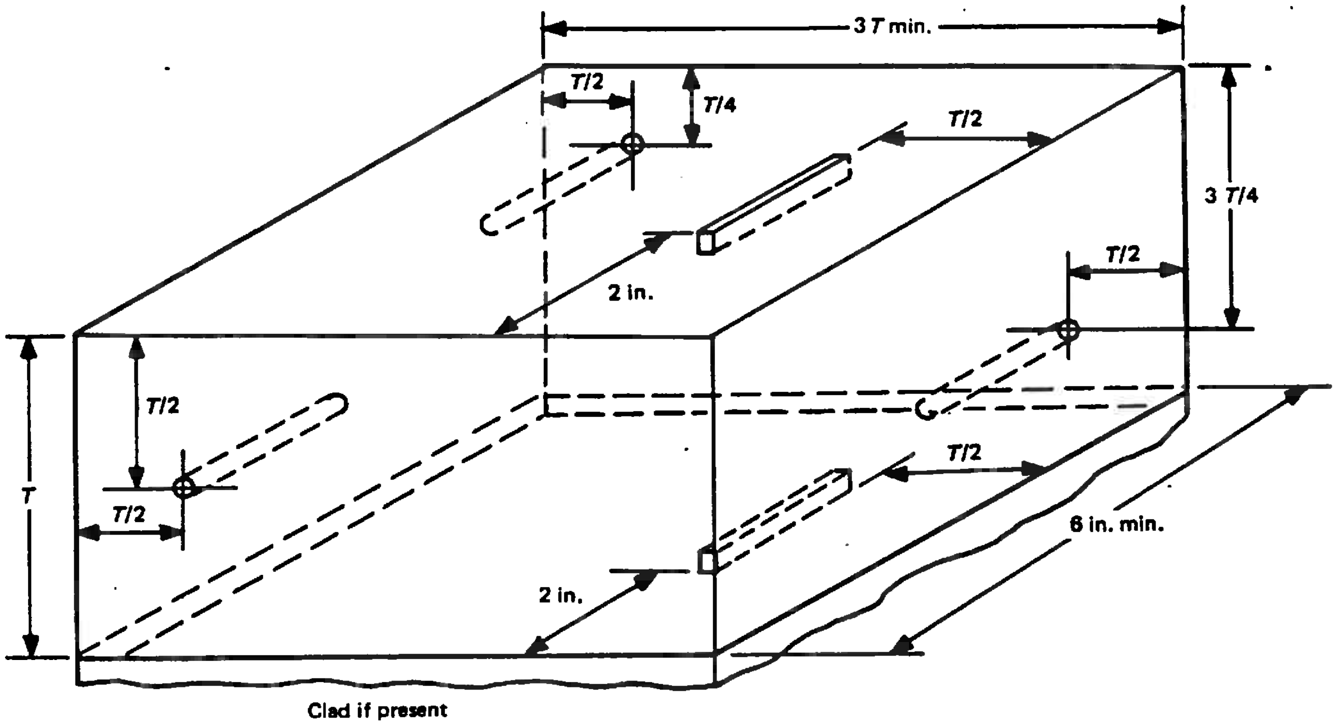
**T-542.2.1.1 Basic Calibration Block Material**

*(a) Block Selection.* The material from which the block is fabricated shall be of the same product form, and material specification or equivalent P-Number grouping as one of the materials being examined. For the purposes of this paragraph, P-Nos. 1, 3, 4, and 5 materials are considered equivalent. For calibration blocks for dissimilar metal welds, the material selection shall be based on the material on the side of the weld from which the examination will be conducted: if the examination will be conducted from both sides, calibration reflectors shall be provided in both materials. Where two or more base material thicknesses are involved, the calibration block thickness shall be determined by the average thickness of the weld.

*(b) Clad.* Where the component material is clad, the block shall be clad by the same welding procedure as the production part. Where the automatic method is impractical, deposition of clad shall be by the manual method. It is desirable to have component materials which have been clad before the drop outs or prolongations are removed.

*(c) Heat Treatment.* The calibration block shall receive at least the minimum tempering treatment required by the material specification for the type and grade, and also a postweld heat treatment of at least 2 hr, if the calibration block contains weld(s) other than cladding.

*(d) Surface Finish.* The finish on the surfaces of the




| Weld Thickness $t$ | Basic Calibration Block Thickness $T$ | Hole Diameter | Notch Size |
|---|---|---|---|
| 1 in. or less | 3/4 in. or $t$ | 3/32 in. | Width = 1/8 in. to 1/4 in. |
| Over 1 in. through 2 in. | 1-1/2 in. or $t$ | 1/8 in. | |
| Over 2 in. through 4 in. | 3 in. or $t$ | 3/16 in. | Depth = 2% $T$ or 0.04 in., whichever is greater, into the base metal. |
| Over 4 in. through 6 in. | 5 in. or $t$ | 1/4 in. | |
| Over 6 in. through 8 in. | 7 in. or $t$ | 5/16 in. | |
| Over 8 in. through 10 in. | 9 in. or $t$ | 3/8 in. | |
| Over 10 in. | $t \pm 1$ in. | [Note (1)] | Length = 2 in. min. |

GENERAL NOTES:
(a) Holes shall be drilled and reamed a minimum of 1-1/2 in. deep, essentially parallel to the examination surface.
(b) Alternatively, the block may be constructed as shown in Fig. T-441.1.
(c) Curved surfaces: for curved surfaces, two curved blocks, one for each representative curvature: or two sets of calibration reflectors oriented 90 deg. from each other shall be used.
(d) Notches may be provided as required.
(e) The tolerance for hole diameter shall be ±1/32 in. The tolerance on notch depth shall be +10 and −20%. The tolerance on hole location through the thickness shall be ±1/8 in.

NOTE:
(1) For each increase in weld thickness of 2 in. or fraction thereof over 10 in., the hole diameter shall increase 1/16 in.

A90

FIG. T-542.2.1 BASIC CALIBRATION BLOCK

block shall be representative of the surface finishes on the components.

*(e) Block Quality.* The calibration block material shall be completely examined with a straight beam search unit. Areas that contain an indication exceeding the remaining back reflection shall be excluded from the beam paths required to reach the various calibration reflectors.

**T-542.3 Calibration Reflectors**

**T-542.3.1 Basic Calibration Reflectors.** The calibration reflectors are specified in T-542.2.1 and T-542.8.1.2.

**T-542.3.2 Additional Reflectors.** Additional reflectors may be installed; these reflectors shall not interfere with establishing the primary reference.

**T-542.3.3 Calibration Block Configuration.** Calibration block configuration requirements are specified in T-542.2.1 and T-542.8.1.1.

**T-542.3.4 Materials With Diameters Greater Than 20 in.** For examinations in materials where the examination surface diameter is greater than 20 in., a block of essentially the same curvature, or alternatively, a flat basic calibration block, shall be used.

**T-542.3.5 Materials With Diameters 20 in. and Less.** The basic calibration block shall be curved for materials with diameters 20 in. and less. Except where otherwise stated in this Article, a single curved basic calibration block may be used to calibrate the examination on surfaces in the range of curvature from 0.9 to 1.5 times the basic calibration block diameter. For example, an 8 in. diameter curved block may be used to calibrate the examination on surfaces in the range of curvature from 7.2 in. to 12 in. diameter. The curvature range from 0.94 in. to 20 in. diameter requires 6 block curvatures as indicated in Fig. T-542.3.5 for any thickness range.

**T-542.3.6** As an alternative to the requirements in T-542.3.4 when examining from the convex surface by the straight beam contact technique, Appendix A may be used.

**T-542.4 System Calibration**

**T-542.4.1 General Requirements.** Calibration shall include the complete ultrasonic examination system and shall be performed in accordance with T-432.1.

**T-542.4.2 Calibration Measurements.** Each calibration shall be performed from the surface (clad or unclad) corresponding to the surface of the component from which the examination will be performed.

**T-542.4.3 Techniques.** Article 4, Appendices B and C, gives general techniques for both angle beam and straight beam calibrations. Other techniques may be used.

**T-542.4.4 Angle Beam Calibration.** As applicable, the calibration shall provide the following measurements (Article 4, Appendix B contains a general technique):

*(a)* sweep range calibration;

*(b)* distance–amplitude correction;

*(c)* position calibration;

*(d)* echo amplitude measurement from the surface notch in the basic calibration block.

When an electronic distance–amplitude correction device is used, the primary reference responses from the basic calibration block shall be equalized over the distance range to be employed in the examination. The response equalization line shall be at a screen height of 40% to 80% of full screen height.

**T-542.4.5 Straight Beam Calibration.** The calibration shall provide the following measurements (Article 4, Appendix C gives a general technique):

*(a)* sweep range calibration;

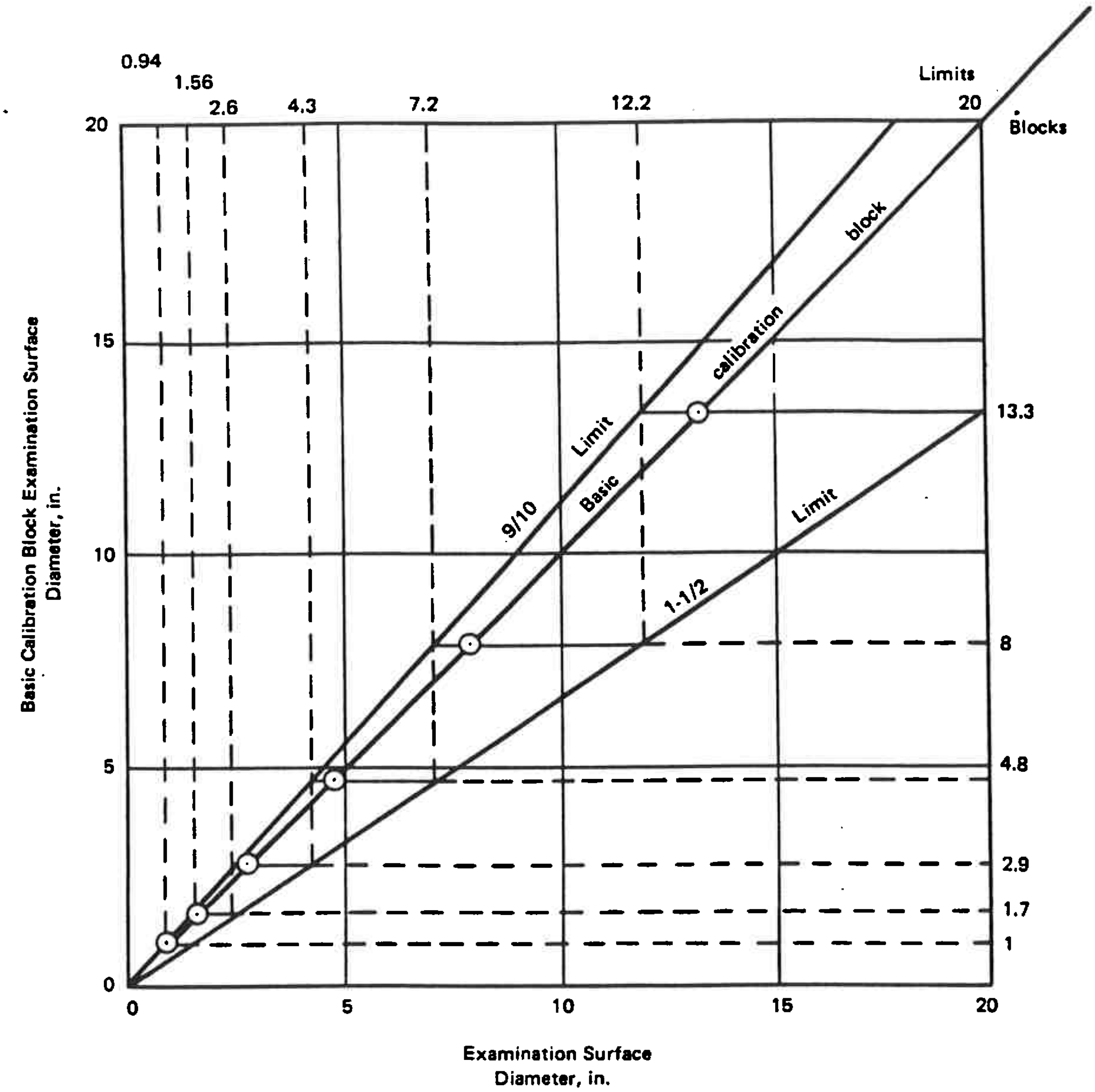
*(b)* distance–amplitude correction.

