

Welding Guidelines for the Chemical, Oil, and Gas Industries

API RECOMMENDED PRACTICE 582
SECOND EDITION, DECEMBER 2009



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Downstream Segment

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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) nonremovable internals for process equipment;
- d) structural items attached and related to process equipment;
- e) other equipment or component item when referenced by an applicable purchase document.

1.2 This document is general in nature and is intended to augment 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 570, *Piping Inspection Code: Inspection, Repair, Alteration, and Rerating of In-service Piping Systems*

API Standard 610, *Centrifugal Pumps for Petroleum, Petrochemical, and Natural Gas Industries*

API Standard 617, *Axial and Centrifugal Compressors and Expander-compressors for Petroleum, Chemical, and Gas Industry Services*

API Standard 620, *Design and Construction of Large, Welded Low-pressure Storage Tanks*

API Standard 650, *Welded Tanks for Oil Storage*

API Standard 653, *Tank Inspection, Repair, Alteration and Reconstruction*

API Recommended Practice 934-A, *Materials and Fabrication of 2 1/4Cr-1Mo, Alloy Steel Heavy Wall Pressure Vessels for High Temperature, High Pressure Hydrogen Service, Second Edition*

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 Technical Report 938-C, *Use of Duplex Stainless Steels in the Oil Refining Industry, First Edition*

ASME Boiler and Pressure Vessel Code (BPVC) ¹, Section II, Part C: Specifications for Welding Rods, Electrodes, and Filler Metals

ASME BPVC, Section VIII: Recommended Guidelines for the Care of Power Boilers

ASME BPVC, Section IX: Welding and Brazing Qualifications

ASME B31.3, Process Piping

ASTM A262 ², Standard Practices for Detecting Susceptibility to Intergranular Attack in Austenitic Stainless Steels

ASTM A370, Standard Test Methods and Definitions for Mechanical Testing of Steel Products

ASTM A578, Standard Specification for Straight-Beam Ultrasonic Examination of Rolled Steel Plates for Special Applications

ASTM A833, Standard Practice for Indentation Hardness of Metallic Materials by Comparison Hardness Testers

ASTM E92, Standard Test Method for Vickers Hardness of Metallic Materials

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, RP for Welding of Cr-Mo Steel Piping and Tubing

NACE MR 0103 ⁴, Standard Material Requirements—Materials Resistant to Sulfide Stress Cracking in Corrosive Petroleum Refining Environments

NACE RP 0472, Standard Recommended Practice: 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

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

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.

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

inspector

Purchaser's representative.

3.3

P-number

Base metals have been grouped with P-numbers as shown in Table 1. P-numbers are assigned by ASME *BPVC* Section IX Committee. For current P-numbers, ASME *BPVC* Section IX should be consulted.

3.4

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.

3.5

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. engineering contractor).

3.6

welding procedure specification

WPS

A document providing the required welding variables for a specific application to assure repeatability by properly trained welders and welding operators.

Table 1—Applicable P-numbers

P-no.	Base Metal Description (Strength and Chemistry)
1	carbon steel max.: 0.030 % C, 0.060 % Si, 1.70 % Mn, 0.045 % S, 0.045 % P
2	wrought iron—deleted
3	low-alloy steel
4	1.25 % Cr-0.5 % Mo nominal
5	Cr-Mo steel—deleted
5A	2.25 % to 3 % Cr, 1 % Mo steel
5B	5 % to 10 % Cr, 1 % Mo steel
5C	quench and tempered 2.25Cr-1Mo (P-5A) metals
6	martensitic stainless steel—12 % Cr
7	ferritic stainless steels 11 % to 18 % Cr
8	austenitic stainless steels (18 % Cr, 8 % Ni nominal)
9A	2 % nickel alloy steels

Table 1—Applicable P-numbers (Continued)

