Welding Guidelines for the Chemical, Oil, and Gas Industries

API RECOMMENDED PRACTICE 582
FIRST EDITION, MARCH 2001

American Petroleum Institute

Helping You Get The Job Done Right.SM

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Downstream Segment

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This document was initiated and developed through the joint efforts of API and Process Industry Practices (PIP).

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Welding Guidelines for the Chemical, Oil, and Gas Industries

1 Scope

1.1 This recommended practice, initiated and developed through the joint efforts of API and Process Industry Practices (PIP), provides supplementary guidelines and practices for welding and welding-related topics for shop and field fabrication, repair and modification of:

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

b. Non-removable internals for pressure vessels.

c. Structural items attached and related to process equipment.

d. Any 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 Section IX and similar codes, standards 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, e.g., pipeline welding and offshore structural welding.

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

2 References

Unless stated otherwise, applicable requirements in the latest issue of the following industry codes, standards and practices shall be considered an integral part of this recommended practice. Other codes and standards are specified by the purchaser.

API

API 510	*Pressure and Vessel Inspection Code—Maintenance Inspection, Rating, Repair, and Alteration*
Std. 650	*Welded Steel Tanks for Oil Storage*

ASME[1]

Boiler & Pressure Vessel Code

Section II, "Materials Part C—Specifications for Welding Rods, Electrodes and Filler Metals"

Section VIII, Rules for Construction of "Pressure Vessels", Division I, and Division II—Alternative Rules"

Section IX, "Welding and Brazing Qualifications".

B31.3	*Process Piping*

ASTM[2]

ASTM A 833	*Standard Practice for Indentation Hardness of Metallic Materials by Comparison Hardness Testers*
ASTM E 92	*Standard Test Method for Vickers Hardness of Metallic Materials*

AWS[3]

AWS A4.2	*Standard Procedures for Calibrating Magnetic Instruments to Measure the Delta Ferrite Content of Austenitic and Duplex Ferritic-Austenitic Stainless Steel Weld Metal*
AWS A5.32	*Specifications 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*

NACE[4]

RP0472	*Standard Recommended Practice: Methods and Controls to Prevent In-Service Environmental Cracking of Carbon Steel Weldments in Corrosive Petroleum Refining Environments*

National Board[5]

NB-23	*National Board Inspection Code*

3 Definitions

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 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 welding procedure specification.

3.4 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).

[1]American Society of Mechanical Engineers, 345 East 47th Street, New York, New York 10017, www.asme.org.

[2]American Society of Testing and Materials, 100 Barr Harbor, West Conshohocken, Pennsylvania 19428-2959, www.astm.org.

[3]American Welding Society, 550 NW LeJeune Road, Miami, FL 33126

[4]National Association of Corrosion Engineers-International, P.O. Box 218340, Houston, Texas 77218, www.nace.org.

[5]National Board of Boiler and Pressure Vessel Inspectors, 1055 Crupper Avenue, Columbus, Ohio 43229, www.nationalboard.com.

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 Section IX.

4.2 Pre-qualified welding procedures per AWS D1.1 and D1.6 are acceptable for structural welding.

4.3 All welding procedure specifications (WPS's) and procedure qualification records (PQR's) 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 WPS's will be used, shall be included in the submittal.

5 Welding Processes

5.1 ACCEPTABLE WELDING PROCESSES

Acceptable welding processes are:

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:
   i. Spray (GMAW-Sp).
   ii. Short Circuiting (GMAW-S).
   iii. Pulsed (GMAW-P).
   iv. Globular (GMAW-G).
d. Submerged Arc Welding (SAW).
e. Electrogas Welding (EGW).
f. Flux Cored Arc Welding (FCAW).
g. Plasma Arc Welding (PAW).
h. Other welding processes approved by the purchaser.

5.2 LIMITATIONS OF FUSION WELDING PROCESSES

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

5.2.1 Automatic Pulsed Gas Tungsten Arc Welding (GTAW-P)

When used for root pass welding of single-sided joints, welding shall be performed with the same make and model of welding system using the same equipment and/or 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.

5.2.2 Short Circuiting Gas Metal Arc Welding (GMAW-S)

The use of GMAW-S shall be limited to the following conditions:

a. The process shall not be used for branch connections or socket welds.
b. For vertical welding, the root pass and second pass progression for a material of any thickness may be either uphill or downhill.
c. The fill and cap pass 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.