When an electronic distance–amplitude correction device is used, the primary reference response shall be equalized on the basic calibration block at a screen height between 40% and 80% of full screen height over the distance range to be employed in the examination.

**T-542.4.6 Calibration Check on Basic Calibration** A89
**Block.** When any part of the examination system is changed, a calibration check shall be made on the basic calibration block to verify that $\frac{1}{4}T$, $\frac{1}{2}T$, and $\frac{3}{4}T$ points on the sweep and distance amplitude correction values recorded satisfy the requirements of T-542.5. Where original calibration data exist for the part of the system replaced, a check as permitted in T-542.4 may be used.

**T-542.4.7 Calibration Check on Basic Calibration Block or Simulator Check.** A calibration check on at least one of the basic reflectors in the basic calibration block or a check using a simulator shall be made at the finish of each examination or series of similar examinations, every 4 hr during the examination, and when examination personnel (except for automated equipment) are changed. The sweep and distance amplitude correction values recorded shall satisfy the requirements of T-545.

**T-542.4.8 Simulator Check.** Any simulator checks that are used shall be correlated with the original cal-




GENERAL NOTES:

(a) Plot examination surface of basic calibration block on diagonal (45 deg.) line.

(b) Draw horizontal line through that point from the 9/10 to the 1-1/2 limit line.

(c) The ends of this line read on the horizontal scale give the range of examination surface diameters which may be examined with a system calibrated on this block.

(d) Thickness range requirements shall also be satisfied.

FIG. T-542.3.5 RATIO LIMITS FOR CURVED SURFACES

ibration on the basic calibration block during the original calibration. The simulator checks may use different types of calibration reflector or block (such as IIW) and/or electronic simulation. However, the simulation used shall be completely identifiable on the calibration sheet(s). The simulator check shall be made on the entire examination system. The entire system does not have to be checked in one operation; however, for its check, the search unit shall be connected to the ultrasonic instrument and checked against a calibration reflector. Accuracy of the simulator checks shall be confirmed, using the basic calibration block, at the conclusion of each period of extended use, or every 3 months, whichever is less. The requirements for calibration confirmation of T-542.5 and T-542.5.1 shall be met.

**T-542.5 Calibration Confirmation.** Calibration (T-542.4.3) shall be performed prior to use of the system in the thickness range under examination. A calibration check shall verify the sweep range calibration and distance–amplitude correction [T-542.4.4(a) or T-542.4.5(a)] as defined in T-542.4.1.

**T-542.5.1 Sweep Range Correction.** If a point on the DAC curve has moved on the sweep line more than 10% of the sweep reading or 5% of full sweep, whichever is greater, correct the sweep range calibration and note the correction in the examination record. If reflectors are recorded on the data sheets, those data sheets shall be voided and a new calibration shall be recorded. All recorded indications since the last valid calibration or calibration check shall be reexamined with the corrected calibration and their values shall be changed on the data sheets.

**T-542.5.2 DAC Correction.** If a point on the distance–amplitude correction (DAC) curve has decreased 20% or 2 dB of its amplitude, all data sheets since the last calibration or calibration check shall be marked void. A new calibration shall be made and recorded and the area covered by the voided data shall be reexamined. If any point of the distance–amplitude correction (DAC) curve has increased more than 20% or 2 dB of its amplitude, all recorded indications since the last valid calibration or calibration check shall be reexamined with the corrected calibration and their values shall be changed on the data sheets.

**T-542.6 Welds in Wrought and Cast Ferritic Product Forms, Excluding Pipe**

**T-542.6.1 Basic Calibration**

**T-542.6.1.1 Basic Calibration Block.** The basic calibration block shall be as specified in T-542.2.1, and shall use side-drilled holes as calibration reflectors. See Fig. T-542.2.1.

**T-542.6.1.2 Angle Beam Calibration.** Angle beam calibrations shall be performed as described in Article 4, Appendix B, supplemented as follows:

**T-542.6.1.3 Frequency.** The nominal frequency shall be 2.25 MHz unless variables such as production material grain structure require the use of other frequencies to assure adequate penetration or better resolution.

**T-542.6.1.4 Beam Angle.** An angle shall be selected as appropriate for the configuration being examined.

**T-542.6.1.5 Distance–Amplitude Correction (DAC) Exemption.** A DAC is not required where the examination is limited to one-half V-path in a material less than 1 in. thick, in which case the amplitude level from a single calibration reflector shall be used.

**T-542.6.1.6 Straight Beam Calibration.** Calibration and straight beam examination shall be performed in accordance with Article 4, Appendix C, supplemented as follows.

**T-542.6.1.7 Frequency.** The nominal frequency shall be 2.25 MHz unless variables such as production material grain structure require the use of other frequencies to assure adequate penetration or better resolution.

**T-542.7 Examination of Welds**

**T-542.7.1 Surface Preparation**

**T-542.7.1.1 Base Metal.** The base metal on each side of the weld shall be free of weld spatter, surface irregularities, or foreign matter that might interfere with the examination.

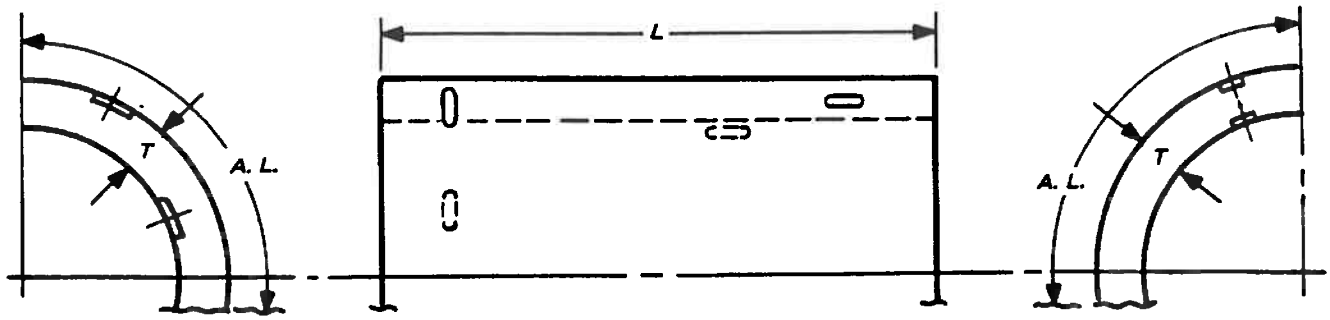
**T-542.7.1.2 Weld Metal.** Where the weld surface interferes with the examination, the weld shall be prepared as needed to permit examination.

**T-542.7.2 Scanning**

**T-542.7.2.1 Straight Beam.** The scanning of the adjacent base metal shall be performed to detect reflectors that might affect interpretation of angle beam results, and is not to be used as an acceptance-rejection examination. Locations and areas of such reflectors shall be recorded.

**T-542.7.2.2** The weld and base metal shall be scanned, where required by the referencing Code Section to the extent possible with the straight beam search unit. The scanning shall be performed at a gain setting of at least two times the primary reference level. Evaluation shall be performed with respect to the primary reference level.

**T-542.7.2.3 Angle Beam Scanning for Reflectors Oriented Parallel to the Weld.** The angle beam shall be directed at approximate right angles to the weld axis from two directions where possible. The search unit shall be manipulated so that the ultrasonic energy passes through the required volumes of weld and adjacent base metal. The scanning shall be performed at a gain setting at least two times the primary reference level. Evaluation shall be performed with respect to the primary reference level.




**Typical Block Dimensions**

Length $L$ 8 in. or $8T$, whichever is greater

Minimum Arc Length $A.L.$
(1) for O.D. 4 in. or less: 270 deg.
(2) for O.D. greater than 4 in.: the greater of $3T$ or 8 in.

**Specific Notch Dimensions**

Length $L$ — 1 in. minimum

Depth $D$ — 10% $T$ with tolerance $D \begin{matrix} +10\% \\ -20\% \end{matrix}$ of depth

Width — 1/8 in. to 1/4 in.
Location — not closer than $T$ from any block edge

FIG. T-542.8.1.1 ANGLE BEAM CALIBRATION (PIPE WELDS)

**T-542.7.2.4 Angle Beam Scanning for Reflectors Oriented Transverse to the Weld.** The angle beam shall be directed essentially parallel to the weld axis. The search unit shall be manipulated so that the angle beam passes through the required volumes of weld and adjacent base metal specified by the referencing Code Section. The scanning shall be performed at a gain setting at least two times the primary reference level. Evaluation shall be performed with respect to the primary reference level. The search unit shall be rotated 180 deg. and the examination repeated.

**T-542.7.2.5 Evaluation.** Any imperfection which causes an indication in excess of 20% DAC shall be investigated to the extent that it can be evaluated in terms of the acceptance standards of the referencing Code Section.