P-no.	Base Metal Description (Strength and Chemistry)
9B	3.5 % nickel alloy steels
9C	4.5 % nickel alloy steels
10A	75 ksi (515 MPa) ≤ 105 ksi (725 MPa) TS (Mn, V steel)
10B	60 ksi (415 MPa) TS (1 % Cr, V steel)
10C	81 ksi (560 MPa) ≤ 83 ksi (570 MPa) TS (C, Mn, Si steel)
10D	not used
10E	not used
10F	deleted
10G	deleted
10H	87 ksi (600 MPa) ≤ 110 ksi (760 MPa) TS (18 % Cr to 29 % Cr, 1.5 % Mo to 4.5 % Mo, 3 % Ni to 8 % Ni—duplex stainless steel)
10I	0 ksi (415 MPa) ≤ 70 ksi (485 MPa) TS (26 % Cr to 27 % Cr, 1 % Mo—super ferritic)
10J	70 ksi (485 MPa) ≤ 80 ksi (550 MPa) TS (29 % Cr, 4 % Mo—super ferritic)
10K	70 ksi (485 MPa) ≤ 85 ksi (585 MPa) TS (26 % Cr to 29 % Cr, 3 % Mo to 4 % Mo, 2 % Ni to 2.5 % Ni—super ferritic)
11A	low-alloy steel—quench and tempered
11B	low-alloy steel—quench and tempered, 105 ksi (725 MPa) min.
12	deleted
15A	open—not used
15B	open—not used
15C	74 ksi (2.25 % Cr, Mo, W, Cu)
15D	open—not used
15E	85 ksi (585 MPa) TS (9 % Cr, 1 % Mo, V)
15F	90 ksi (620 MPa) (11 % Cr, 2 % W, 0.5 % Mo)
21	8 ksi (55 MPa) ≤ 14 ksi (97 MPa) TS aluminum—unalloyed (Al, 1.0 % Mn to 1.5 % Mn, Cu)
22	22 ksi (150 MPa) ≤ 31 ksi (215 MPa) TS (Al, 0.8 % Mg to 3.9 % Mg, 0.2 % Mn to 1.5 % Mn)
23	17 ksi (115 MPa) ≤ 24 ksi (165 MPa) TS (Al, Mg, Si, Cu)
24	not used
25	36 ksi (240 MPa) ≤ 41 ksi (285 MPa) TS (Al, 3.5 % Mg to 5.1 % Mg, 0.4 % Mn to 1.0 % Mn)
26	castings
31	30 ksi (205 MPa) ≤ 38 ksi (260 MPa) TS copper—unalloyed (Cu, Ag, As, P, Fe)
32	40 ksi (275 MPa) ≤ 72 ksi (495 MPa) TS bronze and brass (60 % Cu to 85 % Cu, 20 % Zn to 40 % Zn, 2 % Al, 1 % Sn, Sb, As, Ag, P)
33	40 ksi (275 MPa) ≤ 85 ksi (585 MPa) TS (Cu, 1.6 % Si to 3.5 % Si)
34	38 ksi (260 MPa) ≤ 63 ksi (435 MPa) TS copper nickel (66 % Cu to 90 % Cu, 10 % Ni to 30 % Ni, 2 % Fe, 2 % Mn)
35	50 ksi (345 MPa) ≤ 90 ksi (620 MPa) TS aluminum bronze (81 % Cu to 95 % Cu, 5 % Al to 11 % Al, 5 % Ni, 3 % Fe to 4 % Fe)

Table 1—Applicable P-numbers (Continued)