5.2.3 Pulsed Gas Metal Arc Welding (GMAW-P)

GMAW-P may be used for any material thickness in any position.

Commentary: Whenever the welding system is changed or the settings on existing equipment significantly altered, the fabricator should verify weld properties. The extent of verification or testing should be as agreed between the purchaser and fabricator.

5.2.4 Flux Cored Arc Welding (FCAW)

5.2.4.1 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.

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

5.2.4.3 For procedures requiring either impact or hardness testing, weld metal properties should be reviewed with the consumable manufacturer to ensure the original qualified properties continue to be met.

Table 5-1—Diffusible Hydrogen Limit for FCAW Electrodes

Specified Minimum Tensile Strength for the Electrode (Per AWS A5.20 or A5.29)	Maximum Diffusible Hydrogen Designation (Per AWS A5.20 or A5.29)
≤ 70 ksi (483 MPa)	H8
> 70 ksi (483 MPa)	H4

Note: When welding with 70 ksi (483 MPa) electrodes on steels having a tensile strength of 80 ksi (552 MPa) or greater, H4 designated electrodes shall be used

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.

5.2.4.4 Welding consumables shall be limited to the AWS classification used in the procedure qualification record.

5.2.4.5 For welding pressure-containing equipment, the diffusible hydrogen limit for FCAW electrodes (as manufactured) shall be capable of meeting the specifications in Table 5-1.

5.2.5 Electrogas Welding (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 (AWS A5.26).
b. Welding consumables shall be limited to the classification and the manufacturer's trade name used in the procedure qualification record.
c. Only filler materials having classifications with specified minimum impact test requirements should be used.

5.2.6 Submerged Arc Welding (SAW)

5.2.6.1 SAW procedures shall be re-qualified whenever the welding flux is changed from one manufacturer's trade name to another. Equivalence under ASME Section II, Part C shall not be considered adequate for substitution without re-qualification.

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.

5.2.6.2 Manually held (semi-automatic) SAW is not permitted for welding pressure-containing parts, unless approved by the purchaser.

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 steel and nickel-based 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 procedures 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 non-essential variables that are needed to accurately describe all motion (e.g., direction of travel, travel speed, 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 Section IX, QW-461.9, shall be considered an essential variable for procedure qualification.

6 Welding Consumables (Filler Metal and Flux)

6.1 GENERAL

Filler metals shall be specified in each WPS by AWS specification and classification[6]. Filler metals that do not conform to an AWS specification shall be submitted to the purchaser for approval.

6.1.1 Testing is required to verify consumable mechanical properties whenever:

a. The deposited filler metal does not fall within any of the AWS filler metal specifications.
b. Manufacturer's typical consumable certification or other supplier certifications are not available.

[6]Refer to Appendix A for general guidance and recommended filler metal selection.

Table 6-1—Application of Nickel-Based Electrodes in Sulfur and Non-Sulfur Environments

AWS Filler Material Designation	Max. Design Temperature (non-sulfur environment)	Max. Design Temperature (sulfur environment)
ENiCrFe-3	1000°F (540°C)	700°F (370°C)
ERNiCr-3	1400°F (760°C)	750°F (400°C)
ENiCrFe-2	1400°F (760°C)	750°F (400°C)
ERNiCrMo-3	1100°F (590°C)	1100°F (590°C)

When PWHT is required for either of the above, all-weld-metal test coupons shall be postweld heat treated 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.When the thickness of carbon steel base metals exceeds 1/2 in. (12.7 mm) groove and/or fillet welds shall be made with filler metals producing low hydrogen deposits[7]. However, for pipe welding cellulose type coated electrodes may be used for the root pass and second pass of single-groove welds, regardless of base metal thickness.

6.1.2 If the base metal is exempt from toughness 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 Section II (Part C), or if approved by the purchaser, should be established by the PQR.

6.1.3 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.

6.1.4 Welding consumables shall be clearly identified by classification or trade name, as applicable, and the identity maintained until consumed.

6.2 DISSIMILAR WELDING

6.2.1 When joining dissimilar ferritic steels (P1 though P5), 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 (P1 through P5) to martensitic stainless steels (P6), ferritic stainless steels (P7), or austenitic stainless steels (P8), the filler metal shall be selected based on the following criteria: Type 309 and 309L may be used for design temperatures not exceeding 600°F (315°C).

