# Welding Guidelines for the Chemical, Oil, and Gas Industries

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# Welding Guidelines for the Chemical, Oil, and Gas Industries

## 1 Scope

**1.1** This recommended practice (RP) provides supplementary guidelines and practices for welding and welding related topics for shop and field fabrication, repair and modification of the following:

a) pressure-containing equipment such as pressure vessels, heat exchangers, piping, heater tubes, and pressure boundaries of rotating equipment and attachments welded thereto;

b) tanks and attachments welded thereto;

c) non-removable internals for process equipment;

d) structural items attached and related to process equipment;

e) other equipment or component items when referenced by an applicable purchase document.

**1.2** This document is general in nature and augments the welding requirements of ASME *BPVC* Section IX and similar codes, standards, specifications, and practices such as those listed in Section 2. The intent of this document is to be inclusive of chemical, oil and gas industry standards, although there are many areas not covered herein, e.g. pipeline welding and offshore structural welding are intentionally not covered.

**1.3** This document is based on industry experience and any restrictions or limitations may be waived or augmented by the purchaser.

## 2 Normative References

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies. Other codes and standards are specified by the purchaser.

API 510, *Pressure Vessel Inspection Code: Maintenance, Inspection, Rating, Repair, and Alteration*

API Recommended Practice 934-A, *Materials and Fabrication of 2 1/4Cr-1Mo, 2 1/4Cr-1Mo-1/4V, 3Cr-1Mo, and 3Cr-1Mo-1/4V Steel Heavy Wall Pressure Vessels for High-temperature, High-pressure Hydrogen Service*

API Recommended Practice 934-C, *Materials and Fabrication of 1 1/4Cr-1/2Mo Steel Heavy Wall Pressure Vessels for High-pressure Hydrogen Service Operating at or Below 825 °F (441 °C)*

API Recommended Practice 934-E, *Recommended Practice for Materials and Fabrication of 1 1/4Cr-1/2Mo Steel Pressure Vessels for Service Above 825 °F (440 °C)*

ASME *Boiler and Pressure Vessel Code (BPVC)* [1], *Section I, Rules for Construction of Power Boilers*

ASME *Boiler and Pressure Vessel Code (BPVC) Section II, Part C: Specifications for Welding Rods, Electrodes, and Filler Metals*

ASME *BPVC, Section VIII: Rules for Construction of Pressure Vessels*

ASME *BPVC, Section IX: Welding and Brazing Qualifications*

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[1] ASME International, 3 Park Avenue, New York, New York 10016-5990, www.asme.org.

ASME B31.3, *Process Piping Design*

ASTM A578/578M [2], *Standard Specification for Straight-Beam Ultrasonic Examination of Rolled Steel Plates for Special Applications*

ASTM A923, *Standard Test Method for Detecting Detrimental Intermetallic Phase in Duplex Austenitic/Ferritic Stainless Steels*

ASTM E562, *Standard Test Method for Determining Volume Fraction by Systematic Manual Point Count*

AWS A3.0 [3], *Standard Definitions*

AWS A4.2M (ISO 8249:2000 MOD), *Standard Procedures for Calibrating Magnetic Instruments to Measure the Delta Ferrite Content of Austenitic and Duplex Ferritic-Austenitic Stainless Steel Weld Metal*

AWS A4.3, *Standard Method for Determination of the Diffusible Hydrogen Content of Martensitic, Bainitic and Ferritic Steel Weld Metal Produced by Arc Welding*

AWS A4.4M, *Standard Procedures for Determination of Moisture Content of Welding Fluxes and Welding Electrode Flux Coverings*

AWS A5.32/A5.32M, *Specification for Welding Shielding Gases*

AWS A5.XX, *Series of Filler Metal Specifications*

AWS D1.1, *Structural Welding Code—Steel*

AWS D1.6, *Structural Welding Code—Stainless Steel*

AWS D10.8, *Recommended Practice for Welding of Cr-Mo Steel Piping and Tubing*

AWS D10.10, *Recommended Practices for Local Heating of Welds in Piping and Tubing*, 3rd Edition

NACE MR 0103 [4], *Materials Resistant to Sulfide Stress Cracking in Corrosive Petroleum Refining Environments*

NACE MR0175/ISO 15156, *Petroleum and Natural Gas Industries—Materials for Use in* $H_2S$*-containing Environments in Oil and Gas Production—Parts 1, 2 and 3*

NACE SP0472, *Methods and Controls to Prevent In-service Environmental Cracking of Carbon Steel Weldments in Corrosive Petroleum Refining Environments*

National Board NB-23 [5], *National Board Inspection Code*

WRC Bulletin 452 [6], *Recommended Practices for Local Heating of Welds in Pressure Vessels*

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2 ASTM International, 100 Barr Harbor Drive, West Conshohocken, Pennsylvania 19428, www.astm.org.
3 American Welding Society, 550 NW LeJeune Road, Miami, Florida 33126, www.aws.org.
4 NACE International (formerly the National Association of Corrosion Engineers), 1440 South Creek Drive, Houston, Texas 77218-8340, www.nace.org.
5 National Board of Boiler and Pressure Vessel Inspectors, 1055 Crupper Avenue, Columbus, Ohio 43229, www.nationalboard.org.
6 Welding Research Council, P.O. Box 201547, Shaker Heights, Ohio 44122, www.forengineers.org.

## 3 Definitions

For the purposes of this document, the following definitions apply.

**3.1**
**applicable code**
The code or standard specified by the purchaser to which the equipment shall conform.

**3.2**
**Duplex Stainless Steel**
This refers to standard duplex stainless steel, a stainless steel with 22 % chromium, with UNS S31803 and UNS S32205 (both known as Alloy 2205) being the most widely used. Common duplex stainless castings are UNS J92205 (ASTM A890 Grade 4A, CD3MN) and UNS J93372 (ASTM A890 Grade 1B, CD4MCuN).

**3.3**
**inspector**
The purchaser's representative.

**3.4**
**P-number (shown as P-No. in this document)**
Base metals have been grouped by P-numbers assigned by the ASME *BPVC* Section IX Committee. For current P-numbers, ASME *BPVC* Section IX should be consulted.

**3.5**
**procedure qualification record**
**PQR**
A record of welding variables used to produce an acceptable test weldment and the results of tests conducted on the weldment to qualify a WPS.

**3.6**
**purchaser**
The party that issues the purchase order. This may be the user or owner of the equipment or component, or the purchaser's designated agent (e.g. the engineering contractor).

**3.7**
**Super Duplex Stainless Steel**
A duplex stainless steel with a Pitting Resistance Equivalent Number (PREN) > 35-40, where PREN = % Cr + 3.3 × (% Mo + 0.5 % W) + 16 × % N. Usually, super duplex grades have 25 % chromium, or more. Some common examples are UNS S32760 (Zeron 100), UNS S32750 (Alloy 2507), and UNS S32550 (Ferralium 225). Common super duplex stainless steel castings are UNS J93380 (ASTM A890 Grade 6A, CD3MWCuN) and UNS J93404 (ASTM A890 Grade 5A, CE3MN).

**3.8**
**welding procedure specification**
**WPS**
A document providing the required welding variables for a specific application to ensure repeatability by properly trained welders and welding operators.

## 4 General Welding Requirements

**4.1** Structural (non-pressure boundary) welding requirements shall comply with either AWS D1.1 or AWS D1.6. When approved by the purchaser (engineer), welding procedures may be qualified per ASME *BPVC* Section IX.

**4.2** Prequalified welding procedures per AWS D1.1 and AWS D1.6 will be accepted for structural welding.

**4.3** All welding procedure specifications (WPSs) and procedure qualification records (PQRs) shall be submitted to the purchaser for review and approval prior to the start of fabrication or construction unless submittal is waived by the purchaser. Weld maps, similar guides or fabrication drawings which clearly identify the application of each WPS, indicating where and how these WPSs will be used, shall be included in the submittal.

**4.4** Weld maps, similar guides, drawings or other documentation shall be updated during fabrication to clearly indicate the welder(s) or welding operator(s) that made each weld. Similarly, record the location of any NDE performed and update the information during fabrication.

**4.5** Any pressure boundary welds or welds to the pressure boundary shall comply with the ASME Code, including Section IX, and the applicable API Standard/Recommended Practice.

# 5 Welding Processes

## 5.1 Acceptable Welding Processes

Acceptable welding processes are as follows:

a) shielded metal arc welding (SMAW);

b) gas tungsten arc welding (GTAW) and pulsed GTAW (GTAW-P);

c) gas metal arc welding (GMAW) with solid wire and metal cored electrodes for the following transfer modes:

   1) spray (GMAW-Sp),

   2) short circuiting (GMAW-S),

   3) pulsed (GMAW-P),

   4) globular (GMAW-G), and

   5) other transfer modes approved by the purchaser;

d) submerged arc welding (SAW);

e) electrogas welding (EGW);

f) electroslag welding (ESW), limited to weld overlay for P-No. 1 through P-No. 5 and P-No. 15E base materials;

g) flux-cored arc welding (FCAW);

h) plasma arc welding (PAW);

i) other welding processes approved by the purchaser.

## 5.2 Limitations of Fusion Welding Processes

### 5.2.1 General

The fusion welding processes listed in 5.1 are acceptable with the restrictions and notes contained in 5.2.

### 5.2.2 GTAW-P

When used for root pass welding of single-sided joints, GTAW-P shall be performed with the same make and model of equipment using the same program settings as those used in the procedure qualifications.