P-no.	Base Metal Description (Strength and Chemistry)
41	50 ksi (345 MPa) ≤ 70 ksi (485 MPa) TS nickel—unalloyed
42	70 ksi (485 MPa) TS monel—(67 % Cu, 30 % Ni)
43	105 ksi (725 MPa) ≤ 120 ksi (825 MPa) TS NiCrFe alloys (47 % Ni to 72 % Ni, 15 % Cr to 29 % Cr, 8 % Mo to 16 % Mo, 5 % Fe to 18 % Fe, 14 % W, 13 Co, 3.5 % Cb, Cu)
44	65 ksi (450 MPa) ≤ 110 ksi (760 MPa) TS NiMo, NiMoCr alloys (62 % Ni to 70 % Ni, 16 % Mo to 29.5 % Mo, 1.3 % Cr to 7 % Cr, 25 % Fe, 13 % Co, 3.5 % Cb, Cu, Al, W)
45	65 ksi (450 MPa) ≤ 109 ksi (750 MPa) TS NiFeCr alloys (21 % Ni to 49 % Ni, 15 % Fe to 46 % Fe, 20 % Cr to 33 % Cr, 1.5 % Mo to 7 % Mo, 18 % Co, 3 % W, 2.3 % Cu to 3 % Cu, Cb, Al, Ti, N)
46	70 ksi (485 MPa) ≤ 90 ksi (620 MPa) TS NiCrSi alloys (35 % Ni to 37 % Ni, 19 % Cr to 28 % Cr, 1.25 % Si to 2.7 % Si, 30 % Co)
47	deleted
49	120 ksi (825 MPa) cobalt alloys (Co, 26 % Cr, 9 % Ni, 5 % Mo, 3 % Fe, 2 % W)
51	35 ksi (240 MPa) ≤ 50 ksi (345 MPa) TS titanium—unalloyed (alpha) (Ti, Pd, Ru)
52	65 ksi (450 MPa) ≤ 70 ksi (485 MPa) TS titanium—unalloyed and alloyed (alpha) (Ti, 0.3 % Mo, 0.8 % Ni)
53	90 ksi (620 MPa) TS titanium alloyed (alpha-beta) (Ti, 3 % Al, 2.5 % V)
54	70 ksi (620 MPa) TS titanium—alloyed (alpha) (Ti, 0.3 % Mo, 0.8 % Ni) previous P-52
61	55 ksi (380 MPa) TS zirconium—unalloyed
62	80 ksi (550 MPa) TS zirconium—alloyed (Zr, 2.5 % Cb)

4 General Welding Requirements

4.1 Structural (nonpressure 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.

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) for the following transfer modes:
 - 1) spray (GMAW-Sp),
 - 2) short circuiting (GMAW-S),
 - 3) pulsed (GMAW-P),
 - 4) globular (GMAW-G);
- d) submerged arc welding (SAW);
- e) electrogas welding (EGW);
- f) electroslog welding (ESW), limited to weld overlay for P-1 through P-5 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 restrictions and comments contained in 5.2.

5.2.2 GTAW-P

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

COMMENTARY 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 $\frac{3}{8}$ 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 using the same program settings as those used in the procedure qualification.

COMMENTARY 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 multipass 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) electrodes are used as-welded or in the postweld heat treated (PWHT'd) condition with impact testing required, the specific brand and trade name electrode used in production must be qualified on supporting PQRs with impact test results meeting the minimum design code requirements.

COMMENTARY 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 assure 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 $\frac{3}{8}$ in. (9.5 mm), the diffusible hydrogen limit for FCAW electrodes (as manufactured) shall meet the specifications in Table 2.

Table 2—Diffusible Hydrogen Limit for FCAW Electrodes

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.

COMMENTARY 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 is greater than $\frac{1}{2}$ in.

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 A1 through A5, 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 ⁶. Filler metals that do not conform to an ASME/AWS specification shall be submitted to the purchaser for approval.

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) 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-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-1, Group 2, materials may have the root and hot pass welded with cellulose electrodes, 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 electrode 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, as applicable, and the identity 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-1 through P-5, P-9, and P-11 materials.

⁶ Refer to Annex A for general guidance and recommended filler metal selection.

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.

6.2 Dissimilar Welding

6.2.1 When joining dissimilar ferritic steels (P-1 through P-5), the filler metal shall conform to the nominal chemical composition of either base metal or an intermediate composition. However, when attaching nonpressure 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-1 through P-5) to:

a) martensitic stainless steels (P-6);

b) ferritic stainless steels (P-7); or

c) austenitic stainless steels (P-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);

COMMENTARY Type 309Cb(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 3;

- 3) for service conditions exceeding the limits stated in 6.2.2 a) and 6.2.2 b), 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.

Table 3—Application of Nickel-base Electrodes in Sulfur and Non-sulfur Environments

ASME/AWS Filler Material Classification	Maximum Design Temperature (Non-sulfur Environment)	Maximum Design Temperature (Sulfur 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 Comparable FCAW consumables may be applied for dissimilar welding applications provided they are approved by the purchaser.		