**T-542.8 Ferritic Welds in Ferritic Pipe**

**T-542.8.1 Basic Calibration**

**T-542.8.1.1 Basic Calibration Block (See Fig. T-542.8.1.1).** The basic calibration block for weldments shall be a section of pipe of the same nominal size, schedule, heat treatment, and material specification or equivalent P-Number grouping as one of the materials being examined. For the purposes of this paragraph, P-Nos. 1, 3, 4, and 5 materials are considered equivalent. The block size and reflector locations shall be adequate to perform calibration for the beam angles used. The surface finish of the calibration block shall be representative of the surface finish of the piping.

**T-542.8.1.2 Basic Calibration Reflectors.** The basic calibration reflectors shall be longitudinal and with circumferential notches on both the inner and outer surfaces. The sizes and locations of the calibration reflectors are shown in Fig. T-542.8.1.1.[1]

**T-542.8.2 Angle Beam Calibration**

**T-542.8.2.1 Frequency.** The nominal frequency shall be 2.25 MHz, unless attenuation or a need for greater resolution makes some other frequency more suitable.

[1]When side-drilled holes are to be used for calibration, the block shall be as shown in Fig. T-542.2.1 (see T-542.8.2.5).

**T-542.8.2.2** The nominal beam angle of 45 deg. shall generally be used but other angles may be used where appropriate for the configuration being examined.

**T-542.8.2.3 Distance–Amplitude Correction (DAC).** A DAC curve is required for all pipe welds. For examination of a full wall thickness, the notches shall be used as calibration reflectors. The angle beam shall be directed toward the calibration reflector that yields the maximum response, setting the instrument adjustment to yield 80% of screen height. The search unit shall then be manipulated, without changing instrument settings, to obtain the maximum responses from the calibration reflectors at the distance increments necessary to generate a 3-point DAC curve.

**T-542.8.2.4 Selection of Calibration Reflectors.** A side-drilled hole may be used for initial acceptance of a pipe weld, provided that it can be demonstrated that the hole calibration produces a sensitivity equal to or greater than the notch calibration.

**T-542.8.2.5 Straight Beam Calibration.** Straight beam examination, when required by the referencing Code Section, or, if needed to evaluate an angle beam indication, shall be calibrated on the side drilled holes in the basic calibration block. When required, the straight beam calibration shall be performed to the requirements of Article 4, Appendix C.

**T-542.8.3 Examination of Pipe Weldments**

**T-542.8.3.1 Surface Preparation.** Surface preparation shall be performed to the requirements of T-542.7.1.

**T-542.8.4 Scanning of Pipe Weldments**

**T-542.8.4.1 Straight Beam.** When straight beam scanning is required, it shall be performed according to the requirements of T-542.7.2.1.

**T-542.8.4.2 Angle Beam.** Angle beam scanning of pipe welds shall be performed according to the requirements of T-542.7.2.3 and T-542.7.2.4.

**T-542.8.4.3 Evaluation.** Any imperfection which causes an indication in excess of 20% DAC shall be investigated to the extent that it can be evaluated in terms of the acceptance standards of the referencing Code Section.

**T-542.8.5 Austenitic and High Nickel Alloy Welds**

**T-542.8.5.1 Discussion.** Ultrasonic examination of austenitic and high nickel alloy welds is usually more difficult than in ferritic materials, because of the wide variations that may occur in the acoustic properties of austenitic and high nickel alloy welds, even those in alloys of the same composition, product form, and heat treatment. It may, therefore, be necessary to modify and/or supplement the provisions of this Article in accordance with T-110(c) when examining such welds.

## T-543 Cladding

The pulse-echo ultrasonic techniques described in these paragraphs shall be used where ultrasonic examination of weld metal overlay cladding is required by a referencing Code Section. Examination of roll bonded and explosive clad plate shall be performed in accordance with SA-578 when required by a referencing Code Section.

The techniques described herein shall be used for examination of weld deposited cladding. Technique One shall be used to examine for bond and clad flaw indications or Technique Two shall be used to examine for lack of bond.

**T-543.1 Equipment**

**T-543.1.1 Equipment for Technique One.** Dual search units using an angled pitch-catch technique may be used. The included angle between the beam paths shall be such that the maximum sensitivity of the search unit is in the area of interest. The total transducer area shall not exceed ½ sq in. A nominal frequency of 2.25 MHz shall be used; however, other frequencies may be used to achieve the necessary resolution.

**T-543.1.2 Equipment for Technique Two.** Straight beam search units with a maximum transducer area of 1 sq in. shall be used. A nominal frequency of 2.25 MHz shall be used; however, other frequencies may be used to achieve the necessary resolution.

**T-543.1.3 Calibration Block for Technique One.** A calibration block clad by the same welding procedure as the production part shall be used. The surface condition shall be representative of that of the production part. Either a side-drilled hole $\frac{1}{16}$ in. diameter by 1½ in. minimum depth shall be drilled into the block at the clad interface, or a ⅛ in. diameter flat bottomed hole shall be drilled through the base metal to the clad interface. The thickness of the base material shall be at least twice the thickness of the cladding. The calibration block is shown in Fig. T-543.2.

**T-543.1.4 Calibration Block for Technique Two.** For clad bond examination, a calibration block clad

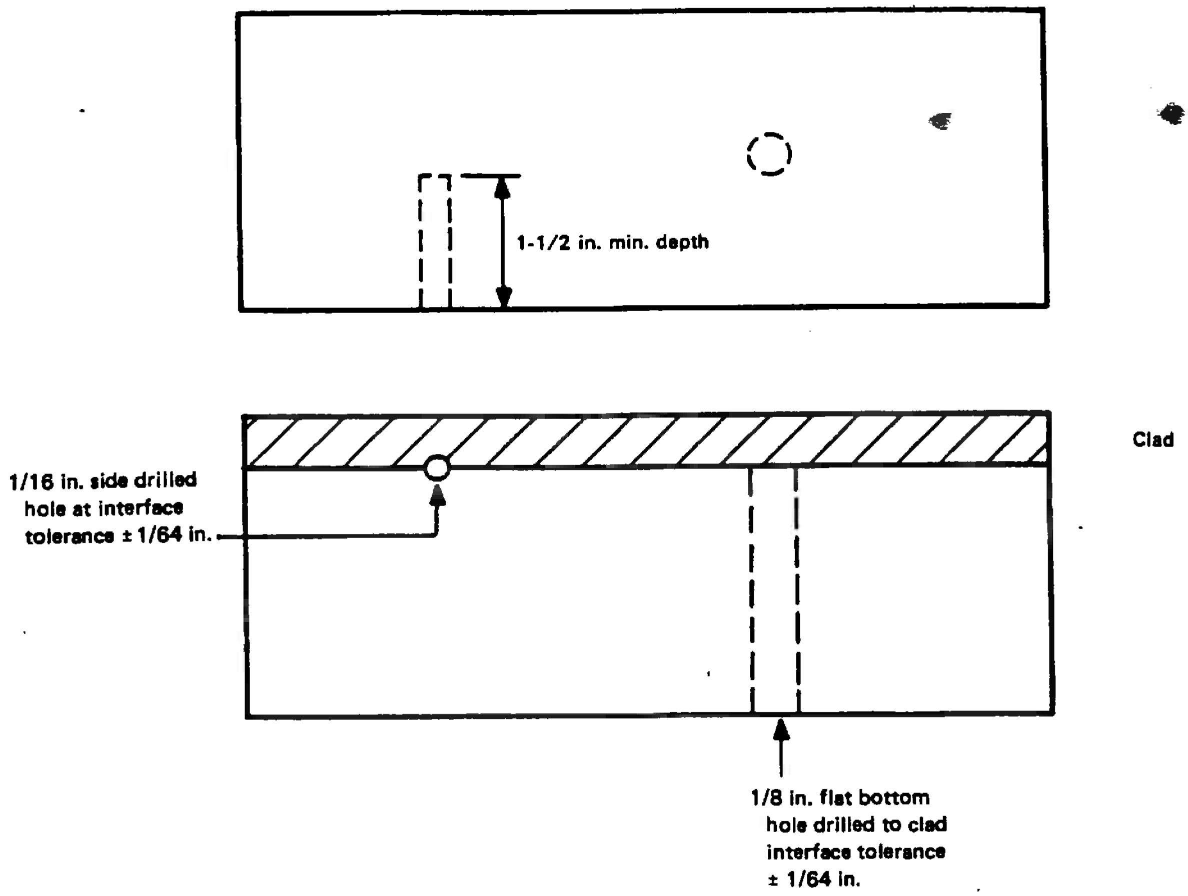



FIG. T-543.2 CALIBRATION BLOCK FOR TECHNIQUE ONE

by the same welding procedure as the production part shall be used. The surface condition shall be representative of the cladding on the production part. A $\frac{3}{8}$ in. flat bottom hole shall be drilled to the weld overlay interface. This hole may be drilled from the base metal or weld overlay side. Other calibration reflectors may be used provided it is demonstrated that equal or greater sensitivity is attained. The thickness of the base material examined shall be within 1 in. of the calibration block thickness when examined from the base metal surface. The thickness of the base material on the calibration block shall be at least twice the thickness of the cladding, when examining from the clad surface.

**T-543.2 Calibration**

**T-543.2.1 Calibration for Technique One.** Calibration shall be accomplished by placing the search unit on the clad surface of the calibration block and manipulating the search unit for the maximum response from the calibration hole. The gain control shall be set so that this response is 80% ±5% of full screen. This is primary reference level.

**T-543.2.2 Calibration for Technique Two.** Calibration shall be accomplished by placing the search unit on the calibration block on the side opposite from which the hole was drilled. The search unit shall be manipulated for the maximum response of the first resolvable indication from the bottom of the calibration hole. The gain shall be set so that this response is 80% ±5% of full screen. This shall be the primary reference level.

**T-543.3 Examination**

**T-543.3.1 Technique One**

*(a) Examination Area.* The entire clad surface shall be examined where practical. The examination shall

erencing Code Section shall be consulted for specific requirements.

*(a)* procedure;

*(b)* ultrasonic examination system (equipment);

*(c)* examination personnel identity and level;

*(d)* calibration sheet identity;

*(e)* identification and location of weld or volume scanned;

*(f)* surface from which examination is conducted;

*(g)* map or record of indications detected or areas clear;

*(h)* date and time examinations were performed;

*(i)* couplant;

*(j)* basic calibration block identification;

*(k)* surface condition;

*(l)* frequency;

*(m)* special equipment.

### T-594 Evaluation Record

Records of any evaluations of indications shall be maintained and documented as required by the referencing Code Section.