Commentary: Type 309Cb should not be used when PWHT is required, except for weld overlay.

c. Nickel-based alloy filler materials may be selected using design conditions shown in Table 6-1.

d. For service conditions exceeding the limits stated in 6.2.2, items a and b, the filler metal selection shall be reviewed with the purchaser.

6.3 AUSTENITIC STAINLESS STEEL WELDING

For welding austenitic stainless steels (P8 Group 1), the following guidelines and restrictions apply:

6.3.1 Appendix A, Table A-2, provides recommended filler metal selections for typical stainless steel applications.

6.3.2 Unless otherwise specified, for materials requiring PWHT or materials in high temperature service (see ASME Section II, Part D, Table 6-360), the Ferrite Number (FN) for the deposited weld metal should not exceed 11 FN measured prior to PWHT.[8]

6.3.3 The minimum Ferrite Number for filler metal should be 3 FN except as noted below.

a. The minimum FN for type 347 shall be 5 FN.

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

6.3.4 When FCAW austenitic stainless steel type weld materials are used at service temperatures above 1022°F (550°C):

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 ferrite number of 9 FN.

[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 recommended practice.

[8]Whenever Ferrite Number measurements are required in this document, they are to be taken prior to any postweld heat treatment.

6.4 DUPLEX STAINLESS STEEL WELDING

When welding duplex stainless steels, the following requirements shall apply:

6.4.1 Ferrite number for the weld procedure qualification and deposited weld metal shall be 30-70 FN as determined by an instrument calibrated to AWS A4.2.

6.4.2 If the deposited weld metal ferrite content (as shown in the procedure qualification record) is greater than 60 FN, the moisture content of duplex stainless steel electrodes shall be controlled to 0.2% maximum as measured by the test procedure given in AWS A5.5, Section 14.

6.5 SUBMERGED ARC WELDING

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

6.5.2 Filler metal/flux combinations specified by the manufacturer for single pass welding shall not be used for multipass welding.

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

6.5.4 Flux from re-crushed slag may be used only with approval of the purchaser.

6.6 CONSUMABLE STORAGE AND HANDLING

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

6.6.2 Storage and baking of welding consumables shall be carried out in a separate oven. The ovens shall be heated by electrical means and shall have automatic heat controls and visible temperature indication.

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 AWS 5.32. 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.

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. (6.3 mm) depth of weld metal has been deposited.

8 Preheating and Interpass Temperature

8.1 Preheating, where required, applies to all welding, tack welding, and thermal cutting of ferritic steels except for thermal cutting of P1 materials. Minimum preheat requirements shall follow the applicable code such as ASME Section VIII, Appendix R; ASME B31.3, Table 330.1.1; and AWS D1.1, Annex XI. Any recommendations or requirements for preheat listed in the relevant code shall be considered mandatory.

8.2 The preheat temperature shall be applied throughout the entire thickness of the weld and at least 3 in. (76 mm) on each side of the weld. The preheat and interpass temperature shall be checked by use of thermocouples, temperature indicating crayons, pyrometers or other suitable methods.

8.3 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.

8.4 Table 8-1 provides recommended maximum interpass temperatures.

9 Postweld Heat Treatment (PWHT)

9.1 Postweld heat treatment 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:

Table 8-1—Recommended Maximum Interpass Temperatures

Material Group	Maximum Interpass Temperature
Carbon and low alloy steels	600ºF (315ºC)
410/410S	600ºF (315ºC)
405	500ºF (250ºC)
Alloy 20Cb-3	350ºF (175ºC)
CA6NM	650ºF (345ºC)
Austenitic stainless steel (P-8)	350ºF (175ºC)
Duplex stainless (P-10H)	300ºF (150ºC)
Ni-Cu Alloy 400	300ºF (150ºC)
Alloy C-276	350ºF (175ºC)
Alloy 600	350ºF (175ºC)
Alloy 625	350ºF (175ºC)
Alloy 800, 800H, 800HT	350ºF (175ºC)

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 process and heat treating package must be approved by the purchaser prior to the project.

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 RP0472, 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 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 1300ºF (705ºC).

9.8 Repairing a postweld heat-treated component without PWHT requires that the repair meet all applicable construction code requirements, or follows NB-23 or API 510. Purchaser approval shall be obtained prior to performing the repair.