6.3 Low-alloy Steel Welding (P-3 to P-5)

Unless otherwise specified, the welding guidelines referenced in API 934-A and API 934-C 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-6, P-7, and P-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-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 10FN 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 the WRC1992 (FN) or DeLong (FN) Diagrams.

6.4.2.2 The minimum FN for deposited weld metal should be 3 FN except for the following (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.
- c) The FN for 16-8-2 weld deposits shall be 1-5 FN.

6.4.2.3 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.

6.4.2.4 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 Stainless Steel Welding

When welding duplex stainless steels, the following requirements shall apply. API 938-C provides guidance on welding duplex stainless steel.

6.5.1 When qualifying the PQR, ferrite content shall be measured on base metal, HAZ and weld metal. Ferrite content in these locations shall be 30 % to 65 %. FN can also be used with approval from the purchaser provided all measurements are FN.

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

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

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 combinations 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 Electroslog 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 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 gases 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 to 5.2.3 e).

7.4 When a back purge is used, the WPS shall state the gas used and the flow rate.

7.5 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.

7.6 For socket, seal, and any other attachment welds on base materials less than 1/4 in. 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, 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 throughout the entire thickness of the weld and at least 3 in. (75 mm) on each side of the weld. Consideration should be given to lowering the preheat temperature below M_f prior to PWHT.

8.3 The preheat and interpass temperature shall be checked by use of thermocouples, temperature indicating crayons, pyrometers or other suitable methods.

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.

Table 4—Recommended Maximum Interpass Temperatures

Material Group	Maximum Interpass Temperature
P-1 (carbon steels)	600 °F (315 °C)
P-3, P-4, P-5A, P-5B, and P-5C (low-alloy steels)	600 °F (315 °C)
P-6 (Type 410)	600 °F (315 °C)
P-6 (CA6NM)	650 °F (345 °C)
P-7 (Type 405/410S)	500 °F (260 °C)
P-8 (austenitic stainless steel)	350 °F (175 °C)
P-10H (duplex stainless)	300 °F (150 °C)*
P-41, P-42	300 °F (150 °C)
P-43, P-44, and P-45	350 °F (175 °C)
NOTE Interpass temperature may vary depending on material grades.	

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 WPS's specifying PWHT should indicate the following:

- a) maximum heating rate,
- b) holding temperature range,
- c) holding time,
- d) maximum cooling rate.

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.

COMMENTARY 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 RP 0472 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 stainless steel or 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.

COMMENTARY If PWHT was originally conducted due to service requirements, specifically environmental cracking prevention, PWHT of the repair should be 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 $\frac{3}{16}$ in. (5 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-4 and P-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 5 lists suggested PWHT holding temperatures. Code requirements, project specifications and tempering temperatures should be considered when selecting final PWHT temperatures.

⁸ 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 5—PWHT Temperature and Holding Time