# ARTICLE 5
# MANDATORY APPENDICES

## APPENDIX I — SCREEN HEIGHT LINEARITY

To verify the ability of the ultrasonic instrument to meet the linearity requirement of T-532, position an angle beam search unit as shown in Fig. I-1 so that indications can be observed from both the ½ and ¾*T* holes in a basic calibration block. Adjust the search unit position to give a 2:1 ratio of amplitudes between the two indications, with the larger set at 80% of full screen height. Without moving the search unit, adjust sensitivity (gain) to successively set the larger indication from 100% to 20% of full screen height, in 10% increments (or 2 dB steps if a fine control is not available), and read the smaller indication at each setting. The reading must be 50% of the larger amplitude, within 5% of full screen height. The settings and readings must be estimated to the nearest 1% of full screen. Alternatively, a straight beam search unit may be used on any calibration block which will provide amplitude differences, with sufficient signal separation to prevent overlapping of the two signals.

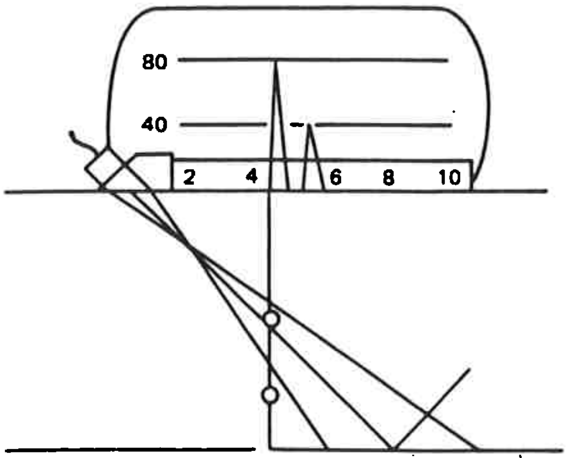



FIG. I-1 LINEARITY

## APPENDIX II — AMPLITUDE CONTROL LINEARITY

To verify the accuracy of the amplitude control of the ultrasonic instrument, as required in T-533, position an angle beam search unit as shown in Fig. I-1 so that the indication from the ½*T* hole in a basic calibration block is peaked on the screen. With the increases and decreases in attenuation shown in the following table, the indication must fall within the specified limits. Other convenient reflectors from any calibration block may be used with angle or straight beam search units.

| Indication Set at % of Full Screen | dB Control Change | Indication Limits % of Full Screen |
|---|---|---|
| 80% | −6 dB | 32 to 48% |
| 80% | −12 dB | 16 to 24% |
| 40% | +6 dB | 64 to 96% |
| 20% | +12 dB | 64 to 90% |

The settings and readings must be estimated to the nearest 1% of full screen.

# ARTICLE 5
# NONMANDATORY APPENDIX

## APPENDIX A — ALTERNATE CALIBRATION BLOCK CONFIGURATION

Flat basic calibration blocks of various thicknesses may also be used to calibrate the examination of convex surface materials greater than 20 in. in diameter. An adjustment of receiver gain may be required when flat calibration blocks are used. The gain corrections apply to the far field portion of the sound beam.

### A-10 DETERMINATION OF GAIN CORRECTION

To determine the required increase in gain, the ratio of the material radius, $R$, to the critical radius of the transducer, $R_c$, must be evaluated as follows.

*(a)* When the ratio of $R/R_c$, the radius of curvature of the material $R$ divided by the critical radius of the transducer $R_c$ from Table A-10 and Fig. A-10(a), is equal to or greater than 1.0, no gain correction is required.

*(b)* When the ratio of $R/R_c$ is less than 1.0, the gain correction must be obtained from Fig. A-10(b).

*(c) Example.* Material with a 10 in. radius ($R$) will be examined with a 1 in. diameter 2.25 MHz boron carbide faced search unit using glycerine as a couplant.

*(1)* Determine the appropriate transducer factor, $F_1$ from Table A-10; $F_1 = 93$.

*(2)* Determine the $R_c$ from Fig. A-10(a); $R_c = 100$ in.

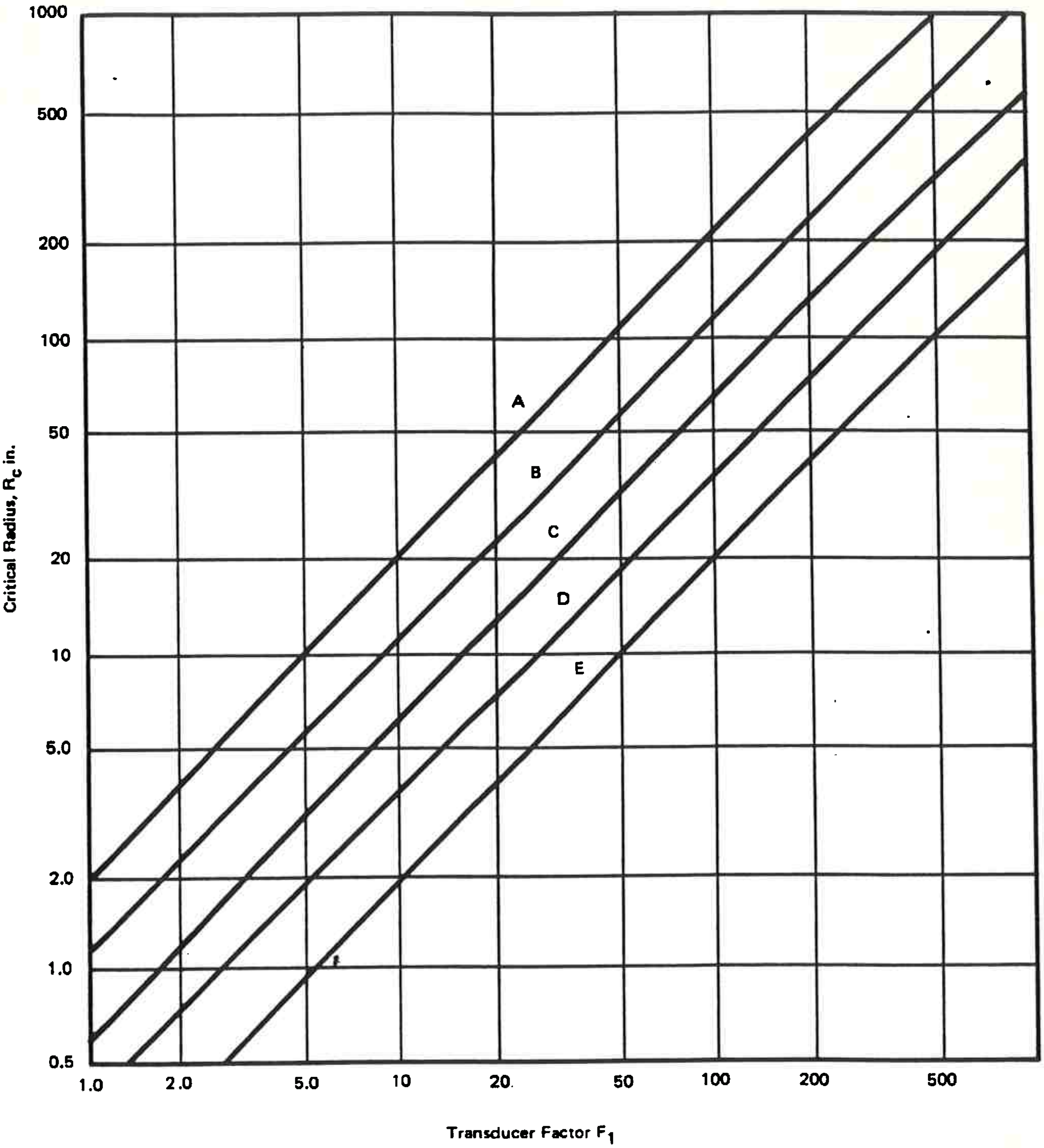
*(3)* Calculate the $R/R_c$ ratio; 10 in./100 in. = 0.1.

*(4)* Using Fig. A-10(b), obtain the gain increase required; 12 dB.

This gain increase calibrates the examination on the curved surface after establishing calibration sensitivity on a flat calibration block.

**TABLE A-10**
**TRANSDUCER FACTOR $F_1$ FOR VARIOUS ULTRASONIC TRANSDUCER DIAMETERS AND FREQUENCIES**

| Frequency MHz | Transducer Diameters, in. 0.25 | 0.5 | 0.75 | 1.0 | 1.125 |
|---|---|---|---|---|---|
| | $F_1$, in. | | | | |
| 1.0 | 2.58 | 10.3 | 23.2 | 41.3 | 52.3 |
| 2.25 | 5.81 | 23.2 | 52.2 | 92.9 | 118 |
| 5.0 | 12.9 | 51.2 | 116 | 207 | 262 |
| 10.0 | 25.8 | 103 | 232 | 413 | 523 |




| Curve | Couplant | Transducer Wearface |
|---|---|---|
| A | Motor oil or water | Aluminum Oxide or Boron Carbide |
| B | Motor oil or water | Quartz |
| | Glycerine or syn. ester | Aluminum Oxide or Boron Carbide |
| C | Glycerine or syn. ester | Quartz |
| D | Motor oil or water | Plastic |
| E | Glycerine or syn. ester | Plastic |