Commentary: If postweld heat treatment was originally conducted due to service requirements, specifically environmental cracking prevention, postweld heat treatment 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 $^{3}/_{16}$ 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 from code required PWHT for ferritic materials based on the use of austenitic or nickel-based filler materials is not permitted.

9.11 Code exemption from PWHT for P4 and P5 materials is not permitted for applications in sour or hydrogen service[9] or where the nominal chromium content of the material exceeds 1.25%.

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 unless it can be demonstrated that an acceptable weld can be made without this operation.

10.5 All slag shall be removed from the backside of each completed austenitic stainless steel or nickel-based 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.

11 Special Procedure Qualification Requirements/Testing

11.1 GENERAL

11.1.1 PQR's for all welding processes shall include the results of any additional tests when specified. Some examples are:

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, HAZ, and base metal).

11.1.2 When specified by the purchaser, mockups simulating production conditions shall be performed whenever the

[9]Purchaser shall define the conditions for sour service (e.g., company specific or reference to NACE document) and/or hydrogen service (e.g., hydrogen partial pressure).

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 Section VIII, Division 2, Article F-3. 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 Section IX.

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 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 Appendix B).

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

12.3.4 Appendix 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) and hydrotesting or final acceptance.

12.5 STUD WELDING

12.5.1 Automatically timed arc and resistance stud welding for attaching load-carrying studs shall be in accordance with UW-27, UW-28 and UW-29 of ASME 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.

12.5.2 Production welds shall be bend or hammer tested in accordance with ASME Section IX, QW193. When permitted by the purchaser, joints with less than 100% fusion may be accepted.

12.5.3 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.

12.6 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 E 92 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 $^1/_{16}$ in. (1.5 mm) from the internal and external surfaces as indicated in Figure 12.1 (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 12.1 with approval of the purchaser.

12.6.1.3 For acceptance, all hardness values for P1 materials (including S1, Group Nos. 1 & 2) in crack inducing environments (defined in NACE RP0472 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.

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 RP0472 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 RP0472 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., B31.3) or standard.

12.6.2.4 Hardness readings (in accordance with NACE RP0472) shall be taken with a portable hardness tester in accordance with ASTM A 833. 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:

a. P-1, P-3, and P-4 material–225 Brinell.

b. P-1 material specified in crack-inducing environments per NACE RP0472, or as identified by the purchaser–200 Brinell.

c. P-5A, P-5B Group 1 and P-5C 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.

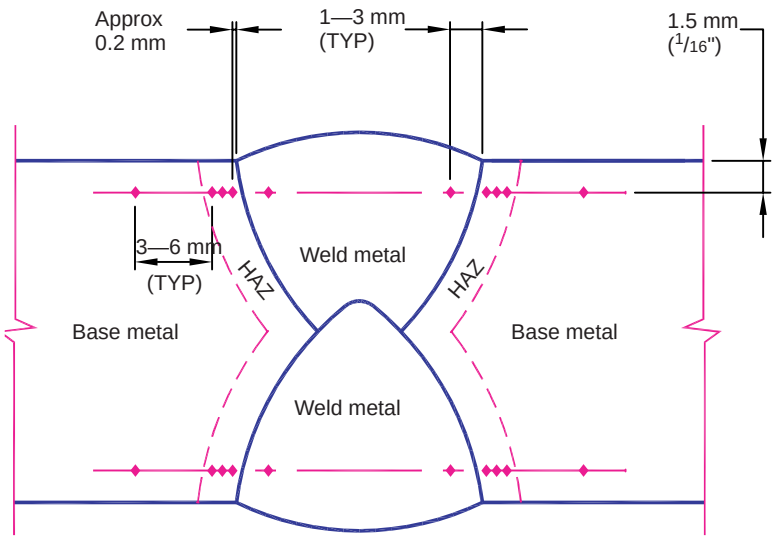

Figure 12-1—Location of Vickers Hardness Indentations

APPENDIX A—WELDING CONSUMABLES FOR SHIELDED METAL ARC WELDING

Tables A-1, A-2, and A-3 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 Note [1, 2, 4]	Carbon Steel	Carbon-Molybdenum Steel	1&1 1/4Cr-1/2 Mo Steel	2 1/4 Cr-1 Mo Steel	5Cr-1/2 Mo Steel	9Cr-1 Mo Steel	2 1/4 Nickel Steel	3 1/2 Nickel Steel	9% Nickel Steel
Carbon Steel	AB [3]	AC	AD	AE	AF	AG	AJ	AK	*
Carbon-Molybdenum Steel		C	CD	CE	CF	CH	*	*	*
1&1 1/4 Cr-1/2 Mo Steel			D	DE	DF	DH	*	*	*
2 1/4 Cr-1 Mo Steel				E	EF	EH	*	*	*
5Cr-1/2 Mo Steel					F	FH	*	*	*
9Cr-1 Mo Steel						H	*	*	*
2 1/4 Nickel Steel							J	JK	LM
3 1/2 Nickel Steel								K	LM
9% Nickel Steel									LM