NOTE The need to specify the make and model, program, equipment settings, and pulse waveform is based upon the effects these variables have on welding arc performance, especially sidewall fusion and out-of-position welding. Studies have shown considerable variation in arc characteristics when one make or model of welding system is compared to another. This variation can lead to welding defects, some of which may be very difficult to detect by radiography.

### 5.2.3 GMAW-S

The use of GMAW-S shall be limited as follows.

a) The process shall not be used for branch connections, nozzle-to-shell welds, or socket welds.

b) GMAW-S may be used for root pass welding on piping. Root pass welding with GMAW-S for other applications is permitted, provided the root pass is completely removed from the backside.

c) The fill and cap passes for butt or fillet welds may be welded with this process, provided the thickness of any member does not exceed $^3/_8$ in. (9.5 mm) and vertical welding is performed with uphill progression.

d) For vertical welding, the root pass and second pass progression for a material of any thickness may be either uphill or downhill.

e) Variations of GMAW-S shall have the same limitations as outlined above. Proposals to use GMAW-S variations without back purging shall be approved by the owner's engineer.

### 5.2.4 GMAW-P

GMAW-P may be used for any material thickness in any position. Welding shall be performed with the same make and model of welding equipment and using the same program settings as those used in the procedure qualification.

NOTE It is recommended that whenever the welding system is changed or the settings on existing equipment significantly altered, that the fabricator verify weld properties. The extent of verification or testing should be as agreed between the purchaser and fabricator.

### 5.2.5 FCAW

**5.2.5.1** Self-shielding FCAW (FCAW-S) may be used only for welding carbon steel structural items. The following guidelines and restrictions apply:

a) electrode types identified by the consumable manufacturer for multi-pass application should be used,

b) only electrode classifications which have specified minimum impact test requirements should be used,

c) FCAW-S shall not be used with other welding processes without qualifying the specific combination.

**5.2.5.2** FCAW with external gas shielding (FCAW-G) may be used for either groove or fillet welds for pressure boundary or structural welding.

**5.2.5.3** For procedures requiring either impact or hardness testing, it is advisable to review weld metal properties with the consumable manufacturer to ensure the original qualified properties continue to be met. When rutile type (i.e. E71T-1 type) consumables are used as-welded or in the postweld heat treated (PWHT'd) condition with impact testing required, the specific brand and trade name of the consumable used in production must be qualified on supporting PQRs with impact test results meeting the minimum design code requirements.

NOTE Welding consumables, including those for FCAW, are routinely used in situations not addressed by the testing requirements in AWS/ASME welding specifications. A periodic review with the manufacturer is good practice to ensure minor variations that occur over time with FCAW consumable formulations (e.g. raw material and microalloying changes) do not adversely affect the ability of these products to perform as intended. Small changes in microalloying additions can have significant effects on properties.

**5.2.5.4** Welding consumables shall be limited to the ASME/AWS classification used in the PQR.

**5.2.5.5** For welding pressure-containing equipment wall thickness in excess of $^{3}/_{8}$ in. (9.5 mm), the diffusible hydrogen limit for FCAW consumables (as manufactured) shall meet the specifications in Table 1.

**Table 1—Diffusible Hydrogen Limits for FCAW Consumables**

| Specified Minimum Tensile Strength for the Base Metal | Maximum Diffusible Hydrogen Designation (per ASME/AWS SFA/A5.20 or SFA/A5.29) |
|---|---|
| ≤ 70 ksi (483 MPa) | H16 |
| > 70 ksi (483 MPa) and ≤ 85 ksi (587 MPa) | H8 |
| > 85 ksi (587 MPa) | H4 |

### 5.2.6 EGW

The use of EGW shall be limited by the following conditions:

a) EGW shall be used only with filler materials specifically intended for the EGW process (ASME/AWS SFA/A5.26/SFA/A5.26M),

b) welding consumables shall be limited to the classification and the manufacturer's trade name used in the PQR,

c) only filler materials having classifications with specified minimum impact test requirements should be used.

### 5.2.7 SAW

**5.2.7.1** SAW procedures shall be requalified whenever the welding flux is changed from one manufacturer's trade name to another. Equivalence under ASME *BPVC* Section II, Part C, or AWS filler metal specifications shall not be considered adequate for substitution without requalification.

NOTE It is recognized that fluxes having the same classification can be very different in their composition. However, nominal flux composition is not included in AWS or ASME specifications/codes and flux suppliers do not normally provide this information. Differences among fluxes of the same classification can result in different and unanticipated weld properties when these fluxes are used interchangeably over the range of variables typically stated in weld procedure specifications.

**5.2.7.2** Manually held (semiautomatic) SAW is not permitted for welding pressure-containing parts, unless approved by the purchaser.

**5.2.7.3** A separate qualification is required for SAW welds in which any pass thickness is greater than $^{1}/_{2}$ in. (13 mm).

### 5.3 Single-sided Welded Joints

For single-sided welded joints where process side corrosion is a concern, welding processes using coatings or fluxes shall not be used for root pass welding of austenitic stainless steels, non-ferrous alloys and nickel-base alloys, unless slag can be removed from the process side of root passes and the area inspected for slag removal.

### 5.4 Combining Welding Processes

Combining two or more welding processes that use alloy filler metals of different nominal compositions, other than ASME weld metal classifications A-Numbers 1 through 5, requires qualification as a combination procedure.

### 5.5 Mechanized and Automated Welding Processes

**5.5.1** Orbital welding and similar fully automated welding processes require separate programming weld schedules for the specific joint geometry, diameter, wall thickness, and welding position. These weld schedules shall report all the essential and nonessential variables that are needed to accurately describe all motion (e.g. travel and oscillation), timing and electrical functions of the welding system. The specific weld schedules relevant to each welding procedure shall be noted on the WPS or as a supplementary table attached to the WPS.

**5.5.2** A change in position according to ASME *BPVC* Section IX, QW-461.9 shall be considered an essential variable for procedure qualification.

## 6 Welding Consumables (Filler Metal and Flux)

### 6.1 General

**6.1.1** Filler metals shall be specified in each WPS by ASME II, Part C/AWS specification and classification. Filler metals that do not conform to an ASME/AWS specification shall be submitted to the purchaser for approval.

NOTE Refer to Annex A for general guidance and recommended filler metal selection.

**6.1.2** Testing is required to verify consumable mechanical properties whenever:

a) the deposited filler metal does not fall within any of the ASME/AWS filler metal specifications, or

b) the manufacturer's typical consumable certification or other supplier certifications are not available.

When PWHT is required for either 6.1.2 a) or 6.1.2 b), all-weld-metal test coupons shall be PWHT'd with the nominal temperature and maximum time to be used in production. The tensile strength, yield strength and elongation shall meet the base metal properties.

**6.1.3** Groove and/or fillet welds shall be made with filler metals producing low hydrogen deposits [7]. However, for the following conditions cellulose type coated electrodes are permitted.

a) For API 620 and API 650 storage tank fabrication and erection, where the base metal thickness is less than $^{1}/_{2}$ in. (13 mm) and the minimum specified tensile strength of the base material is less than 70 ksi (483 MPa), cellulose type coated electrodes may be used.

b) For pipe welding of ASME P-No. 1, Group 1, carbon steel base metal, the root pass and second pass of single-groove welds, regardless of base metal thickness, may be welded with cellulose type coated electrodes. In addition, ASME P-No. 1, Group 2, materials may have the root and hot pass welded with cellulose electrodes,

[7] Some industry codes/standards (e.g. API 650) may be more restrictive for certain materials and/or specific applications. Governing industry codes and standards take precedence over this RP.

provided a minimum preheat of 300 °F (149 °C) is used and maintained until the joint is completed or 1/2 in. (13 mm) of weld thickness is completed.

**6.1.4** For carbon steel, if the base metal is exempt from impact testing the weld metal should have a toughness equal to or greater than 20 ft-lb (27 J) at either 0 °F (–18 °C) or the minimum design metal temperature (MDMT), whichever is lower. The weld metal toughness should be certified by the filler metal manufacturer according to ASME *BPVC* Section II, Part C/AWS filler metal specifications, or if approved by the purchaser, should be established by the PQR.

**6.1.5** Procedures using any consumable with a "G" classification shall be restricted to the brand and type of consumable used for the PQR. The nominal chemical composition of the specified brand and type of consumable should be identified on the WPS.

**6.1.6** Welding consumables shall be clearly identified by trade name, where applicable, or AWS classification, and the identity must be maintained until consumed.

**6.1.7** Unless specifically authorized by the purchaser, welding consumables shall be used only for the welding process applications recommended in the ASME II, Part C/AWS filler metal specification or by its manufacturer (e.g. filler metals designed for 'single-pass welding' shall not be used for multiple pass applications and fluxes designated for non-PWHT applications shall not be used for PWHT applications).

**6.1.8** Table A.1 provides recommended filler metal selections for typical P-No. 1 through P-No. 5, P-No. 9, and P-No. 11 materials.

## 6.2 Dissimilar Welding

**6.2.1** When joining dissimilar ferritic steels (P-No. 1 though P-No. 5), the filler metal shall conform to the nominal chemical composition of either base metal or an intermediate composition. However, when attaching non-pressure parts to pressure parts, the filler metal chemical composition shall match the nominal chemical composition of the pressure part.

**6.2.2** When joining ferritic steels (P-No. 1 through P-No. 5 and P-No. 15E) to:

a) martensitic stainless steels (P-No. 6); or

b) ferritic stainless steels (P-No. 7); or

c) austenitic stainless steels (P-No. 8), the filler metal shall be selected based on the following criteria:

1) Type 309 and Type 309L may be used for design temperatures not exceeding 600 °F (315 °C);

NOTE 1 Due to high differential thermal expansion, nickel-base filler metals are preferred for temperatures above 600 °F (315 °C).