FIG. A-10(a) CRITICAL RADIUS $R_c$ FOR TRANSDUCER/COUPLANT COMBINATIONS

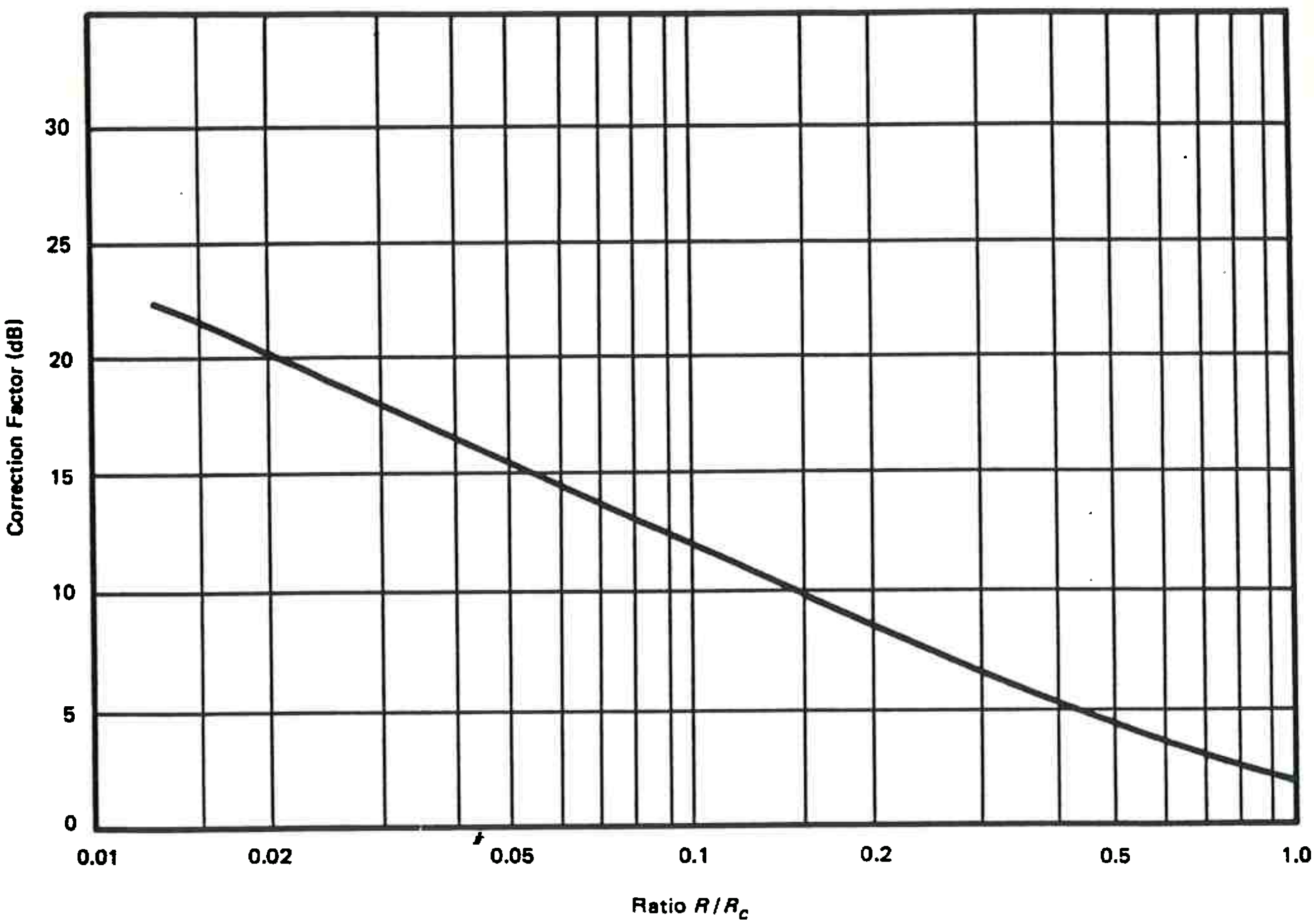



FIG. A-10(b) CORRECTION FACTOR (GAIN) FOR VARIOUS ULTRASONIC EXAMINATION PARAMETERS

# ARTICLE 7



**Figures**

# ARTICLE 7
# MAGNETIC PARTICLE EXAMINATION

## T-700 INTRODUCTION

The magnetic particle examination method may be applied to detect cracks and other discontinuities on or near the surfaces of ferromagnetic materials. The sensitivity is greatest for surface discontinuities and diminishes rapidly with increasing depth of subsurface discontinuities below the surface. Typical types of discontinuities that can be detected by this method are cracks, laps, seams, cold shuts, and laminations.

In principle, this method involves magnetizing an area to be examined, and applying ferromagnetic particles (the examinations medium) to the surface. The particles will form patterns on the surface where cracks and other discontinuities cause distortions in the normal magnetic field. These patterns are usually characteristic of the type of discontinuity that is detected.

Whichever technique is used to produce the magnetic flux in the part, maximum sensitivity will be to linear discontinuities oriented perpendicular to the lines of flux. For optimum effectiveness in detecting all types of discontinuities, each area should be examined at least twice, with the lines of flux during one examination approximately perpendicular to the lines of flux during the other.

## T-710 SCOPE

When specified by the referencing Code Section, the magnetic particle examination techniques described in this Article shall be used. In general, this Article is in conformance with SE-709, Standard Recommended Practice for Magnetic Particle Examination. This document provides additional details to be considered in the procedures used.

When this Article is specified by a referencing Code Section, the magnetic particle method described in this Article shall be used together with Article 1, General Requirements. Definition of terms used in this Article may be found in Appendix A, Glossary of Terms Used in Nondestructive Examination, or SE-269.

## T-720 GENERAL REQUIREMENTS

### T-721 Procedure

Examination procedures shall be based on the following information:

*(a)* the materials, shapes, or sizes to be examined, and the extent of the examination;
*(b)* magnetization techniques to be used;
*(c)* equipment to be used for magnetization;
*(d)* surface preparation (finishing and cleaning);
*(e)* type of ferromagnetic particles to be used: manufacturer, color, wet or dry, etc.;
*(f)* magnetization currents (type and amperage);
*(g)* demagnetization.

### T-722 Method of Examination

Examination shall be done by the continuous method; that is, the magnetizing current remains on while the examination medium is being applied and while excess of the examination medium is being removed.

### T-723 Techniques and Materials

The ferromagnetic particles used as an examination medium shall be either wet or dry, and may be either fluorescent or nonfluorescent.

One or more of the following five magnetization techniques shall be used:

*(a)* prod technique;
*(b)* longitudinal magnetization technique;
*(c)* circular magnetization technique;
*(d)* yoke technique;
*(e)* multidirectional magnetization technique.

### T-724 Surface Preparation

*(a)* Satisfactory results are usually obtained when the surfaces are in the as-welded, as-rolled, as-cast, or as-forged conditions. However, surface preparation by grinding or machining may be necessary where surface irregularities could mask indications due to discontinuities.

*(b)* Prior to magnetic particle examination, the surface to be examined and all adjacent areas within at least 1 in. shall be dry and free of all dirt, grease, lint, scale, welding flux and spatter, oil, or other extraneous matter that could interfere with the examination.

*(c)* Cleaning may be accomplished using detergents, organic solvents, descaling solutions, paint removers, vapor degreasing, sand or grit blasting, or ultrasonic cleaning methods.

*(d)* If coatings are left on the part in the area being examined, it must be demonstrated that indications can be detected through the maximum coating thickness applied.

NOTE: Refer to T-110 for guidance for demonstration of the special procedure/technique.

### T-725 Magnetization

A suitable and appropriate means for producing the necessary magnetic flux in the part shall be employed, using one or more of the techniques listed in T-722 and described in T-740.

### T-726 Examination Medium

The finely divided ferromagnetic particles used for the examination shall meet the following requirements.

*(a) Dry Particles.* If dry particles are used, the color of the particles (dry powder) shall provide adequate contrast with the surface being examined. Additional specific requirements on the use of dry particles are given in SE-709, Standard Recommended Practice for Magnetic Particle Examination. Magnetic particles examination shall not be performed if the surface temperature of the part exceeds 600°F.

*(b) Wet Particles.* If wet particles are used, the color of the particles shall provide adequate contrast with the surface being examined. The particles shall be suspended in a suitable liquid medium in the concentration recommended in SE-709, Standard Recommended Practice for Magnetic Particle Examination, which contains additional specific requirements on the use of wet particles. The temperature of the wet particle suspension and the surface of the part shall not exceed 135°F.

*(c) Fluorescent Particles.* With fluorescent particles the examination is performed using an ultraviolet light, called *black light.* The examination shall be performed as follows.

*(1)* It shall be performed in a darkened area.

*(2)* The examiner shall be in the darkened area for at least 5 min prior to performing the examination to enable his eyes to adapt to dark viewing. If the examiner wears glasses or lenses, they shall not be photosensitive.

*(3)* The black light shall be allowed to warm up for a minimum of 5 min prior to use or measurement of the intensity of the ultraviolet light emitted.

*(4)* The black light intensity shall be measured with a black light meter. A minimum of 800 $\mu W/cm^2$ on the surface of the part being examined shall be required. The black light intensity shall be measured at least once every 8 hr, and whenever the work station is changed.

### T-727 Magnetizing Field Adequacy and Direction

T-727.1 When it is necessary to verify the adequacy or direction of the magnetizing field, the magnetic particle field indicator described in Fig. T-727 shall be used by positioning the indicator on the surface to be examined.

When using this indicator, a suitable flux or field strength is indicated when a clearly defined line of magnetic particles forms across the copper face of the indicator when the magnetic particles are applied simultaneously with the magnetizing force.

When a clearly defined line of particles is not formed, or is not formed in the desired direction, the magnetizing technique shall be changed or adjusted.

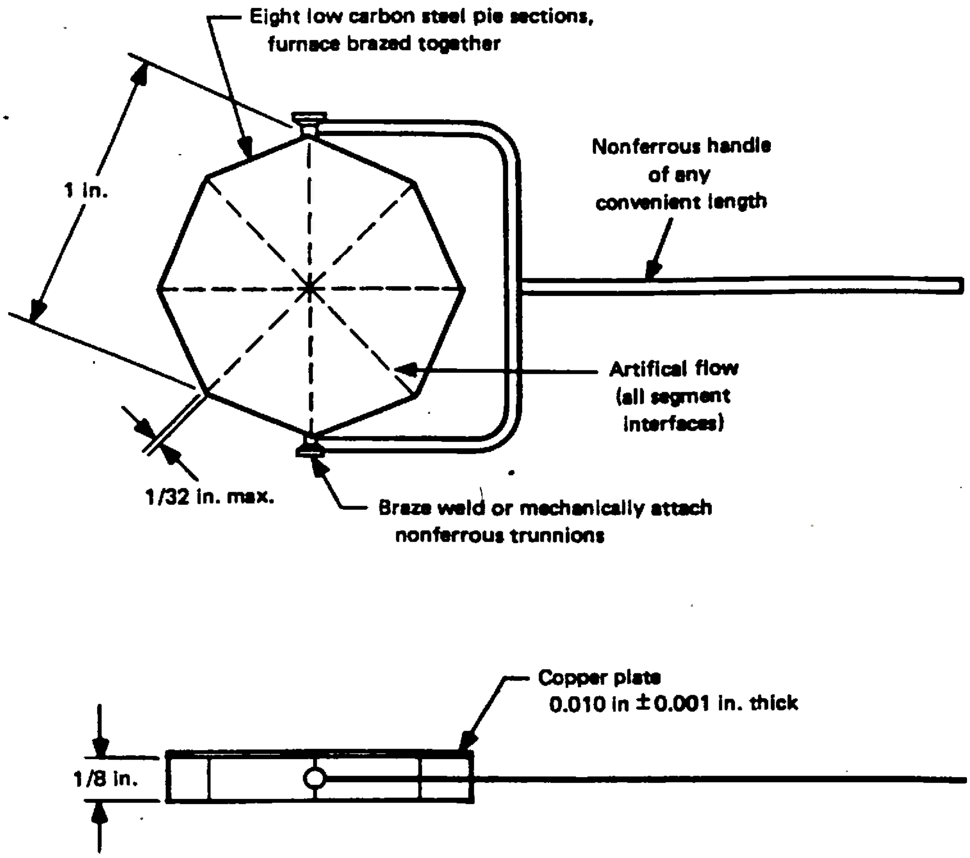
T-727.2 The magnetic particle field indicator is only permitted for determining field adequacy when specifically referenced by the magnetizing technique in T-744.2(c), T-744.2(d), T-747.2, T-245.1(b), T-245.1(b)(6), T-745.2(a), and T-745.2(b).