Legend

A AWS A5.1 Classification E70XX low hydrogen[5]
B AWS A5.1 Classification E6010 for root pass[5]
C AWS A5.5 Classification E70XX-A1, low hydrogen
D AWS A5.5 Classification E70XX-B2L or E80XX-B2, low hydrogen
E AWS A5.5 Classification E80XX-B3L or E90XX-B3, low hydrogen
F AWS A5.5 Classification E80XX-B6 or E80XX-B6L, low hydrogen
G AWS A5.5 Classification E80XX-B7 or E80XX-B7L, low hydrogen
H AWS A5.5 Classification E80XX-B8 or E80XX-B8L, low hydrogen
J AWS A5.5 Classification E80XX-C1 or E70XX-C1L, low hydrogen
K AWS A5.5 Classification E80XX-C2 or E70XXC2L, low hydrogen
L AWS A5.11 Classification ENiCrMo-3
M AWS A5.11 Classification ENiCrMo-6
* An unlikely or unsuitable combination. Consult the purchaser if this combination is needed.

Notes:

[1] Table A-1 refers to coated electrodes. For bare wire welding (SAW, GMAW, GTAW), use equivalent electrode classifications (AWS A5.14, A5.17, A5.18, A5.20, A5.23, A5.28). Refer to the text for information on other processes.

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

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

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

[5] Refer to 6.1.3.

Table A-2—Stainless Steel Alloys

Base Material Note [1, 2, 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
Carbon and Low-Alloy Steel	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
Type 410S Stainless Steel		ABC	ABC	AB	AB	AB	AB	AB	AB	AB	AB	AB
Type 410 Stainless Steel			ABC	AB	AB	AB	AB	AB	AB	AB	AB	AB
Type 304 Stainless Steel				D	DH	DJ	A	DF	DGH	DI	DE	DE
Type 304L Stainless Steel					H	DHJ	A	DF	GH	HI	DE	DE
Type 304H Stainless Steel						J	A	DFJ	DGHJ	DIJ	DEJ	EJ
Type 310 Stainless Steel							K	AK	A	A	A	A
Type 316 Stainless Steel								F	FG	FI	EF	EF
Type 316L Stainless Steel									G	GI	EG	EG
Type 317L Stainless Steel										I	EI	EI
Type 321 Stainless Steel											E	E
Type 347 Stainless Steel												E

Legend

A AWS A5.4 Classification E309-XX
B AWS A5.11 Classification ENiCrFe-2 or -3[4]
C AWS A5.4 Classification E410-XX [(0.05% C max. and heat treatment @1400ºF (760ºC) required]
D AWS A5.4 Classification E308-XX
E AWS A5.4 Classification E347-XX
F AWS A5.4 Classification E316-XX
G AWS A5.4 Classification E316L-XX
H AWS A5.4 Classification E308L-XX
I AWS A5.4 Classification E317L-XX
J AWS A5.4 Classification E308H-XX
K AWS A5.4 Classification E310-XX

Notes:

[1] Appendix A-2 refers to coated electrodes. For bare wire welding (SAW, GMAW, GTAW), use equivalent electrode classifications (AWS A5.9, A5.14). Refer to the text for information on other processes.

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

[3] See 6.3 of this document for weld metal delta ferrite requirements.

[4] Refer to 6.2.2 for the temperature limitation for nickel-based filler metals.

Table A-3—Copper-Nickel and Nickel-Based Alloys

Base Material Note[1]	70-30 & 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 & 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)				KJ	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

A AWS 5.11, Classification ENiCrFe-2 or -3
B AWS A5.11, Classification ENiCu-7
C AWS A5.11, Classification ENi-1
D AWS A5.11, Classification ENiCrMo-10
E AWS A5.11, Classification ENiCrMo-4
F AWS A5.11, Classification ENiMo-7
G AWS A5.11, Classification ENiCrMo-9
H AWS A5.11, Classification ENiCrMo-11
J AWS A5.11, Classification ENiCrMo-3
K AWS A5.11, Classification ENiCrCoMo-1
* An unlikely or unsuitable combination. Consult the purchaser if this combination is needed.