NOTE 2 Type 309 Cb (Nb) should not be used when PWHT is required, except for weld overlay.

2) nickel-base alloy filler materials may be selected using design conditions shown in Table 2;

3) for service conditions exceeding the limits stated in 6.2.2.c.1 and 6.2.2.c.2, the filler metal selection shall be reviewed with the purchaser;

4) ASME/AWS Classification ER310 (E310-XX) and ASME/AWS Classification ERNiCrFe-6 shall not be used.

NOTE The use of dissimilar metal welds (carbon or low-alloy to austenitic stainless steel) in services corrosive to carbon and low-alloy steel should be carefully evaluated. Failures have been reported due to hydrogen charging of zones exhibiting high hardness adjacent to the fusion line. It is unclear whether the charging is due to corrosion of the carbon or low-alloy steel alone or accelerated due to the presence of a galvanic couple. In addition, carbon or low-alloy to austenitic stainless steel welds might be susceptible to brittle fracture at service temperatures below –20 °F (–29 °C).

**Table 2—Application of Nickel-base Electrodes in Sulfidation and Non-sulfidation Environments**

| ASME/AWS Filler [1] Material Classification | Maximum Design Temperature (Non-sulfidation [2] Environment) | Maximum Design Temperature (Sulfidation Environment) |
|---|---|---|
| ENiCrFe-3 | 1000 °F (540 °C) | 700 °F (370 °C) |
| ERNiCr-3, ENiCrFe-2 | 1400 °F (760 °C) | 750 °F (400 °C) |
| ERNiCrMo-3, ENiCrMo-3 | 1100 °F (590 °C) | 900 °F (480 °C) |
| NOTE 1 Comparable FCAW consumables may be applied for dissimilar welding applications, provided they are approved by the purchaser.<br>NOTE 2 Refer to API 939-C for the definition of sulfidation. | | |

## 6.3 Low-alloy Steel Welding (P-No. 3 to P-No. 5 and P-No. 15E)

Unless otherwise specified, the welding guidelines referenced in API 934-A, API 934-C, and API 934-E should be followed for welding Cr-Mo steel pressure vessels for high-temperature, high-pressure hydrogen service. C-Mo and Cr-Mo steel piping systems in high-temperature service (below the creep range and whether or not hydrogen is present) should be fabricated using the guidelines in AWS D10.8.

## 6.4 Stainless Steel Welding (P-No. 6, P-No. 7, and P-No. 8)

**6.4.1** Table A.2 provides recommended filler metal selections for typical stainless steel applications.

**6.4.2** For welding austenitic stainless steels (P-No. 8, Group 1), the following guidelines and restrictions apply.

**6.4.2.1** Unless otherwise specified, for materials requiring PWHT or materials in high-temperature service (see ASME *BPVC* Section II, Part D, Table A-360), the ferrite number (FN) for the deposited weld metal should not exceed 10 FN measured prior to PWHT.

NOTE Whenever FN measurements are required in this document, they are to be taken prior to any PWHT and shall be measured with an instrument calibrated to, and listed in, AWS A4.2M or by actual, as-deposited chemical composition using WRC 1992 (FN) Diagram.

**6.4.2.2** The minimum FN for deposited weld metal should be 3 FN, except for the following (if PWHT is performed, the FN shall be measured prior to PWHT).

a) The minimum FN for Type 347 weld deposits shall be 5 FN. The minimum FN may be reduced to 3 FN, provided the fabricator submits data verifying that hot cracking will not occur using the lower FN consumable to be used in production and this is approved by the purchaser.

b) When joining stainless steels for cryogenic service, non-magnetic applications, or special corrosive service, weld deposits with a lower FN may be required.

**6.4.2.3** The FN for 16-8-2 weld deposits shall be 1-5 FN.

**6.4.2.4** When austenitic stainless steel type FCAW weld materials are exposed to temperatures above 1000 °F (538 °C) during fabrication and/or during service:

a) materials shall have a formulation that does not intentionally add bismuth and bismuth in the deposited weld metal shall not exceed 0.002 %,

b) materials shall have a maximum FN of 9 FN.

**6.4.2.5** When welding thick-wall forgings of chemically stabilized stainless steels (such as Type 321, Type 347, and Type 316Cb), grain size of the forging and welding heat input should be controlled, as required by the purchaser, in order to reduce the risk of cracking.

## 6.5 Duplex and Super Duplex Stainless Steel Welding

**6.5.1** The requirements in 6.5.2 through 6.5.8 shall apply when welding duplex and super duplex stainless steels.

**6.5.2** Procedure qualification requirements, including ferrite testing, shall be per 11.3 of this RP.

**6.5.3** Autogeneous welding shall not be performed without approval from the purchaser.

**6.5.4** Consumables and as-welded deposits shall meet the chemical composition requirements shown in Table 3.

NOTE Table A.3 provides recommended filler metal selections for typical duplex stainless steel applications.

**6.5.5** When welding duplex and super duplex stainless steels, consumables shall meet the following requirements.

**6.5.5.1** SAW flux shall be a basic flux.

**6.5.5.2** Filler metal(s) and flux used for the procedure qualification shall be the same manufacturer and manufacturer's trade name as to be used for production.

**6.5.6** Any change in backing gas composition shall be considered an essential variable.

**6.5.7** The oxygen content of the back purging gas at the weld shall be reduced to a maximum of 0.50 % (5000 ppm) before welding. An oxygen concentration monitoring system shall be established.

**6.5.8** Shielding and back purging gases shall be argon or an argon/nitrogen mixture. Other shielding and back purging gases may be used if approved by the purchaser.

**Table 3—Additional Chemical Requirements for Duplex and Super Duplex Stainless Steel Consumables and As-welded Deposits**

| Element | Minimum Chemical Composition (Duplex) | Minimum Chemical Composition (Super Duplex) |
|---|---|---|
| Nitrogen | 0.14 % | 0.20 % |
| Nickel | 8.0 % | 9.0 % |
| Molybdenum | 3.0 % | 3.5 % |
| NOTE At the option of the purchaser, a minimum Pitting Resistance Equivalent Number (PREN) may be specified. | | |

### 6.6 SAW

**6.6.1** The flux trade name and designation used for the procedure qualification shall be specified in both the WPS and PQR.

**6.6.2** Filler metal/flux classifications specified by the manufacturer for single-pass welding shall not be used for multi-pass welding.

**6.6.3** Alloyed submerged arc fluxes shall not be used for welding low-alloy steels. Fluxes that compensate for arc losses of alloying elements are permitted.

**6.6.4** Recrushed slag is not permitted for welding pressure-containing parts.

**6.6.5** Controls shall be in place to ensure recovered flux is not contaminated in the recovery process and that the process meets the flux manufacturer's requirements for protection from moisture.

### 6.7 Electroslag Welding (for Corrosion Resistant Weld Overlay)

If the manufacturer proposes to use an active flux to attain the specified chemistry, the manufacturer shall submit samples produced at both extreme limits, maximum and minimum, of the specified heat input range. Both samples shall meet the overlay chemistry specifications.

### 6.8 Consumable Storage and Handling

**6.8.1** Welding consumables shall be stored and handled in accordance with the manufacturer's instructions.

**6.8.2** Storage and baking of welding consumables shall be carried out in separate ovens. The ovens shall be heated by electrical means and shall have automatic temperature control. Welding consumable storage and baking ovens shall have a visible temperature indicator.

**6.8.3** The fabricator shall have a documented procedure covering the storage, segregation, distribution, and return of all welding consumables. Filler metal identity must be maintained.

### 6.9 Alloy Consumable Controls

Prior to production welding, each heat and lot of consumables shall be subject to positive material identification (PMI) using a weld metal button/pad or other suitable means, as agreed with the purchaser. After PMI confirmation, alloy welding consumables shall be segregated and uniquely identified from other consumables in the shop.

## 7 Shielding and Purging Gases

**7.1** When shielding gas(es) are used, the WPS shall indicate the shielding gas (or gas mixture), percent composition of gas(es) and flow rate.

**7.2** Shielding gases shall meet the purity requirements of ASME/AWS SFA/A5.32/5.32M. Gas purity should be recorded on the PQR and WPS when a single gas is used.

**7.3** Back purging is required for the GTAW and GMAW processes for welding materials having a nominal chromium content greater than 2-$^{1}/_{4}$ %, unless the joint is ground or back gouged to sound metal. For GMAW-S variations, see 5.2.3 e).

a) When a back purge is used, the WPS shall state the gas used, including composition of the gas mixture and the flow rate.

b) Whenever a back purging gas is selected to prevent oxidation or scale formation on the underside of the weld, the purge shall be maintained until at least $^1/_4$ in. (6.5 mm) depth of weld metal has been deposited.

c) For socket, seal, and any other attachment welds on base materials less than $^1/_4$ in. (6.5 mm) thick, the back purging shall be maintained throughout the welding operation.

# 8 Preheating and Interpass Temperature

**8.1** Preheating, where required, applies to all welding, tack welding, and thermal cutting. Minimum preheat requirements shall follow the applicable code and recommended practice such as Appendix R of ASME *BPVC* Section VIII Division 1, Table 330.1.1 of ASME B31.3, API 934-A, API 934-C, API 934-E, and Annex XI of AWS D1.1. Any recommendations or requirements for preheat listed in the relevant code shall be considered mandatory.