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 hr/in. (1 minimum)
1	carbon steel	all	wet H ₂ S	1150 to 1200	1 hr/in. (1 minimum)
1	carbon steel	all	caustic	1150 to 1200	1 hr/in. (1 minimum)
1	carbon steel	all	amine	1150 to 1200	1 hr/in. (1 minimum)
1	carbon steel	all	carbonates	1200 to 1250	1 hr/in. (1 minimum)
1	carbon steel	all	HF acid	1150 to 1200	1 hr/in. (1 minimum)
1	carbon steel	all	deaerator	1150 to 1200	1 hr/in. (1 minimum)
1	carbon steel	all	ethanol	1150 to 1200	1 hr/in. (1 minimum)
3	C-1/2Mo	according to code	code	1150 to 1200	1 hr/in. (1 minimum)
3	C-Mn-Mo	all	all	1150 to 1200	1 hr/in. (1 minimum)
4	1Cr-1/2Mo, 1 1/4Cr-1/2Mo	all	for maximum tempering (creep)	1275 to 1325	1 hr/in. (2 minimum)
4	1Cr-1/2Mo, 1 1/4Cr-1/2Mo	all	for optimum high-temperature properties (toughness)	1250 to 1300	1 hr/in. (2 minimum)
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	1 hr/in. (2 minimum) refer to API-934-C for more details
5A	2 1/4Cr-1Mo	all	for maximum tempering (creep)	1300 to 1350	1 hr/in. (2 minimum)
5A	2 1/4Cr-1Mo	all	for maximum high-temperature properties (toughness)	1275 to 1325	1 hr/in. (2 minimum)
5A	2 1/4Cr-1Mo	all	heavy wall pressure vessels for high-temperature, high-pressure hydrogen service	1250 to 1300	1 hr/in. (2 minimum) refer to API 934-A for more details
5B	5Cr-1/2Mo	all	all	1325 to 1375	1 hr/in. (2 minimum)
5B	9Cr-1Mo	all	all	1350 to 1400	1 hr/in. (2 minimum)
5B	9Cr-1Mo-V	all	all	1375 to 1425	1 hr/in. (2 minimum)
5C	2 1/4Cr-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	1 hr/in. (2 minimum)
7	ferritic stainless steels	according to code	all	according to code	1 hr/in. (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 hr/in. (1 minimum)
9B	3 1/2 Ni				

Table 5—PWHT Temperature and Holding Time (Continued)

P-no.	Material Type	Nominal Thickness at Weld (in.)	Service Environment	Holding Temperature (°F) ^a	Time at Holding Temperature (hr)
10H	duplex stainless steels	according to code	all	according to code	1 hr/in. (1 minimum)
11A	8 Ni, 9 Ni	according to code	all	according to code	1 hr/in. (1 minimum)
45	alloy, 800, 800H, 800HT	according to code	all	according to code	according to code
^a For quenched and tempered or normalizing and tempering 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 CA-15 and Type CA-15M materials, a double tempering heat treatment is required. Initial heat treatment at 1150 °F minimum, followed by air cooling to ambient temperature, and second heat treatment at 1150 °F minimum (but lower than initial temperature) and air cooling to ambient temperature. 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.					

9.13 Local PWHT involving circumferential bands around piping or vessels shall be performed as follows in order to control harmful thermal gradients.

- a) The holding temperature (soak) band width shall be the greater of $W + 4t$ or the governing code requirement, where W is the width of the weld cap and t is the thickness of the component.
- b) Beyond the edges of the holding temperature band, a gradient band shall be applied so that the temperature at its outer edges is not less than $1/2$ the holding temperature. The width of this gradient shall be $2.5 \sqrt{rt}$, where r is the component radius and t is the component thickness.
- c) Beyond the edges of the gradient band, a decay band shall be applied to allow the temperature to gradually approach ambient. The width of this decay band shall be $2.5 \sqrt{rt}$, where r is the component radius and t is the component thickness.

9.14 Local spot PWHT (called 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 described 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 type 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 or non-ferrous materials, nor shall brushes or tools that have been previously used on carbon or low-alloy steel.

10.8 If carbon-arc cutting or gouging are used on stainless steels, the surface must be ground to a bright surface finish.

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

11 Special Procedure Qualification Requirements/Testing

11.1 General

11.1.1 Procedure qualification requirements (PQR's) 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 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, WPS's 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 WPS's for seal welding of tube-to-tubesheets shall be qualified in accordance with ASME *BPVC* Section IX, QW 202.6a, b, or c.

12 Other Items

12.1 Backing Materials

Where metallic backing material is permitted, the P-number 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 and is not permitted for the root pass or final layer.

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 WPS's 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.