Notes:

[1] Appendix A.3 refers to coated electrodes. For bare wire welding (SAW, GMAW, GTAW), use equivalent electrode classification (AWS A5.14). Refer to the text for information on other processes.

APPENDIX B—WELD OVERLAY AND CLAD RESTORATION (BACK CLADDING)

B.1 General

B.1.1 Weld overlays shall be deposited with a minimum of two layers. Single-layer overlays shall require the approval of the purchaser.

B.1.2 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.1.3 The PQR chemical analysis shall report all elements for which specific values are given for the consumable in ASME Section II Part C.

B.1.4 Production weld overlay shall have the chemical composition checked using either:

a. A physical sample (e.g., drillings, chips) removed for quantitative analysis.
b. A portable spectrograph or portable X-ray fluorescence machine approved by the purchaser.

B.1.5 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 Sections B.3 through B.6.

B.1.6 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.1.7 For the submerged arc welding process (SAW), alloy additions made from the flux shall require approval by the purchaser.

B.1.8 All overlays shall be 100% liquid penetrant examined. If the item is postweld heat-treated (PWHT), this examination shall be performed after PWHT.

B.1.9 Consumables for commonly used overlay systems are shown in Table B-1. The purchaser shall approve other systems.

B.1.10 When PWHT of the base metal is required, PWHT does not have to be performed for welding attachments to the overlay/clad when the minimum overlay/clad thickness is $^3/_{16}$ in. (5 mm). When the overlay/clad is less than $^3/_{16}$ 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 P1 materials when PWHT is a requirement due to material thickness and not for process reasons.

B.2 Clad Restoration (Back Cladding)

B.2.1 The clad layer shall be stripped back for a minimum distance of $^3/_{16}$ in. (5 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 Section IX.

Table B-1—Filler Material Selection for Overlay of Carbon and Low Alloy Steels

	Weld Overlay Materials [1, 2]			
	Equipment Requiring PWHT		Equipment Not Requiring PWHT	
Overlay Material	First Layer	Top Layer(s)	First Layer	Top Layer(s)
405 / 410S	ENiCrFe-2 or -3 or ERNiCr-3		ENiCrFe-2 or -3 or ERNiCr-3	
304 SS	[3]	[3]	E/ER309	E/ER308
304L SS	E/ER309L	E/ER308L	E/ER309L	E/ER308L
316 SS	[3]	[3]	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/ER309Cb	E/ER347	E/ER309Cb	E/ER347
Alloy 20Cb-3	E/ER320LR	E/ER320LR	E/ER320LR	E/ER320LR
Alloy 400	E/ERNiCu-7 [4]	E/ERNiCu-7	E/ERNiCu-7 [4]	E/ERNiCu-7

[1] Use of this table is limited to carbon and low-alloy steel backing materials.
[2] For overlay not involving clad restoration, use the combination of consumables that results in the desired weld metal chemical composition in the top layers.
[3] E/ER308 and E/ER316 are not normally used in the postweld heat-treated condition. The purchaser shall approve the use of non-low-carbon E/ER308 and E/ER316 in the postweld heat-treated condition.
[4] ENi-1 or ERNi-1 may be used as an alternate.

Table B-2—Typical Chemical Composition Requirement 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	2.0–3.0		
316L	0.08	16.0	10.0	2.0–3.0		
317L	0.04	18.0	11.0	3.0–4.0		
347	0.08	17.0	9.0			10 X C, min. to 1.0 max.

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.

B.3.3 The ferrite content of the final layer of weld overlay shall be in the range of 3-11 FN, except for type 347, which shall have a range of 5-11 FN.

B.3.4 Ferrite measurements shall be taken before PWHT.

B.3.5 Magnetic instruments for measuring ferrite shall be calibrated annually in accordance with AWS A4.2.

B.4 Ferritic Stainless Steel Alloys

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

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

B.5.1 The PQR shall report Ni, Cu, and Fe. The Fe content shall not exceed 7% 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 shall be specified by the purchaser in a separate specification.

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

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

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