**8.2** The preheat temperature shall be applied, and for low-alloy steels, maintained until PWHT is completed throughout the entire thickness of the weld and at least 3 in. (75 mm) on each side of the weld, unless a dehydrogenation heat treatment (DHT) is applied immediately after welding is completed. Consideration should be given to lowering the preheat temperature to below Mf (martensite finish temperature) prior to PWHT.

**8.3** Preheat and interpass temperatures shall be checked by use of thermocouples, temperature indicating crayons, pyrometers or other suitable methods. For austenitic stainless steels, duplex stainless steels, and nickel alloys, digital hand-held contact thermocouples are preferred over temperature indicating crayons to avoid the potential contamination from tramp elements, such as fluorides, chlorides, and sulfides, which may be contained in the crayons.

**8.4** The maximum interpass temperature shall be specified in the WPS and PQR for austenitic stainless steels, duplex stainless steels, and non-ferrous alloys and when impact testing is required for carbon and low-alloy steels. Table 4 provides recommended interpass temperatures.

**8.5** When welding high carbon equivalent forgings and fittings, special welding procedures, including preheat and cooling rate control for hardness management, needs to be developed to reduce the risk of hydrogen assisted cracking.

**8.6** The maximum interpass temperatures for duplex and super duplex stainless steels shall be according to Table 5.

**8.7** Preheat, interpass, and preheat maintenance temperatures shall be measured on the weld metal or on the immediately adjacent base metal. Temperature indicating crayons are not permitted directly on weld metal or on the joint preparation.

# 9 Post-weld Heat Treatment (PWHT)

**9.1** PWHT used for a PQR shall be in accordance with a procedure based on the requirements of the applicable code and purchase order. For production use, the heat treatment procedure shall be reviewed and approved by the purchaser prior to PWHT.

**9.2** All WPSs specifying PWHT should indicate the following:

a) maximum heating rate,

b) holding temperature range,

c) holding time,

d) maximum cooling rate.

**Table 4—Recommended Maximum Interpass Temperatures**

| Material Group | Maximum Interpass Temperature |
|---|---|
| P-No. 1 (carbon steels) | 600 °F (315 °C) |
| P-No. 3, P-No. 4, P-No. 5A, P-No. 5B, P-No. 5C, and P-No. 15E (low-alloy steels) | 600 °F (315 °C) |
| P-No. 6 (Type 410) | 600 °F (315 °C) |
| P-No. 6 (CA6NM) | 650 °F (345 °C) |
| P-No. 7 (Type 405/410S) | 500 °F (260 °C) |
| P-No. 8 (austenitic stainless steel) | 350 °F (175 °C) |
| P-No. 10H (duplex and super duplex stainless steels) | Refer to Table 5 |
| P-No. 11A, Group 1 | 350 °F (175 °C) |
| P-No. 41, P-No. 42 | 300 °F (150 °C) |
| P-No. 43, P-No. 44, and P-No. 45 | 350 °F (175 °C) |

**Table 5—Maximum Recommended Interpass Temperatures for Duplex and Super Duplex Stainless Steels**

| Base Metal or Component Thickness | Maximum Interpass Temperature | |
|---|---|---|
| | Duplex Stainless Steel (e.g. UNS S32205) | Super Duplex Stainless Steel (e.g. UNS S32750) |
| < 1/8 in. (3 mm) | 120 °F (50 °C) | 120 °F (50 °C) |
| < 1/4 in. (6 mm) | 160 °F (70 °C) | 160 °F (70 °C) |
| < 3/8 in. (9.5 mm) | 210 °F (100 °C) | 210 °F (100 °C) |
| > or = 3/8 in. (9.5 mm) | 300 °F (150 °C) | 250 °F (120 °C) |

NOTE For P-No. 10H material, the production interpass temperature shall not exceed the interpass temperature used during procedure qualification.

As an alternative, the WPS may reference a separate project-specific PWHT procedure.

**9.3** For special heat treating methods, such as induction and internally fired, the PWHT procedure shall be approved by the purchaser prior to production.

**9.4** Unless waived by the purchaser, PQR hardness testing shall be performed to verify that hardness requirements can be met following a specified PWHT.

NOTE Testing is often waived when PWHT is performed for reasons such as dimensional stability or construction code thickness requirements.

**9.4.1** When testing is performed due to service conditions (NACE SP0472 or as defined by purchaser), testing requirements and methods given in 12.6.1 shall be used for PQR testing, unless otherwise specified by the purchaser.

**9.4.2** When testing is performed for reasons other than service related conditions, testing requirements shall be specified by the purchaser.

**9.5** Production hardness testing may be required by the purchaser to verify adequacy of heat treatments. The purchaser may specify testing requirements as noted in 12.6.2, or define company specific requirements.

**9.6** PWHT of austenitic stainless steel, duplex/super duplex stainless steel, and non-ferrous alloys requires approval by the purchaser.

**9.7** Except for weld overlays, welding procedure qualification tests for austenitic stainless steel to ferritic steel welds shall employ the maximum PWHT temperature limit specified in the welding procedure whenever the stainless steel is heated above 1300 °F (705 °C).

**9.8** Repairing a PWHT'd component without PWHT requires that the repair meet all applicable construction code requirements, or follow NB-23 or API 510. Purchaser approval shall be obtained prior to performing the repair. Procedure qualifications shall be done in accordance with ASME IX.

NOTE If PWHT was originally conducted due to service requirements, specifically environmental cracking prevention, PWHT of the repair should be strongly considered.

**9.9** When repairs are made to cladding or overlay welds on low-alloy steels without subsequent PWHT, a minimum remaining clad or overlay thickness of $^{3}/_{16}$ in. (4.8 mm) is required, unless it can be demonstrated that no new HAZ is formed in the base metal with thinner overlay.

**9.10** Exemption of code required PWHT for ferritic materials based on the use of austenitic or nickel-base filler materials is not permitted.

**9.11** Code exemption of PWHT for P-No. 4 and P-No. 5 materials is not permitted for applications in sour or hydrogen service [8] or where the nominal chromium content of the material exceeds 1.25 %.

**9.12** Table 6 lists suggested PWHT holding temperatures and times. Code requirements, project specifications and tempering temperatures should be considered when selecting final PWHT temperatures.

**Table 6—PWHT Temperatures and Holding Times**

| P-No. | Material Type | Nominal Thickness at Weld (in.) | Service Environment | Holding Temperature (°F) [a] | Time at Holding Temperature (hr) |
|---|---|---|---|---|---|
| 1 | carbon steel | according to code | code | 1100 to 1200 | 1, minimum |
| 1 | carbon steel | all | wet $H_2S$ | 1150 to 1200 | 1, minimum |
| 1 | carbon steel | all | caustic | 1150 to 1200 | 1, minimum |
| 1 | carbon steel | all | amine | 1150 to 1200 | 1, minimum |
| 1 | carbon steel | all | carbonates | 1200 to 1250 | 1, minimum |
| 1 | carbon steel | all | HF acid | 1150 to 1200 | 1, minimum |
| 1 | carbon steel | all | deaerator | 1150 to 1200 | 1, minimum |
| 1 | carbon steel | all | ethanol | 1150 to 1200 | 1, minimum |
| 3 | C-$^{1}/_{2}$Mo | according to code | code | 1150 to 1200 | 1, minimum |
| 3 | C-Mn-Mo | all | all | 1150 to 1200 | 1, minimum |
| 4 | 1Cr-$^{1}/_{2}$Mo, 1 $^{1}/_{4}$Cr-$^{1}/_{2}$Mo | all | for maximum tempering (creep) | 1275 to 1325 | 2, minimum |
| 4 | 1Cr-$^{1}/_{2}$Mo, 1 $^{1}/_{4}$Cr-$^{1}/_{2}$Mo | all | for optimum high-temperature properties (toughness) | 1250 to 1300 | 2, minimum |

8 The purchaser shall define the conditions for sour service (e.g. company specific or reference to NACE MR 0103) and/or hydrogen service (e.g. hydrogen partial pressure).

**Table 6—PWHT Temperatures and Holding Times (Continued)**

| P-No. | Material Type | Nominal Thickness at Weld (in.) | Service Environment | Holding Temperature (°F) [a] | Time at Holding Temperature (hr) |
|---|---|---|---|---|---|
| 4 | 1Cr-1/2Mo, 1 1/4Cr-1/2Mo | all | heavy wall pressure vessels for high-pressure hydrogen service operating at or below 825 °F (441 °C) | 1225 to 1275 | 2, minimum, see to API 934-C for more details |
| 4 | 1 1/4Cr-1/2Mo | all | pressure vessels for service above 825 °F (440 °C) | 1225 to 1275 | 2, minimum, see to API 934-E for more details |
| 5A | 2 1/4Cr-1Mo | all | for maximum tempering (creep) | 1300 to 1350 | 2, minimum |
| 5A | 2 1/4Cr-1Mo | all | for maximum high-temperature properties (toughness) | 1275 to 1325 | 2, minimum |
| 5A | 2 1/4Cr-1Mo | all | heavy wall pressure vessels for high-temperature, high-pressure hydrogen service | 1250 to 1300 | 2, minimum, see API 934-A for more details |
| 5B | 5Cr-1/2Mo | all | all | 1325 to 1375 | 2, minimum |
| 5B | 9Cr-1Mo | all | all | 1350 to 1400 | 2, minimum |
| 15E | 9Cr-1Mo-V | according to code | all | 1375 to 1425 | 2, minimum |
| 5C | 2 1/2Cr-1Mo-V | all | heavy wall pressure vessels for high-temperature, high-pressure hydrogen service | 1275 to 1325 | 8, minimum, see API 934-A for more details |
| 6 | martensitic stainless steels | according to code | all | according to code [b] | 2, minimum |
| 7 | ferritic stainless steels | according to code | all | according to code | 1, minimum |
| 8 | austenitic stainless steels | according to code | all | according to code [c] | according to code |
| 9A | 1 1/2 to 2 1/2 Ni | according to code | all | 1100 to 1150 | 1, minimum |
| 9B | 3 1/2 Ni | | | | |
| 10H | duplex stainless steels | according to code | all | according to code | according to code |
| 11A | 8 Ni, 9 Ni | according to code | all | according to code [d] | 1, minimum |
| 45 | alloy, 800, 800H, 800HT | according to code | all | according to code | according to code |

a) For quenched and tempered or normalized and tempered materials, the PWHT holding temperature shall be at least 25 °F (15 °C) below the original tempering temperature of the base metal, unless the fabricator demonstrates that mechanical properties can be achieved at a higher PWHT temperature and holding time.