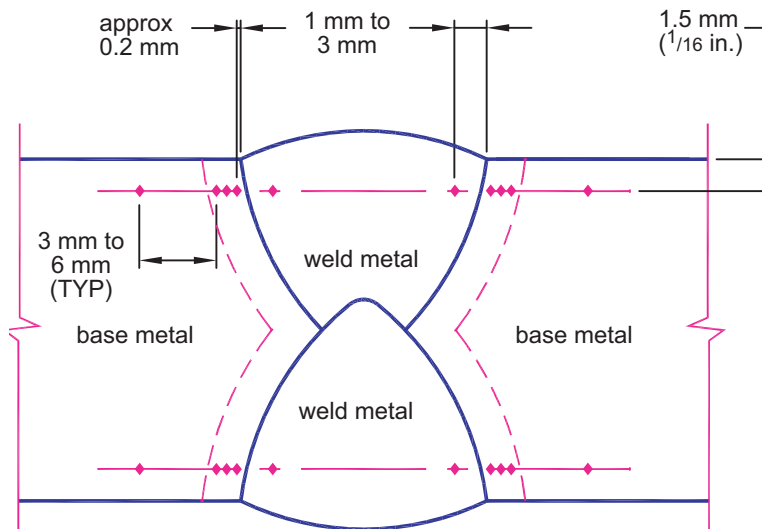
12.6 Hardness Testing—Weld Procedure Qualification and Production Testing

12.6.1 When specified by the purchaser, weld procedure qualification testing shall include the following.

12.6.1.1 The welding procedure qualification shall be hardness tested in accordance with ASTM E92 using a 10 kg-load. The procedure qualification test shall meet the requirements (e.g. PWHT) imposed on production joints. The hardness survey shall be performed on a transverse weld cross section that has been polished and etched to identify the weld metal, fusion line and HAZ.

12.6.1.2 Hardness traverses shall be performed $\frac{1}{16}$ in. (1.5 mm) from the internal and external surfaces as indicated in Figure 1 (typical weld). The HAZ readings shall include locations as close as possible (approximately 0.2 mm) to the weld fusion line. Prior hardness traverses may be accepted as equivalent to Figure 1 with approval of the purchaser. For other weld geometries, refer to NACE MR 0103.

12.6.1.3 For acceptance, all hardness values for P-1 materials (including Group No.s 1 and 2) in crack inducing environments (defined in NACE RP 0472 and identified by the purchaser), shall be 248 HV10 or lower. For all other P-numbers, the acceptance values shall be specified by the purchaser.



NOTE HV10 measurement for HAZ requires 0.04 in. (1 mm) minimum spacing between indentations. In some cases, it is acceptable that hardness measurement location is off-the line in order to satisfy the minimum spacing requirements.

Figure 1—Location of Vickers Hardness Indentations

12.6.1.4 The hardness test results shall be recorded in the PQR.

12.6.1.5 PQR hardness testing is required where the purchaser requires production hardness testing for environmental cracking or other services as specified by the purchaser.

12.6.2 When specified by the purchaser, production hardness testing shall be as follows.

12.6.2.1 Pressure-retaining welds shall be hardness tested in accordance with NACE RP 0472 and requirements given below.

12.6.2.2 Testing shall be performed after any required PWHT. The test location and frequency shall be in accordance with NACE RP 0472 unless otherwise specified by the applicable code/standard or as modified by the purchaser.

12.6.2.3 Readings in the HAZ shall be conducted if specified by the applicable code (e.g. ASME B31.3) or standard.

12.6.2.4 Hardness readings (per NACE RP 0472) shall be taken with a portable hardness tester in accordance with ASTM A833. Other hardness testing techniques may be employed if approved by the purchaser. When access is available, tests shall be performed on the process-contacted side of the weld.

12.6.2.5 Unless otherwise agreed between the manufacturer and purchaser, the maximum allowable hardness for welds shall be as follows.

- a) P-1, P-3, and P-4 material—225 Brinell.
- b) P-1 material specified in crack inducing environments per NACE RP 0472, or as identified by the purchaser—200 Brinell. Other materials required to be resistant to sulfide stress cracking in corrosive petroleum refining environments should follow NACE MR 0103 guidance.
- c) P-5B Group 1—241 Brinell.
- d) P-5A and P-5C—Refer to API 934-C.

e) P-6 and P-7 (410S) material—241 Brinell.

NOTE Limitation of P-5B, Group 2, to be as agreed between the purchaser and fabricator.

12.6.2.6 Hardness test results and locations shall be recorded.

12.7 Single-pass Welds

Single-pass welds are not permitted for pressure-containing fitting, or flange connections, including socket and slip-on type joints.