### T-728 Rectified Current

*(a)* Whenever direct current is required rectified current may be used. The rectified current for magnetization shall be either three-phase (full-wave rectified) current, or single phase (half-wave rectified) current.

*(b)* The amperage required with three-phase, full-wave rectified current shall be verified by measuring the average current.

*(c)* The amperage required with single-phase (half-wave rectified) current shall be verified by measuring




A91 FIG. T-727 MAGNETIC PARTICLE FIELD INDICATOR

the average current output during the conducting half cycle only.

### T-729 Demagnetization

When residual magnetism in the part could interfere with subsequent processing or usage, the part shall be demagnetized any time after completion of the examination.

## T-730 CALIBRATION OF EQUIPMENT

### T-731 Frequency of Calibration

*(a) Frequency.* Each piece of magnetizing equipment with an ammeter shall be calibrated at least once a year, or whenever the equipment has been subjected to major electric repair, periodic overhaul, or damage. If equipment has not been in use for a year or more, calibration shall be done prior to first use.

*(b) Procedure.* The accuracy of the unit's meter shall be verified annually by equipment traceable to a national standard. Comparative readings shall be taken for at least three different current output levels encompassing the usable range.

*(c) Tolerance.* The unit's meter reading shall not deviate by more than ±10% of full scale, relative to the actual current value as shown by the test meter.

NOTE: When measuring half-wave rectified current with a direct current test meter, readings shall be multiplied by 2.

## T-740 EXAMINATION

### T-741 Direction of Magnetization

At least two separate examinations shall be performed on each area. During the second examination, the lines of magnetic flux shall be approximately perpendicular to those used during the first examination.

A different technique for magnetization may be used for the second examination.

### T-742 Examination Coverage

All examinations shall be conducted with sufficient overlap to assure 100% coverage at the required sensitivity (T-727).

### T-743 Prod Technique

**T-743.1 Magnetizing Procedure.** For the prod technique, magnetization is accomplished by portable prod type electrical contacts pressed against the surface in the area to be examined. To avoid arcing, a remote control switch, which may be built into the prod handles, shall be provided to permit the current to be turned on after the prods have been properly positioned.

**T-743.2 Magnetizing Current.** Direct or rectified magnetizing current shall be used. The current shall be 100 (minimum) amp/in. to 125 (maximum) amp/in. of prod spacing for sections $\frac{3}{4}$ in. thick or greater. For sections less than $\frac{3}{4}$ in. thick, the current shall be 90 amp/in. to 110 amp/in. of prod spacing.

**T-743.3 Prod Spacing.** Prod spacing shall not exceed 8 in. Shorter spacing may be used to accommodate the geometric limitations of the area being examined or to increase the sensitivity, but prod spacings of less than 3 in. are usually not practical due to banding of the particles around the prods. The prod tips shall be kept clean and dressed. If the open circuit voltage of the magnetizing current source is greater than 25 V, lead, steel, or aluminum (rather than copper) tipped prods are recommended to avoid copper deposits on the part being examined.

### T-744 Longitudinal Magnetization Technique

**T-744.1 Magnetizing Procedure.** For this technique, magnetization is accomplished by passing current through a multi-turn fixed coil (or cables) that is wrapped around the part or section of the part to be examined. This produces a *longitudinal* magnetic field parallel to the axis of the coil.

If a fixed, prewound coil is used the part shall be placed near the side of the coil during inspection. This is of special importance when the coil opening is more than 10 times the cross-sectional area of the part.

**T-744.2 Magnetic Field Strength.** Direct or rectified current shall be used to magnetize parts examined by this technique. The required field strength shall be calculated based on the length $L$ and the diameter $D$ of the part in accordance with (a), (b), or as established in (c), below. Long parts shall be examined in sections not to exceed 18 in., and 18 in. shall be used for the part $L$ in calculating the required field strength. For noncylindrical parts, $D$ shall be the maximum cross-sectional diagonal.

*(a) Parts With L/D Ratios Equal to or Greater Than 4.* The magnetizing current shall be within ±10% of the ampere-turns' value determined as follows:

$$\text{Ampere-turns} = \frac{35{,}000}{(L/D) + 2}$$

For example, a part 10 in. long × 2 in. diameter has an $L/D$ ratio of 5. Therefore,

$$\frac{35{,}000}{(5 + 2)} = 5000 \text{ ampere-turns}$$

*(b) Parts With L/D Ratios Less Than 4 but Not Less Than 2.* The magnetizing ampere-turns shall be within ±10% of the ampere-turns' value determined as follows:

$$\text{Ampere-turns} = \frac{45{,}000}{L/D}$$

*(c)* If the area to be magnetized extends beyond 6 in. on either side of the coils, field adequacy shall be demonstrated using the magnetic field indicator per T-727.

*(d)* For large parts due to size and shape, the magnetizing current shall be 1200 ampere-turns to 4500 ampere-turns. The field adequacy shall be demonstrated using the magnetic field indicator per T-727.

**T-744.3 Magnetizing Current.** The current required to obtain the necessary magnetizing field strength shall be determined by dividing the ampere-turns obtained in steps (a) or (b) above by the number of turns in the coil as follows:

$$\text{Amperes (meter reading)} = \frac{\text{ampere-turns}}{\text{turns}}$$

For example, if a 5-turn coil is used and the ampere-turns required are 5000, use

$$\frac{5000}{5} = 1000 \text{ amperes } (\pm 10\%)$$

## 45 Circular Magnetization Technique

**'-745.1 Direct Contact Technique**

ı) *Magnetizing Procedure.* For this technique, magzation is accomplished by passing current through part to be examined. This produces a *circular* magıc field that is approximately perpendicular to the :ction of current flow in the part.

*b) Magnetizing Current.* Direct or rectified (half/e rectified or full-wave rectified) magnetizing curt shall be used. The required current shall be denined using the following guidelines:

*(1)* for parts with outer diameters up to 5 in. — ) amp/in. to 900 amp/in. of diameter shall be used;

*(2)* for parts with outer diameters over 5 in. up 10 in. — 500 amp/in. to 700 amp/in. of diameter ıll be used;

*(3)* for parts with outer diameters over 10 in. up 15 in. — 300 amp/in. to 500 amp/in. of diameter ıll be used;

*(4)* for parts with outer diameters over 15 in. — ) amp/in. to 330 amp/in. of outer diameters shall used;

*(5)* for parts with geometric shapes other than ınd, the greatest cross-sectional diagonal in a plane right angles to the current flow shall determine the hes to be used in the above computations;

*(6)* If the current levels required for (b)(3) and above cannot be obtained, the maximum current tainable shall be used and the field adequacy shall demonstrated by using the magnetic particle field licator per T-727. For noncylindrical parts and when ımining large parts by clamping contacts to the wall ckness, field adequacy shall be demonstrated by us; the magnetic particle field indicator per T-727.

**T-745.2 Central Conductor Technique**

*(a) Magnetizing Procedure.* For this technique, a ıtral conductor is used to examine the internal sur:es of ring or cylindrically shaped parts. The central nductor technique may also be used for examining : outside surfaces of these shapes. Where large diıeter cylinders are to be examined, the conductor all be positioned close to the internal surface of the linder. When the conductor is not centered, the cirmference of the cylinder shall be examined in in:ments and a magnetic particle field indicator, aped in accordance with T-727, shall be used to termine the extent of the arc that may be examined : each conductor position. Bars, or cables passed rough the bore of a cylinder, may be used to induce cular magnetization.

*(b) Magnetizing Current.* The field strength required all be equal to that determined in T-745.1(b) for a single-turn central conductor. The magnetic field will increase in proportion to the number of times the central conductor cable passes through a hollow part. For example, if 6000 amp are required to examine a part using a single central conductor, 3000 amp are required when 2 turns of the through cable are used; and 1200 amp are required if 5 turns are used. When the central conductor technique is used, magnetic field adequacy shall be verified using a magnetic particle field indicated in accordance with T-727 (see Fig. T-745.2).

## T-746 Yoke Technique

**T-746.1 Application.** This method shall only be applied to detect discontinuities that are open to the surface of the part.

**T-746.2 Magnetizing Procedure.** For this technique alternating or direct current electromagnetic yokes, or permanent magnet yokes, shall be used.

NOTE: Except for materials ¼ in. or less in thickness, alternating current yokes are superior to direct or permanent magnet yokes of equal lifting power for the detection of surface discontinuities.

**T-746.3 Lifting Power of Yokes**

*(a)* The magnetizing force of yokes shall be checked at least once a year, or whenever a yoke has been damaged. If a yoke has not been in use for a year or more, a check shall be done prior to first use.

*(b)* Each alternating current electromagnetic yoke shall have a lifting power of at least 10 lb at the maximum pole spacing that will be used.

*(c)* Each direct current or permanent magnetic yoke shall have a lifting power of at least 40 lb at the maximum pole spacing that will be used.

*(d)* Each weight shall be weighed with a scale from a reputable manufacturer and stenciled with the applicable nominal weight prior to first use. A weight need only be verified again if damaged in a manner that could have caused potential loss of material.

## T-747 Multidirectional Magnetization Technique

**T-747.1 Magnetizing Procedure.** For this technique magnetization is accomplished by high amperage power packs operating as many as three circuits that are energized one at a time in rapid succession. The effect of these rapidly alternating magnetizing currents is to produce an overall magnetization of the part in multiple directions. Circular or longitudinal magnetic fields may be generated in any combination using the various techniques described in T-744 and T-745.