b) For Type CA6NM material, a double tempering heat treatment is required. Initial heat treatment at 1225 °F to 1275 °F, followed by air cooling to ambient temperature, and second heat treatment at 1100 °F to 1150 °F and air cooling to ambient temperature.

c) For Type 321 and Type 347 materials, postweld thermal stabilization may be specified at 1600 °F to 1650 °F for two to four hours.

d) For 9 % Ni, the entire vessel, assembly, or plate must be at the PWHT holding temperature at the same time. The cooling rate from the holding temperature shall not be less than 300 °F (167 °C) per hour down to a temperature of 600 °F (315 °C). A local or partial PWHT cannot be used since this results in portions of the structure being in the embrittlement range of 600 °F to 1000 °F (315 °C to 540 °C) for extended periods of time, thereby impairing material toughness.

**9.13** Local PWHT involving circumferential bands around piping or vessels shall be performed according to AWS D10.10 and WRC Bulletin 452, respectively.

**9.14** Local spot PWHT (called a "bull's eye") on vessels or piping shall require approval of the purchaser.

# 10 Cleaning and Surface Preparation

**10.1** The methods for cleaning base metal surfaces to be welded shall be specified in the WPS.

**10.2** For equipment that will be coated following fabrication, the purchaser should specify the extent of any additional weld surface preparation requirements.

**10.3** Welding shall not be performed when the base metal surface is wet or damp.

**10.4** For double-welded joints, the backside of the joints shall be cleaned/gouged to sound metal.

**10.5** All slag shall be removed from the backside of each completed austenitic stainless steel or nickel-base alloy weld, unless otherwise permitted by the purchaser.

**10.6** Aluminum flake weld-through primers may be used for weld joint surface protection. The WPS should indicate the weld-through primer by type and brand. The use of other types of weld-through primers or coatings is not permitted, unless approved by the purchaser, and the purchaser may require additional procedure qualifications or weldability tests.

**10.7** Carbon steel wire brushes or other tools shall not be used on stainless steel, duplex or super duplex stainless steels, or non-ferrous materials, nor shall brushes or tools be used that have been previously used on carbon or low-alloy steel.

**10.8** If carbon-arc cutting or gouging are used on austenitic stainless steels, the surface must be ground to a bright surface finish. Carbon-arc cutting or gouging is prohibited on duplex or super duplex stainless steels.

NOTE Poor gouging technique can allow localized spots to absorb carbon. These spots are prone to sensitization and can result in a pit initiation site.

**10.9** For 9 % nickel material, machine or grind thermally cut edges to remove dross and burn serrations.

# 11 Special Procedure Qualification Requirements/Testing

## 11.1 General

**11.1.1** PQRs for all welding processes shall include the results of any additional tests, when specified. Some examples are as follows.

a) Hardness Testing—Record hardness results and location (e.g. weld metal, HAZ, and base metal).

b) Impact Testing—Record the absorbed energy values with test temperature, specimen size, percent shear and lateral expansion (when required) for specified notch locations (e.g. weld metal and HAZ).

**11.1.2** When specified by the purchaser, mockups simulating production conditions shall be performed whenever the accessibility and restraint of the code qualification coupon fails to simulate production conditions.

**11.1.3** For special applications determined by the purchaser, such as, but not limited to severe corrosion service or high-temperature service, special qualification tests, such as stress corrosion cracking or temper embrittlement tests, may be specified.

## 11.2 Tube-to-tubesheet Welding

**11.2.1** For all tube-to-tubesheet designs where the weld is the fundamental strength or pressure-containing element, WPSs shall be qualified and tested in accordance with ASME *BPVC* Section IX, QW-193, and QW-288. The vendor shall submit a complete fabrication plan (including assembly, cleaning, weld preparation, rolling and testing) to the purchaser for approval.

**11.2.2** WPSs for seal welding of tube-to-tubesheets shall be qualified in accordance with ASME *BPVC* Section IX, QW-202.6a, b, or c.

## 11.3 Additional Procedure Qualification Requirements for Duplex and Super Duplex Stainless Steels

### 11.3.1 General

Procedure qualifications shall be done on duplex and super duplex stainless steel base metals of the same UNS number as to be used in production and according to the following requirements.

NOTE These requirements do not apply to material that will be solution annealed.

### 11.3.2 Thickness and Heat Input

**11.3.2.1** The minimum and maximum qualified weld thickness ($t$) shall be as follows:

a) For $t$ < or = $^5/_8$ in. (16 mm), the minimum qualified thickness shall be the thickness of the qualification test coupon (T) and the maximum qualified thickness shall be 2T, up to a maximum of $^5/_8$ in. (16 mm).

b) For $t$ > $^5/_8$ in. (16 mm), but < 1-$^1/_8$ in. (29 mm), the minimum and maximum qualified thicknesses may be qualified by qualification test coupons within this range.

c) For $t$ > or = 1-$^1/_8$ in. (29 mm), the minimum qualified thickness is T and the maximum qualified thickness shall be 1.2T.

**11.3.2.2** The heat input shall not exceed the maximum used during procedure qualification. The minimum heat input qualified shall be the higher of 0.5 kJ/mm (12.7 kJ/in.) or 50 % of the maximum used on the PQR. See ASME *BPVC* Section IX, QW-409.1(c) and Appendix H for waveform-controlled welding.

### 11.3.3 Welding Position

For manual and semi-automatic welding, the procedure shall be qualified in the 3G, 5G, or 6G positions. Vertical weld progression shall be uphill.

### 11.3.4 Ferrite to Austenite Ratio

**11.3.4.1** Measurement of the ferrite to austenite content in the deposited weld metal and heat affected zone (HAZ) shall be performed according to ASTM E562 and at a magnification of 400X, or greater. The number of fields and points per sampled area shall be in agreement with the guidance displayed in the 10 % relative accuracy column in ASTM E562, Table 3.

As a guideline, magnification should be based on the initial determination of the sample areas to be tested to ensure that the microstructure can be clearly resolved without having adjacent grid points fall over the same constituent feature. A 100-point grid mapped over 10 fields in a target area (weld/HAZ) may be considered sufficient for material with 30 %, or greater, ferrite content.

**11.3.4.2** The following three areas shall be evaluated for ferrite/austenite and reported in the PQR:

a) root pass,

b) mid-thickness,

c) cover pass (this is to be used as a reference for the test required on production welds).

Ferrite content shall be measured in each location using both the point count method and ferrite scope. The ferrite scope testing at each location shall consist of 5 readings averaged using a ferrite scope calibrated in accordance with AWS A4.2M. The ferrite scope Ferrite Number (FN) readings are to be used as a reference during ferrite testing of production welds.

**11.3.4.3** Ferrite content shall be within the following ranges:

a) weld metal—30 % to 65 %,

b) HAZ—40 % to 65 %,

c) base metal—40 % to 60 %.

NOTE 1 Ferrite content down to 25 % may be acceptable for the weld metal if corrosion or other tests are satisfactory to the purchaser. When a nickel alloy consumable is used, the ferrite content in the weld deposit is not required to be tested.

NOTE 2 To convert from ferrite % to FN, the following can be used: For 22 % Cr duplex stainless steel, ferrite % = 0.7 × FN; For 25 % Cr duplex and super duplex stainless steels, ferrite % = 0.65 × FN.

**11.3.5 Hardness Testing**

**11.3.5.1** For duplex stainless steel, the maximum allowable hardness is 320 HV10.

**11.3.5.2** For super duplex stainless steel, the maximum allowable hardness is 350 HV10.

**11.3.6 Corrosion and Impact Testing**

**11.3.6.1 General**

Either the corrosion or impact test described below shall be performed on the PQR sample.

NOTE The corrosion test is more sensitive and should be required for critical applications, as determined by the purchaser.

**11.3.6.2 Corrosion Test**

a) One test specimen that includes the weld, HAZ, and base metal shall be removed from each procedure qualification test coupon and tested in accordance with ASTM A923, Method C (for duplex and super duplex stainless steels), and examined at 20× magnification. Acceptance criteria shall be per ASTM A923, except that no pitting is allowed. The Rapid Screening Test method per ASTM A923 is not permitted.

b) Third-party laboratories used for testing shall have prior experience with duplex stainless steel testing using ASTM G48 Method A or ASTM A923, Method C. The vendor shall submit the laboratory name and qualifications to the owner to be used for qualification and production testing.

c) If the test results do not meet the acceptance criteria, then a new specimen may be taken and retested. The owner must be notified before proceeding with retesting.

#### 11.3.6.3 Impact Test

a) Impact tests shall be performed in accordance with ASME *BPVC*, Section VIII requirements.

b) For Charpy V notch impact tests of the weld metal and HAZ, three specimens for each location are required. The following values for grade UNS S32205 are required for full-size specimens.