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	*	*	*
2 1/4 Cr-1 Mo steel				E	EF	EFH	*	*	*
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.

* 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 wire welding (SAW, GMAW, GTAW), use equivalent electrode classifications (ASME/AWS SFA/A5.14, SFA/A5.17, SFA/A5.18, SFA/A5.20, SFA/A5.23, SFA/A5.28). 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 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 insure 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, Classification E309-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.
- 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 welding (SAW, GMAW, GTAW), use equivalent electrode classifications (ASME/AWS SFA/A 5.9, SFA/A5.14). 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		
		2304	2205	F255	Zeron 100	2507	DP3W	P1-P5	P8 (Type 304)	P8 (Type 316)	P8 (Type 254 SMO)	P43 (Type IN625)	P45 (Type IN825)
TN	UNS												
2304	S32304	A-DF	A-DF	A-DF	A-DF	A-DF	A-DF	AEF	AEF	AF	GH	GH	GH
2205	S31803		A-D	A-D	A-D	A-D	A-D	AEF	AEF	AF	GH	GH	GH
	S32205												
F255	S32550			B-D	B-D	B-D	B-D	ABEF	ABEF	ABF	GH	GH	GH
zeron 100	S32760				CDGH	CDGH	CDGH	A-DEF	A-DEF	A-DF	GH	GH	GH
2507	S32750					CDGH	CDGH	A-DEF	A-DEF	A-DF	GH	GH	GH
DP3W	S39274						CDGH	A-DEF	A-DEF	A-DF	GH	GH	GH

Key

- A ASME SFA 5.4, Classification E(R) 2209—duplex filler material.
 B ASME SFA 5.4, Classification E (R)2553—duplex filler material.
 C ASME SFA 5.4, Classification E(R) 2594—duplex filler material.
 D DP3W (unclassified)—duplex filler material.
 E ASME SFA 5.4, Classification E(R) 309L—high-alloy austenitic filler material.
 F ASME SFA 5.4, Classification E(R) 309LMo—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 This table refers to coated electrodes. For bare wire welding (SAW, GMAW, GTAW), use equivalent electrode classification (ASME/AWS SFA/A5.9 and SFA/A5.14). Refer to the text for information on other processes.

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 C-276 (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 wire welding (SAW, GMAW, GTAW), use equivalent electrode classification (ASME/AWS SFA/A 5.14). 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 as follows.

- a) The procedure qualification demonstrates that metallographic examination of overlay cross sections per ASME *BPVC* Section IX show that at least 5 % penetration has been achieved.
- b) The welding procedure qualification and any production tests required by the purchaser shall 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 SA 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 when using the X-ray fluorescence method. When carbon is specified, a physical sample is required for quantitative analysis. Alternatively, an optical emission spectrometer may be used to check all required elements, including carbon. 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.

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 $\frac{3}{16}$ in. (4.8 mm). When the overlay/clad is less than $\frac{3}{16}$ in. (5 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-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)
405/410S	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/ER309L	E/ER308L	E/ER309L	E/ER308L
316 SS	b	b	E/ER309Mo	E/ER316
316L SS	E/ER309LMo	E/ER316L	E/ER309LMo	E/ER316L
317L SS	E/ER309LMo	E/ER317L	E/ER309LMo	E/ER317L
321/347 SS	E/ER309L/E309Cb(Nb)	E/ER347	E/ER309L/E309Cb(Nb)	E/ER347
Alloy 20-Cb3	E/ER320LR	E/ER320LR	E/ER320LR	E/ER320LR
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/ER308 and E/ER316 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 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 $\frac{3}{16}$ in. (5 mm) from the edge of the bevel. The edge of the cladding shall be rounded with a minimum radius of $\frac{1}{16}$ 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 backing material welds made with ferritic electrodes do 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 purchaser shall specify chemistries of austenitic overlay systems not shown in Table B.2.

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

Overlay Type	% C (max).	% Cr (min.)	% Ni (min.)	% Mo	% Cu	% 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 × 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) for two-layer overlay. 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)

B.6.1 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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