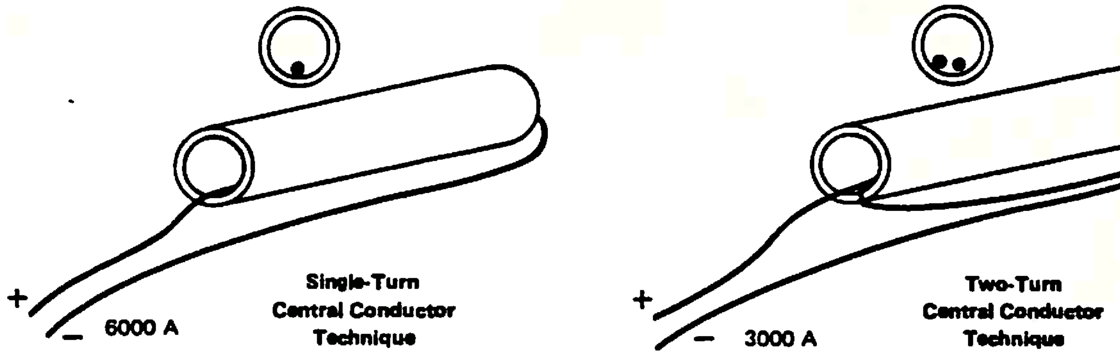



FIG. T-745.2 SINGLE-TURN AND TWO-TURN CENTRAL CONDUCTOR TECHNIQUE

**T-747.2 Magnetic Field Strength.** Only three phase, full-wave rectified current shall be used to magnetize the part. The initial magnetizing current requirements for each circuit shall be established using the previously described guidelines (see T-744 and T-745). The adequacy of the magnetic field shall be demonstrated in accordance with T-727, and a magnetic particle field indicator shall be used to verify that an adequate field is obtained in at least two nearly perpendicular directions. For areas where adequate field strengths cannot be demonstrated, additional magnetic particle techniques shall be used to obtain the required two directional coverage.

## T-750 EVALUATION

*(a)* All indications shall be evaluated in terms of the acceptance standards of the referencing Code Section.

*(b)* Discontinuities on or near the surface are indicated by retention of the examination medium. However, localized surface irregularities due to machining marks or other surface conditions may produce false indications.

*(c)* Broad areas of particle accumulation which might mask indications from discontinuities are prohibited, and such areas shall be cleaned and reexamined.

## T-760 REPORTS

### T-761 Multidirectional Magnetization Technique Sketch

A technique sketch shall be prepared for each different geometry examined, showing the part geometry, cable arrangement and connections, magnetizing current for each circuit, and the areas of examination where adequate field strengths are obtained. Parts with repetitive geometries, but different dimensions, may be examined using a single sketch provided that the magnetic field strength is adequate when demonstrated in accordance with T-747.2.

# ARTICLE 6
# LIQUID PENETRANT EXAMINATION



**Figure**

# ARTICLE 6
# LIQUID PENETRANT EXAMINATION

## T-600 INTRODUCTION

The liquid penetrant examination method is an effective means for detecting discontinuities which are open to the surface of nonporous metals and other materials. Typical discontinuities detectable by this method are cracks, seams, laps, cold shuts, laminations, and porosity.

In principle, a liquid penetrant is applied to the surface to be examined and allowed to enter discontinuities. All excess penetrant is then removed, the part is dried, and a developer is applied. The developer functions both as a blotter to absorb penetrant that has been trapped in discontinuities, and as a contrasting background to enhance the visibility of penetrant indications. The dyes in penetrants are either color contrast (visible under white light) or fluorescent (visible under ultraviolet light).

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## T-610 SCOPE

When specified by the referencing Code Section, the liquid penetrant examination techniques described in this Article shall be used. The following listed SE Standards provide details which may be considered in the specific procedures used:

*(a)* SE-165, Standard Practice for Liquid Penetrant Inspection Method

*(b)* SE-1209, Standard Test Method for Fluorescent Penetrant Examination Using the Water Washable Process

*(c)* SE-1219, Standard Test Method for Fluorescent Penetrant Examination Using the Solvent Removable Process

*(d)* SE-1220, Standard Test Method for Visible Penetrant Examination Using the Solvent Removable Process

When this Article is specified by a referencing Code Section, the liquid penetrant method described in this Article shall be used together with Article 1, General Requirements. Definitions of terms used in this Article may be found in Appendix A, Glossary of Terms Used in Nondestructive Examination, or in SE-270.

## T-620 GENERAL REQUIREMENTS

### T-621 Procedure

**T-621.1 Initial Procedure.** Liquid penetrant examination shall be performed in accordance with a procedure. Such a procedure shall consider at least the following information:

*(a)* the materials, shapes, or sizes to be examined, and the extent of the examination;

*(b)* type (number or letter designation if available) of each penetrant, penetrant remover, emulsifier, and developer;

*(c)* processing details for pre-examination cleaning and drying, including the cleaning materials used and minimum time allowed for drying;

*(d)* processing details for applying the penetrant; the length of time that the penetrant will remain on the surface (dwell time), and the temperature of the surface and penetrant during the examination if outside 60°F to 125°F range;

*(e)* processing details for removing excess penetrant from the surface, and for drying the surface before applying the developer;

*(f)* processing details for applying the developer, and length of developing time before interpretation;

*(g)* processing details for post-examination cleaning.

**T-621.2 Procedure Revision.** A revised procedure may be required:

*(a)* whenever a change or substitution is made in the type or family group of penetrant materials (including developers, emulsifiers, etc.) or in the processing techniques;

*(b)* whenever a change or substitution is made in the type of precleaning materials or processes;

*(c)* for any change in part processing that can close surface openings of discontinuities or leave interfering deposits, such as the use of grit blast cleaning or acid treatments.

A90 ### T-622 Techniques

Either a color contrast (visible) penetrant or a fluorescent penetrant shall be used with one of the following three penetrant processes:

*(a)* water washable
*(b)* post-emulsifying
*(c)* solvent removable

The visible and fluorescent penetrants used in combination with these three pentrant processes result in six liquid penetrant techniques.

### T-623 Penetrant Materials

The term *penetrant materials*, as used in this Article, is intended to include all penetrants, solvents or cleaning agents, developers, etc., used in the examination process.

A90 ### T-624 Technique Restrictions

Fluorescent penetrant examination shall not follow a color contrast penetrant examination. Intermixing of penetrant materials from different families or different manufacturers is not permitted. A retest with water washable penetrants may cause loss of marginal indications due to contamination.

### T-625 Control of Contaminants

The user of this Article shall obtain certification of contaminant content for all liquid penetrant materials used on nickel base alloys, austenitic stainless steels, and titanium. These certifications shall include the penetrant manufacturers' batch numbers and the test results obtained in accordance with (a) and (b) below. These records shall be maintained as required by the referencing Code Section.

*(a)* When examining nickel base alloys, all materials shall be analyzed individually for sulphur content as follows.

*(1)* An individual sample of the penetrant materials with exception of cleaners shall be prepared for analysis by heating 50 g of the material in a 150 mm nominal diameter glass Petri dish at a temperature of 194°F to 212°F for 60 min.

PRECAUTION: Provide adequate ventilation to dissipate the emitted vapor.

*(2)* Analysis of the residue shall be as follows: If the residue is less than 0.0025 g, the material is acceptable without further analysis. If the residue is 0.0025 g or more, the procedure shown in (a)(1) above shall be repeated and the residue analyzed in accordance with ASTM D 129 or ASTM D 1552. Alternately, the material may be decomposed in accordance with ASTM D 129 and analyzed in accordance with ASTM D 516 Method B. The sulphur content shall not exceed 1% of the residue by weight.

*(3)* An individual sample of cleaner/remover material shall be prepared for analysis by heating 100 g of the material in a 150 mm nominal diameter glass Petri dish at a temperature of 194°F to 212°F for 60 min.

PRECAUTION: Provide adequate ventilation to dissipate the emitted vapor.

*(4)* Analysis of the residue shall be as follows: If the residue is less than 0.005 g, the material is acceptable without further analysis. If the residue is 0.005 g or more, the procedure shown in (a)(3) above shall be repeated and the residue analyzed in accordance with ASTM D 129 or ASTM D 1552. Alternately the material may be decomposed in accordance with D 129 and analyzed in accordance with ASTM D 516 Method B. The sulphur content shall not exceed 1% of the residue by weight.

*(b)* When examining austenitic stainless steel or titanium, all materials shall be analyzed individually for chlorine and fluorine content as follows.

*(1)* An individual sample of the penetrant materials with the exception of cleaners shall be prepared for analysis by heating 50 g of the material in a 150 mm nominal diameter glass Petri dish at a temperature of 194°F to 212°F for 60 min.

PRECAUTION: Provide adequate ventilation to dissipate the emitted vapor.

*(2)* Analysis of the residue shall be as follows: If the residue is less than 0.0025 g, the material is acceptable without further analysis. If the residue is 0.0025 g or more, the procedure shown in (a)(1) above shall be repeated and the residue analyzed in accordance with ASTM D 808 or SE-165 Annex 2 for chlorine and SE-165 Annex 3 for fluorine. The chlorine plus fluorine content shall not exceed 1% of the residue by weight.

*(3)* An individual sample of the cleaner/remover material shall be prepared for analysis by heating 100 g of the material in a 150 mm nominal diameter glass

Petri dish at a temperature of 194°F to 212°F for 60 min.

PRECAUTION: Provide adequate ventilation to dissipate the emitted vapor.

*(4)* Analysis of the residue shall be as follows: If the residue is less than 0.005 g, the material is acceptable without further analysis. If the residue is 0.005 g or more, the procedure shown in (a)(3) above shall be repeated and the residue analyzed in accordance with ASTM D 808 or SE-165 Annex 2 for chlorine and SE-165 Annex 3 for fluorine. The chlorine plus fluorine content shall not exceed 1% of the residue by weight.

### T-626 Surface Preparation

*(a)* In general, satisfactory results may be obtained when the surface of the part is in the as-welded, as-rolled, as-cast, or as-forged condition. Surface preparation by grinding, machining, or other methods may be necessary where surface irregularities could mask indications of unacceptable discontinuities.

CAUTION: Conditioning of surfaces prior to examination can affect the results. See Article 24, SE-165, Annex 1, for general precautions relative to surface conditioning.

A90 *(b)* Prior to each liquid penetrant examination, the surface to be examined and all adjacent areas within at least 1 in. shall be dry and free of all dirt, grease, lint, scale, welding flux, weld spatter, paint, oil, and other extraneous matter that could obscure surface openings or otherwise interfere with the examination.

*(c)* Typical cleaning agents which may be used are detergents, organic solvents, descaling solutions, and paint removers. Degreasing and ultrasonic cleaning methods may also be used.

*(d)* Cleaning solvents shall meet the requirements of T-625. The cleaning method employed is an important part of the examination process.

### A90 T-627 Drying After Preparation

After cleaning, drying of the surfaces to be examined shall be accomplished by normal evaporation or with forced hot or cold air. A minimum period of time shall be established to ensure that the cleaning solution has evaporated prior to application of the penetrant.