   1) Weld metal: 25 ft-lb (34 J), average and 20 ft-lb (27 J), minimum at –40 °F (–40 °C),

   2) HAZ: 40 ft-lb (54 J), average and 32 ft-lb (43 J), minimum at –40 °F (–40 °C).

Acceptance values for other grades of duplex stainless steel shall be agreed upon with the owner's engineer.

c) The orientation of standard size specimens shall be per the governing code. If the specimen orientation is not specified, the orientation shall be per ASME *BPVC*, Section VIII Div. 1, UG84. In addition, the weld metal impact specimen shall be removed from the T/2 (mid-wall) position. Furthermore, the HAZ impact specimen location may need to be adjusted to ensure the notch is completely in the HAZ, but should be as close as feasible to the T/2 position.

d) The lateral expansion shall be 0.015 in. (0.38 mm), minimum.

#### 11.3.7 Tube-to-tubesheet Joints

**11.3.7.1** In addition to the macro-examination required by ASME *BPVC* Section IX, QW-193, the microstructure and ferrite content of one randomly selected weld section shall be assessed using the procedures detailed in 11.3.4.

**11.3.7.2** Hardness (HV10) readings shall be taken in the weld deposit and tubesheet base metal, and HV5 readings shall be taken in the HAZ. A minimum of 6 readings shall be taken on each of the tube-to-tubesheet joints prepared for metallography. Hardness shall not be above 320 HV on duplex grades and shall not be above 350 HV for super duplex grades.

**11.3.7.3** When required by the purchaser for standard and 25 % Cr grades, a quadrant section of a tube-to-tubesheet weld shall be corrosion tested in accordance with 11.3.6.2. No pitting is allowed. This does not apply to dissimilar tube-to-tubesheet welds.

## 12 Other Items

### 12.1 Backing Materials

Where metallic backing material is permitted, the P-No., or its nominal chemical composition shall be specified in the WPS and/or the applicable fabrication drawing. For joints between similar materials, the chemical composition of backing materials shall match the nominal base metal chemical composition.

### 12.2 Peening

Peening is permitted only with the approval of the purchaser.

### 12.3 Weld Overlay and Clad Restoration (Back Cladding)

**12.3.1** Weld overlays shall be qualified in accordance with ASME *BPVC* Section IX.

**12.3.2** WPSs for weld overlay shall include the chemical composition/composition ranges of the major elements for the particular alloy (see Annex B).

**12.3.3** Single-sided welding of clad or weld overlaid material shall be qualified using clad or overlaid materials.

**12.3.4** Annex B provides detailed requirements (e.g. production chemical composition sampling) and guidelines for performing weld overlay and clad restoration (back cladding).

## 12.4 Temporary Attachments

Temporary attachments welded to the base metal shall be compatible with the base metal and welded in accordance with a qualified weld procedure. Temporary attachments shall be removed by gouging or grinding and the base metal restored to its original condition before final heat treatment (if required), pressure testing, and final acceptance. The base metal shall be inspected with MT or PT upon removal of the attachment.

## 12.5 Stud Welding

**12.5.1** Automatically timed arc and resistance stud welding for attaching load-carrying studs shall be per UW-27, UW-28, and UW-29 of ASME *BPVC* Section VIII, Division 1 or AWS D1.1, Section 7 for structural attachment. A production test sample of at least five consecutively welded studs shall be tested at the beginning of each shift and after performing maintenance operations on the stud welding equipment. Note that adjustments might be necessary due to increased power draw during the shift.

**12.5.2** Automatically timed arc and resistance stud welding for attaching non-load-carrying studs (such as extended heat transfer surfaces and insulation attachment pins) shall be qualified on materials having the same nominal chemistries as the production welds and a WPS shall be prepared. A production test sample of at least five consecutively welded studs shall be tested at the beginning of each shift and after performing maintenance operations on automatic equipment.

**12.5.3** Production welds shall be bend or hammer tested in accordance with ASME *BPVC* Section IX, QW-192. When permitted by the purchaser, joints with less than 100 % fusion may be accepted.

## 12.6 Hardness Testing—Weld Procedure Qualification and Production Testing

**12.6.1** When specified by the purchaser, hardness testing shall be performed in accordance with the latest edition of NACE MR0103 or NACE MR0175/ISO 15156.

**12.6.2** Hardness testing results shall comply with the latest edition of NACE SP0472 and NACE MR0103.

## 12.7 Single-pass Welds

Single-pass welds are not permitted, unless approved by the purchaser.

## 12.8 Additional Production Requirements for Welding Duplex and Super Duplex Stainless Steel

**12.8.1** ASME *BPVC* Section VIII, Division 1 Required Production Test Plates: Each heat of plate used to fabricate shell and head segments shall be subjected to production testing. Test plates shall be made from the same heat as the base material and installed as run-off tabs at the end of longitudinal weld seams. The test plate shall be of sufficient size to equal the cooling gradient of the component. The samples shall be subjected to ferrite-to-austenite ratio testing as required in 11.3.4 and impact testing as required in 11.3.6.3.

**12.8.2** Pressure boundary welds shall have ferrite measurements made by using a ferrite scope calibrated in accordance with AWS A4.2M. A total of five (5) measurements shall be taken in the center of each weld cap and, if accessible, the root pass. Welds made from each weld procedure, welder, and heat/lot of filler metal shall be tested. The weld cap and root pass shall be prepared as recommended by the manufacturer of the testing instrument. The acceptance criteria shall be per 11.3.4.3.

**12.8.3** Whenever ferrite testing is required for production welds, the number of tests shall be as follows:

a) For piping, each weld shall be tested and the number of tests for circumferential welds shall be as follows: for NPS up to 24, two (2) ferrite tests; for NPS 26 through NPS 36, three (3) ferrite tests; and for NPS 38 and larger, four (4) ferrite tests.

b) For equipment, the main pressure-retaining welds should be tested at least once in every 10 ft. (3.0 m) of linear weld. Nozzle connection welds should have one (1) test per weld.

c) See 11.3.4.1 for further details on ferrite measurements.

**12.8.4** Hardness tests in the weld metal and base metal are required on the greater of $^{1}/_{3}$ of all welded joints or one spot per 50 ft. (15.2 m) of weld. The maximum permitted hardness shall be per 11.3.5.

# Annex A
(informative)

## Welding Consumables for Shielded Metal Arc Welding (SMAW)

Table A.1, Table A.2, Table A.3, and Table A.4 provide generally accepted electrode selections for the base materials shown. They do not attempt to include all possible choices. Welding consumables not shown for a particular combination of base materials shall be approved by the purchaser.

## Table A.1—Carbon and Low-alloy Steel

| **Base Material** (see Notes 1, 2, and 4) | **Carbon Steel** | **Carbon-molybdenum Steel** | **1 and 1 1/4 Cr-1/2 Mo Steel** | **2 1/4 Cr-1 Mo Steel** | **5 Cr-1/2 Mo Steel** | **9 Cr-1 Mo Steel** | **2 1/4 Nickel Steel** | **3 1/2 Nickel Steel** | **9 % Nickel Steel** |
|---|---|---|---|---|---|---|---|---|---|
| Carbon steel | AB (see Note 3) | AC | AD | ADE | ADEF | ADEFH | AJ | AK | * |
| Carbon-molybdenum steel | | C | CD | CDE | CDE | CDEFH | * | * | * |
| 1 and 1 1/4 Cr-1/2 Mo steel | | | D | DE | DEF | DEFH | * | * | * |
| 1/4 Cr-1 Mo steel | | | | E | EF | EFH (see Note 4) | * | * | * |
| 5 Cr-1/2 Mo steel | | | | | F | FH | * | * | * |
| 9 Cr-1 Mo steel | | | | | | H (see Note 4) | * | * | * |
| 2 1/4 nickel steel | | | | | | | J | JK | LM |
| 3 1/2 nickel steel | | | | | | | | K | LM |
| 9 % nickel steel | | | | | | | | | LM |

**Key**

A ASME/AWS SFA/A 5.1, Classification E70XX low hydrogen (see Note 5).

B ASME/AWS SFA/A 5.1, Classification E6010 for root pass (see Note 5).

C ASME/AWS SFA/A 5.5, Classification E70XX-A1, low hydrogen.

D ASME/AWS SFA/A 5.5, Classification E70XX-B2L (see Note 6) or E80XX-B2, low hydrogen.

E ASME/AWS SFA/A 5.5, Classification E80XX-B3L (see Note 6) or E90XX-B3, low hydrogen.

F ASME/AWS SFA/A 5.5, Classification E80XX-B6 or E80XX-B6L (see Note 6), low hydrogen.

H ASME/AWS SFA/A 5.5, Classification E80XX-B8 or E80XX-B8L (see Note 6), low hydrogen.

J ASME/AWS SFA/A 5.5, Classification E80XX-C1 or E70XX-C1L, low hydrogen.

K ASME/AWS SFA/A 5.5, Classification E80XX-C2 or E70XXC2L, low hydrogen.

L ASME/AWS SFA/A 5.11, Classification ENiCrMo-3.

M ASME/AWS SFA/A 5.11, Classification ENiCrMo-6, ENiCrFe-4, ENiCrFe-9, ENiCrMo-3, ENiCrMo-4, ENiCrMo-10, ENiMo-8, or ENiMo-9.

* An unlikely or unsuitable combination. Consult the owner's engineer if this combination is needed.