## T-640 EXAMINATION

### T-641 Techniques for Standard Temperatures A90

As a standard technique, the temperature of the penetrant and the surface of the part to be processed shall not be below 60°F nor above 125°F throughout the examination period. Local heating or cooling is permitted provided the part temperature remains in the range of 60°F to 125°F during the examination. Where it is not practical to comply with these temperature limitations, other temperatures and times may be used, provided the procedures are qualified as specified in T-648.

### T-642 Penetrant Application A90

The penetrant may be applied by any suitable means, such as dipping, brushing, or spraying. If the penetrant is applied by spraying using compressed-air-type apparatus, filters shall be placed on the upstream side near the air inlet to preclude contamination of the penetrant by oil, water, dirt, or sediment that may have collected in the lines.

### T-643 Penetration Time A90

Penetration time is critical. The minimum penetration time shall be as recommended in SE Standards referenced in T-610 or as qualified by demonstration for specific applications.

### T-644 Excess Penetrant Removal A90

After the specified penetration time has elapsed, any penetrant remaining on the surface shall be removed, taking care to minimize removal of penetrant from discontinuities.

**T-644.1 Water Washable Penetrants.** Excess water washable penetrant shall be removed with a water spray. The water pressure shall not exceed 50 psi, and the water temperature shall not exceed 110°F. A90

**T-644.2 Post-Emulsifying Penetrants.** With post-emulsifying penetrants, the emulsifier shall be applied by spraying or dipping. Emulsification time is critical, and governed by surface roughness and type of discontinuities sought. It shall not exceed 5 min unless other times have been qualified by actual tests. After emulsification, the mixture shall be removed by a water spray using the same processes as for water washable penetrants. A90

**T-644.3 Solvent Removable Penetrants.** Excess solvent removable penetrants shall be removed by wiping with a cloth or absorbent paper, repeating the operation A90 until most traces of penetrant have been removed. The remaining traces shall be removed by lightly wiping the surface with cloth or absorbent paper moistened with solvent. To minimize removal of penetrant from discontinuities, care shall be taken to avoid the use of excess solvent. **Flushing the surface with solvent, following the application of the penetrant and prior to developing, is prohibited.**

### A90 T-645 Drying After Excess Penetrant Removal

*(a)* For the water washable or post-emulsifying technique, the surfaces may be dried by blotting with clean materials or by using circulating air, provided the temperature of the surface is not raised above 125°F.

*(b)* For the solvent removable technique, the surfaces may be dried by normal evaporation, blotting, wiping, or forced air.

### A90 T-646 Developing

The developer shall be applied as soon as possible after penetrant removal; the time interval shall not exceed that established in the procedure. Insufficient coating thickness may not draw the penetrant out of discontinuities; conversely, excessive coating thickness may mask indications.

With color contrast penetrants, only a wet developer shall be used. With fluorescent penetrants, a wet or dry developer may be used.

A90 **T-646.1 Dry Developer Application.** Dry developer shall be applied only to a dry surface by a soft brush, hand powder bulb, powder gun, or other means, provided the powder is dusted evenly over the entire surface being examined.

A90 **T-646.2 Wet Developer Application.** Prior to applying suspension type wet developer to the surface, the developer must be thoroughly agitated to ensure adequate dispersion of suspended particles.

*(a) Aqueous Developer Application.* Aqueous developer may be applied to either a wet or dry surface. It shall be applied by dipping, brushing, spraying, or other means, provided a thin coating is obtained over the entire surface being examined. Drying time may be decreased by using warm air, provided the surface temperature of the part is not raised above 125°F. Blotting is not permitted.

*(b) Nonaqueous Developer Application.* Nonaqueous developer shall be applied only to a dry surface. It shall be applied by spraying, except where safety or restricted access preclude it. Under such conditions, developer may be applied by brushing. Drying shall be by normal evaporation.

T-646.3 Developing time for final interpretation begins immediately after the application of a dry developer or as soon as a wet developer coating is dry. A9

### T-647 Interpretation A9

**T-647.1 Final Interpretation.** Final interpretation shall be made within 7 to 30 min after the requirements of T-646.3 are satisfied. If bleed-out does not alter the examination results, longer periods are permitted. If the surface to be examined is large enough to preclude complete examination within the prescribed or established time, the examination shall be performed in increments. A9

**T-647.2 Characterizing Indication(s).** The type of discontinuities are difficult to evaluate if the penetrant diffuses excessively into the developer. If this condition occurs, close observation of the formation of indications during application of the developer may assist in characterizing and determining the extent of the indications(s). A9

**T-647.3 Color Contrast Penetrants.** With a color contrast penetrant, the developer forms a reasonably uniform white coating. Surface discontinuities are indicated by bleed-out of the penetrant which is normally a deep red color that stains the developer. Indications with a light pink color may indicate excessive cleaning. Inadequate cleaning may leave an excessive background making interpretation difficult. Adequate illumination is required to ensure adequate sensitivity during the examination and evaluation of indications. A9

**T-647.4 Fluorescent Penetrants.** With fluorescent penetrants, the process is essentially the same as in T-647.3, with the exception that the examination is performed using an ultraviolet light, called *black light.* The examination shall be performed as follows. A9

*(a)* It shall be performed in a darkened area.

*(b)* The examiner shall be in the darkened area for at least 5 min prior to performing the examination to enable his eyes to adapt to dark viewing. If the examiner wears glasses or lenses, they shall not be photosensitive.

*(c)* The black light shall be allowed to warm up for a minimum of 5 min prior to use or measurement of the intensity of the ultraviolet light emitted.

*(d)* The black light intensity shall be measured with a black light meter. A minimum of 800 $\mu W/cm^2$ on the surface of the part being examined shall be required. The black light intensity shall be measured at least once every 8 hr, and whenever the work station is changed.

90 **T-648 Procedure for Nonstandard Temperatures**

90 **T-648.1 General.** When it is not practical to conduct a liquid penetrant examination within the temperature range of 60°F to 125°F, the examination procedure at the proposed lower or higher temperature range requires qualification. This shall require the use of a quench cracked aluminum block, which in this Article is designated as a liquid penetrant comparator block.

90 **T-648.2 Liquid Penetrant Comparator.** The liquid penetrant comparator blocks shall be made of aluminum, ASTM B 209, Type 2024 or SB-211, Type 2024, ⅜ in. thick, and should have approximate face dimensions of 2 in. × 3 in. At the center of each face, an area approximately 1 in. in diameter shall be marked with a 950°F temperature-indicating crayon or paint. The marked area shall be heated with a blowtorch, a Bunsen burner, or similar device to a temperature between 950°F and 975°F. The specimen shall then be immediately quenched in cold water which produces a network of fine cracks on each face.

The block shall then be dried by heating to approximately 300°F. After cooling, the block shall be cut in half. One-half of the specimen shall be designated block "A" and the other block "B" for identification in subsequent processing. Figure T-648.2 illustrates the comparator blocks "A" and "B." As an alternate to cutting the block in half to make blocks "A" and "B," separate blocks 2 in. × 3 in. can be made using the heating and quenching technique as described above. Two comparator blocks with closely matched crack patterns may be used. The blocks shall be marked "A" and "B."

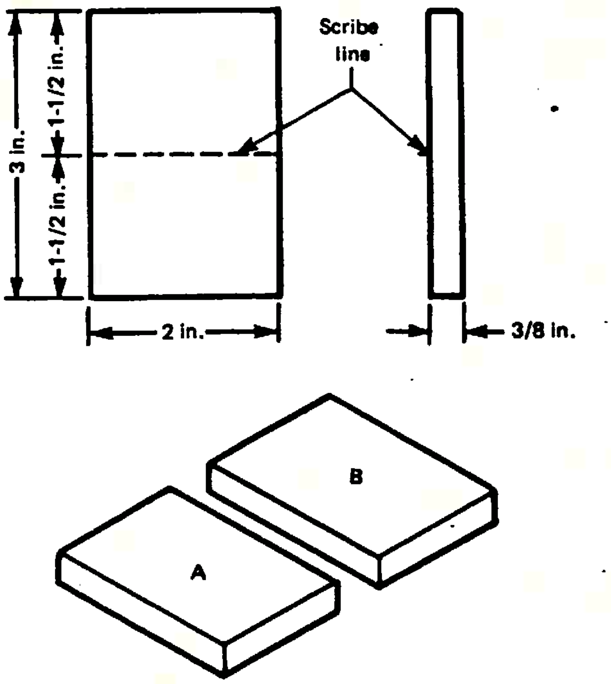


FIG. T-648.2 LIQUID PENETRANT COMPARATOR A90
(NOTE: Dimensions given are for guidance only and are not critical.)

90 **T-648.3 Comparator Application**

*(a)* If it is desired to qualify a liquid penetrant examination procedure at a temperature of less than 60°F, the proposed procedure shall be applied to block "B" after the block and all materials have been cooled and held at the proposed examination temperature until the comparison is completed. A standard procedure which has previously been demonstrated as suitable for use shall be applied to block "A" in the 60°F to 125°F temperature range. The indications of cracks shall be compared between blocks "A" and "B." If the indications obtained under the proposed conditions on block "B" are essentially the same as obtained on block "A" during examination at 60°F to 125°F, the proposed procedure shall be considered qualified for use.

90 *(b)* If the proposed temperature for the examination is above 125°F, block "B" shall be held at this temperature throughout the examination. The indications of cracks shall be compared as described in T-648.3(a) while block "B" is at the proposed temperature and block "A" is at the 60°F to 125°F temperature range.

*(c)* A procedure qualified at a temperature lower than 60°F shall be qualified from that temperature to 60°F.

*(d)* To qualify a procedure for temperatures above 125°F, the upper and lower temperature limits shall be established and the procedure qualified at these temperatures.

*(e)* As an alternate to the requirements of T-648.3(a) and T-648.3(b) when using color contrast penetrants, it is permissible to use a single comparator block for the standard and nonstandard temperatures and to make the comparison by photography. A90

*(1)* When the single comparator block and photographic technique is used, the processing details (as applicable) described in T-648.3(a) and T-648.3(b) apply. The block shall be thoroughly cleaned between the two processing steps. Photographs shall be taken after processing at the nonstandard temperature and then after processing at the standard temperature. The indication of cracks shall be compared between the two photographs. The same criteria for qualification as T-648.3(a) shall apply. A90

A90 *(2)* The identical photographic techniques shall be used to make the comparison photographs.

## T-650 EVALUATION

*(a)* All indications shall be evaluated in terms of the acceptance standards of the referencing Code Section.

*(b)* Discontinuities at the surface will be indicated by bleed-out of penetrant; however, localized surface irregularities due to machining marks or other surface conditions may produce false indications.

*(c)* Broad areas of fluorescence or pigmentation which could mask indications of discontinuities are unacceptable, and such areas shall be cleaned and reexamined.