NOTE 1 This table refers to coated electrodes. For bare and cored wire welding (SAW, GMAW, GTAW, FCAW), use equivalent electrode classifications (ASME/AWS SFA/A5.14, SFA/A5.17, SFA/A5.18, SFA/A5.20, SFA/A5.23, SFA/A5.28, SFA/A5.29, SFA/A5.34). Refer to the text for information on other processes.

NOTE 2 Higher alloy electrode specified in the table should normally be used to meet the required tensile strength or toughness after PWHT. The lower alloy electrode specified may be required in some applications to meet weld metal hardness requirements.

NOTE 3 Other E60XX and E70XX welding electrodes may be used if approved by the purchaser.

NOTE 4 This table does not cover modified versions of Cr-Mo alloys.

NOTE 5 See 6.1.3.

NOTE 6 PWHT can cause the strength of these filler metals to drop below minimum requirements. Care should be taken to ensure adequate strength in the PWHT condition.

## Table A.2—Stainless Steel Alloys

| **Base Material** (see Notes 1, 2, and 3) | **Type 405 Stainless Steel** | **Type 410S Stainless Steel** | **Type 410 Stainless Steel** | **Type 304 Stainless Steel** | **Type 304L Stainless Steel** | **Type 304H Stainless Steel** | **Type 310 Stainless Steel** | **Type 316 Stainless Steel** | **Type 316L Stainless Steel** | **Type 317L Stainless Steel** | **Type 321 Stainless Steel** | **Type 347 Stainless Steel** | **Type 347H Stainless Steel** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Carbon and low-alloy steel | AB | AB | AB | AB | AB | AB | AB | AB | AB | AB | AB | AB | AB |
| Type 405 stainless steel | ABC | ABC | ABC | AB | AB | AB | AB | AB | AB | AB | AB | AB | AB |
| Type 410S stainless steel | | ABC | ABC | AB | AB | AB | AB | AB | AB | AB | AB | AB | AB |
| Type 410 stainless steel | | | ABC | AB | AB | AB | AB | AB | AB | AB | AB | AB | AB |
| Type 304 stainless steel | | | | D | DH | DJ | A | DF | DGH | DI | DE | DE | DE |
| Type 304L stainless steel | | | | | H | DHJ | A | DF | GH | HI | DE | DE | DE |
| Type 304H stainless steel (see Note 5) | | | | | | J | A | DFJ | DGHJ | DIJ | DEJ | EJ | EJ |
| Type 310 stainless steel | | | | | | | K | AK | A | A | A | A | A |
| Type 316 stainless steel | | | | | | | | F | FG | FI | EF | EF | EF |
| Type 316L stainless steel | | | | | | | | | G | GI | EG | EG | EG |
| Type 317L stainless steel | | | | | | | | | | I | EI | EI | EI |
| Type 321 stainless steel | | | | | | | | | | | E (see Note 1) | E | E |
| Type 347 stainless steel | | | | | | | | | | | | E | E |
| Type 347H stainless steel (see Note 5) | | | | | | | | | | | | | E |

**Key**

A ASME/AWS SFA/A 5.4, Classifications E309-XX or E309L-XX.

B ASME/AWS SFA/A 5.11, Classification ENiCrFe-2 or -3 or ENiCrMo-3 (see Note 4).

C ASME/AWS SFA/A 5.4, Classification E410-XX (0.05 % C max.) (heat treatment at 1400 °F required).

D ASME/AWS SFA/A 5.4, Classification E308-XX or E308L-XX.

E ASME/AWS SFA/A 5.4, Classification E347-XX.

F ASME/AWS SFA/A 5.4, Classification E316-XX.

G ASME/AWS SFA/A 5.4, Classification E316L-XX.

H ASME/AWS SFA/A 5.4, Classification E308L-XX.

I ASME/AWS SFA/A 5.4, Classification E317L-XX.

J ASME/AWS SFA/A 5.4, Classification E308H-XX.

K ASME/AWS SFA/A 5.4, Classification E310-XX.

NOTE 1 This table refers to coated electrodes. For bare wire or cored welding (SAW, GMAW, GTAW, FCAW), use equivalent electrode classifications (ASME/AWS SFA/A 5.9, SFA/A5.14, SFA/A5.22, SFA/A5.34). Refer to the text for information on other processes. Either ER347 or ER321 may be used for GTAW or PAW of Type 321 stainless steel.

NOTE 2 The higher alloy electrode specified in the table is normally preferred.

NOTE 3 See Section 6 weld metal delta ferrite requirements.

NOTE 4 See 6.2.2 for the temperature limitation for nickel-base filler metals.

NOTE 5 E16-8-2 is often specified when the weld deposit will be exposed to high creep strains where sigma phase may affect performance.

## Table A.3—Duplex Stainless Steels

| Base Metals | Duplex Alloys | | | | | | Undermatched Alloys | | | Overmatched Alloys | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UNS** | **S32304** | **S31803<br>S32205<br>J92205** | **S32550** | **S32760<br>J93380** | **S32750** | **S39274** | **P1-P5** | **P8 (TP 304)** | **P8 (TP 316)** | **P8 (TP 254 SMO)** | **P43 (IN 625)** | **P45 (IN 825)** |
| S32304 | A-DF | A-DF | A-DF | A-DF | A-DF | A-DF | AEF | AEF | AF | GH | GH | GH |
| S31803<br>S32205 | | A-D | A-D | A-D | A-D | A-D | AEF | AEF | AF | GH | GH | GH |
| J92205 | | A-D | A-D | A-D | A-D | A-D | AEF | AEF | AF | GH | GH | GH |
| S32550 | | | B-D | B-D | B-D | B-D | ABEF | ABEF | ABF | GH | GH | GH |
| S32760 | | | | CDGH | CDGH | CDGH | A-DEF | A-DEF | A-DF | GH | GH | GH |
| J93380 | | | | CDGH | CDGH | CDGH | A-DEF | A-DEF | A-DF | GH | GH | GH |
| S32750 | | | | | CDGH | CDGH | A-DEF | A-DEF | A-DF | GH | GH | GH |
| S39274 | | | | | | CDGH | A-DEF | A-DEF | A-DF | GH | GH | GH |

**Key**

A ASME SFA 5.4, Classification E2209—duplex filler material.

B ASME SFA 5.4, Classification E2553—duplex filler material.

C ASME SFA 5.4, Classification E2594—duplex filler material.

D DP3W (unclassified)—duplex filler material.

E ASME SFA 5.4, Classification E309L—high-alloy austenitic filler material.

F ASME SFA 5.4, Classification E309LMo—high-alloy austenitic filler material.

G ASME SFA 5.11, Classification ENiCrMo-10—nickel-base filler material.

H ASME SFA 5.11, Classification ENiCrMo-14—nickel-base filler material.

NOTE 1 This table refers to coated electrodes. For bare and cored wire welding (SAW, GMAW, GTAW, FCAW), use equivalent electrode classification (ASME/AWS SFA/A5.9, SFA/A5.14, SFA/A5.22, and SFA/A5.34). Refer to the text for information on other processes.

NOTE 2 At times, ENiCrMo-10, ENiCrMo-13, and ENiCrMo-14 are used for duplex and super duplex weld joints when severe corrosion is anticipated.

**Table A.4—Copper-nickel and Nickel-base Alloys**

| **Base Material** (see Note 1) | **70-30 and 90-10 Cu-Ni** | **Alloy 400 (N04400)** | **Nickel 200 (N02200)** | **Alloy 800 (N08800), 800H (N08810), 800HT (N08811)** | **Alloy 600 (N06600)** | **Alloy 625 (N06625)** | **Alloy 825 (N08825)** | **Alloy C-22 (N06022)** | **Alloy C276 (N10276)** | **Alloy B-2 (N10665)** | **Alloy G-3 (N06985)** | **Alloy G-30 (N06030)** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Carbon and low-alloy steel | BC | BC | C | A | A | A | A | D | E | F | G | H |
| 300 series stainless steel | BC | AC | AC | A | A | A | A | D | E | F | G | H |
| 400 series stainless steel | B | B | AC | A | A | A | A | D | E | F | G | H |
| 70-30 and 90-10 Cu-Ni | B | B | C | C | C | C | C | * | * | * | * | * |
| Alloy 400 (N04400) | | B | BC | A | A | A | A | A | A | F | A | A |
| Nickel 200 (N02200) | | | C | AC | AC | AC | AC | CD | CE | CF | CG | CH |
| Alloy 800 (N08800), 800H (N08810), 800HT (N08811) (see Note 2) | | | | K | A | A | A | DJ | EJ | FJ | GJ | HJ |
| Alloy 600 (N06600) | | | | | A | AJ | A | DJ | EJ | FJ | GJ | HJ |
| Alloy 625 (N06625) | | | | | | J | J | DJ | EJ | FJ | GJ | HJ |
| Alloy 825 (N08825) | | | | | | | J | DJ | EJ | FJ | GJ | HJ |
| Alloy C-22 (N06022) | | | | | | | | D | EJ | FJ | GJ | HJ |
| Alloy C-276 (N10276) | | | | | | | | | E | FJ | GJ | HJ |
| Alloy B-2 (N10665) | | | | | | | | | | F | GJ | HJ |
| Alloy G-3 (N06985) | | | | | | | | | | | G | HJ |
| Alloy G-30 (N06030) | | | | | | | | | | | | H |

**Key**

A ASME/AWS SFA/A 5.11, Classification ENiCrFe-2 or -3.

B ASME/AWS SFA/A 5.11, Classification ENiCu-7.

C ASME/AWS SFA/A 5.11, Classification ENi-1.

D ASME/AWS SFA/A 5.11, Classification ENiCrMo-10.

E ASME/AWS SFA/A 5.11, Classification ENiCrMo-4.

F ASME/AWS SFA/A 5.11, Classification ENiMo-7.

G ASME/AWS SFA/A 5.11, Classification ENiCrMo-9.

H ASME/AWS SFA/A 5.11, Classification ENiCrMo-11.

J ASME/AWS SFA/A 5.11, Classification ENiCrMo-3.

K ASME/AWS SFA/A 5.11, Classification ENiCrCoMo-1 or matching filler.

* An unlikely or unsuitable combination. Consult the purchaser's engineer if this combination is needed.

NOTE 1 Table A.4 refers to coated electrodes. For bare or cored wire welding (SAW, GMAW, GTAW, FCAW), use equivalent electrode classification (ASME/AWS SFA/A 5.14, SFA/A5.34). Refer to the text for information on other processes.

NOTE 2 For Alloys 800, 800H, and 800HT, if sulfidation or stress relaxation cracking is a concern, use matching filler metals.

# Annex B
(normative)

# Weld Overlay and Clad Restoration (Back Cladding)

## B.1 General

**B.1.1** Weld overlays shall be deposited with a minimum of two layers. Machine or automated single-layer overlays are permitted when approved by the purchaser.

**B.1.2** ESW is permitted for weld overlay applications, provided that the following conditions are met.

a) The procedure qualification demonstrates that metallographic examination of overlay cross sections; as required for hard-facing overlay per ASME *BPVC* Section IX, QW-453, Note 8; indicates that at least 5 % penetration has been achieved.

b) The welding procedure production tests required by the purchaser include metallographic examination of overlay cross sections to verify that the overlay penetrated into the base metal with no lack of fusion present.

c) After welding and PWHT, spot UT is performed. For vessels, perform UT on at least four strips, approximately 3.2 in. (80 mm) wide, along the full length of the shell and one (1) strip approximately 3.2 in. (80 mm) wide across each head on weld overlay. UT shall meet the requirements of ASTM 578, Level C.

**B.1.3** Overlap of adjacent weld beads shall be considered an essential variable and shall be the same in production as that used to qualify the weld overlay procedure.

**B.1.4** The PQR chemical analysis shall report all elements for which specific values are given for the consumable in ASME *BPVC* Section II, Part C/AWS filler metal specifications.

**B.1.5** Production weld overlay shall have the chemical composition checked using either:

— a physical sample (e.g. drillings, chips) removed for quantitative analysis; or

— a portable spectrograph or portable X-ray fluorescence machine approved by the purchaser.

**B.1.6** All elements specified for the production overlay chemical composition shall be analyzed and reported, except for carbon and nitrogen when using the X-ray fluorescence method. When carbon and nitrogen are specified, a physical sample is required for quantitative analysis. Alternatively, an optical emission spectrometer may be used to check all required elements, including carbon and nitrogen. Specified elements/acceptance requirements for production overlay and back cladding are found for the particular alloy(s) in B.3 through B.6.

**B.1.7** By separate specification, the purchaser shall establish the method of measurement and requirements for the extent of ferrite and chemical composition checks on production welds. The frequency of sampling for production overlay shall be specified by the purchaser. If PWHT will be performed, the ferrite measurements shall be taken prior to PWHT.

**B.1.8** For the SAW, alloy additions made from the flux shall require approval by the purchaser.

**B.1.9** All overlays shall be 100% liquid penetrant examined. If the item is PWHT, this examination shall be performed after PWHT.

**B.1.10** Consumables for commonly used overlay systems are shown in Table B.1. The purchaser shall approve other systems.

**B.1.11** When PWHT of the base metal is required, PWHT does not have to be performed for welding attachments to the overlay/clad when the actual overlay/clad thickness is $^{3}/_{16}$ in. (4.8 mm) or greater. When the overlay/clad is less than $^{3}/_{16}$ in. (4.8 mm) thick, a specially qualified WPS shall be provided to verify that the attachment weld does not affect the base material.

NOTE This requirement may be waived for P-No. 1 materials when PWHT is a requirement due to material thickness and not for process reasons.

**B.1.12** Electrode nominal diameter and ASME/AWS classification shall be considered essential variables.

**Table B.1—Filler Material Selection for Overlay of Carbon and Low-alloy Steels**

| Overlay Material | Weld Overlay Materials [a, d] | | | |
|---|---|---|---|---|
| | Equipment Requiring PWHT | | Equipment Not Requiring PWHT | |
| | First Layer | Top Layer(s) | First Layer | Top Layer(s) |
| 405/410 S | ENiCrFe-2 or -3 or ERNiCr-3 or E/ER309/309L | | ENiCrFe-2 or -3 or ERNiCr-3 or E/ER309/309L | |
| 304 SS | [b] | [b] | E/ER309 | E/ER308 |
| 304L SS | E/ER/EQ309L | E/ER/EQ308L | E/ER/EQ309L | E/ER/EQ308L |
| 316 SS | [b] | [b] | E/ER309Mo | E/ER316 |
| 316L SS | E/ER/EQ309LMo | E/ER/EQ316L | E/ER/EQ309LMo | E/ER/EQ316L |
| 317L SS | E/ER/EQ309LMo | E/ER/EQ317L | E/ER/EQ309LMo | E/ER/EQ317L |
| 321/347 SS | E/ER/EQ309L/ E309Cb (Nb) | E/ER/EQ347 | E/ER/EQ309L/ E309Cb (Nb) | E/ER/EQ347 |
| Alloy 20-Cb3 | E/ER/EQ320LR | E/ER/EQ320LR | E/ER/EQ320LR | E/ER/EQ320LR |
| Alloy 400 | E/ERNiCu-7 [c] | E/ERNiCu-7 | E/ERNiCu-7 [c] | E/ERNiCu-7 |

a) Use of this table is limited to carbon and low-alloy steel backing materials.

b) E/ER/EQ308 and E/ER/EQ316 are not normally used in the PWHT'd condition. The purchaser shall approve the use of non-low-carbon E/ER308 and E/ER316 in the PWHT'd condition.

c) ENi-1 or ERNi-1 may be used as alternates.

d) Table B.1 refers to coated electrodes and bare wires. For SAW and FCAW, use equivalent electrode classifications (ASME/AWS SFA/A5.9, SFA/A5.14, SFA/A5.22, and SFA/A5.34). Refer to the text for information on other processes.

## B.2 Clad Restoration (Back Cladding)

**B.2.1** The clad layer shall be stripped back for a minimum distance of $^{3}/_{16}$ in. (4.8 mm) from the edge of the bevel. The edge of the cladding shall be rounded with a minimum radius of $^{1}/_{16}$ in. (1.5 mm) or tapered at a minimum angle of 30°. The stripped-back area shall be etched with either a nitric acid or copper sulfate solution to ensure complete removal of the clad.

**B.2.2** When the clad stripback depth impinges upon the minimum backing material design thickness, the overlay shall be qualified as a composite joint in accordance with QW-217 of ASME *BPVC* Section IX.

**B.2.3** Positive steps shall be taken to ensure that the weld joining the backing material does not come into contact with the cladding material.

## B.3 Austenitic (300 Series) Stainless Steel Overlay

**B.3.1** Austenitic stainless steel overlays or back cladding shall have a first layer that is predominantly austenitic and free of cracks.

**B.3.2** The completed overlay shall have the chemical composition given in Table B.2. The location of the chemical composition sample shall be specified by the purchaser. The purchaser shall specify chemistries of austenitic overlay systems not shown in Table B.2.

**Table B.2—Chemical Composition Requirements for Austenitic Stainless Steel Overlays**

| Overlay Type | % C (max.) | % Cr (min.) | % Ni (min.) | % Mo | % Cb (Nb) |
|---|---|---|---|---|---|
| 308 | 0.08 | 18.0 | 8.0 | | |
| 308L | 0.04 | 18.0 | 8.0 | | |
| 316 | 0.08 | 16.0 | 10.0 | 2.0 to 3.0 | |
| 316L | 0.04 | 16.0 | 10.0 | 2.0 to 3.0 | |
| 317L | 0.04 | 18.0 | 11.0 | 3.0 to 4.0 | |
| 347 | 0.08 | 17.0 | 9.0 | | $8 \times$ C min. to 1.0 max. |

**B.3.3** The ferrite content of the final layer of weld overlay shall be in the range of 3 FN to 10 FN, except for Type 347 which shall have a range of 5 FN to 11 FN. The minimum FN may be reduced to 3 FN, provided the fabricator submits data verifying that hot cracking will not occur using the lower FN consumable to be used in production and this is approved by the purchaser.

**B.3.4** Ferrite measurements shall be taken before PWHT.

**B.3.5** Magnetic instruments for measuring ferrite shall be calibrated annually per AWS A4.2M.

## B.4 Ferritic Stainless Steel Alloys

The purchaser shall specify the requirements for ferritic stainless steel overlays.

## B.5 Monel Alloy 400 (67Ni-30Cu)

**B.5.1** The PQR shall report Ni, Cu, and Fe. The Fe content shall not exceed 7 % (5 % for HF acid service). Other chemical composition requirements (in addition to Fe) for the production overlay shall be specified by the purchaser.

**B.5.2** Where ferricyanide testing for the presence of free iron contamination on production welds is required, it is to be specified by the purchaser in a separate specification.

**B.5.3** Single layer overlays are not permitted.

## B.6 Nickel-base Alloys (Other Than Ni-Cu Alloy 400)

The chemical composition requirements for overlay with nickel-base alloys other than Ni-Cu Alloy 400 shall be specified by the purchaser.

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