Case N-754-1
Optimized Structural Dissimilar Metal Weld Overlay for Mitigation of PWR Class 1 Items
Section XI, Division 1

Inquiry: As an alternative to the provisions of IWA-4410, IWA-4611, and IWA-4540 for reducing a defect to an acceptable size in accordance with the provisions of the Construction Code or Section XI, is it permissible to increase the wall thickness, or to apply a preemptive overlay to a specified location, by deposition of an optimized structural weld overlay on the outside surface of the piping, component, or associated weld?

Reply: It is the opinion of the Committee that, in lieu of the requirements of IWA-4410, IWA-4611, and IWA-4540, a defect in austenitic stainless steel or austenitic nickel alloy piping, components, or associated welds may be reduced to a flaw of acceptable size in accordance with IWB-3640 by the addition of a repair-optimized structural weld overlay. This Case is limited to mitigation repair of as-found inside surface and subsurface flaws that measure not more than 50% in depth from the inside surface. In addition, for these materials, in lieu of IWA-4410, a pre-emptive optimized weld overlay may be applied to welds in which no flaws have been found. The weld overlay shall be applied by deposition of weld reinforcement (weld overlay) around the entire circumference on the outside surface of the piping, component, or associated weld, including ferritic materials when necessary, provided the following requirements are met.

1 GENERAL REQUIREMENTS

1.1 DEFINITIONS

(a) mitigation: as used in this Case, mitigation is an activity performed to reduce or eliminate the susceptibility of materials specified in (e) to crack initiation or crack propagation. Mitigation can be preemptive, i.e., taken before crack initiation, or repair, i.e., taken after crack initiation is discovered.

(b) optimized structural weld overlay (OWOL): deposition of weld reinforcement around the entire circumference on the outside surface of the piping, component, or associated weld, such that the weld reinforcement is capable of compliance with the requirements of this Case with consideration of the outer 25% of the wall thickness of the piping, component, or associated weld beneath the weld reinforcement in the design. An optimized structural weld overlay can be either a preemptive or repair optimized structural weld overlay as defined in (c) and (d).

(c) pre-emptive optimized structural weld overlay: OWOL that is applied around the entire circumference on the outside surface over material with no inside-surface-connected flaws found during an examination performed in accordance with 2(a)(3), prior to the weld overlay being applied.

(d) repair optimized structural weld overlay: OWOL that is applied over material with inside surface or sub-surface flaws not greater than 50% of the wall thickness from the inside surface found during an examination performed in accordance with 2(a)(3) prior to the weld overlay being applied.

(e) SCC-susceptible materials: for PWRs, UNS N06600, N06082, or W86182 surfaces with a nominal operating temperature greater than or equal to 525°F (275°C) and in contact with the reactor coolant environment.

(f) life of the overlay: the amount of time for a flaw or postulated flaw to grow to the flaw depth assumed in the design of the OWOL.

1.2 GENERAL OWOL REQUIREMENTS

(a) This Case applies to OWOLs on austenitic nickel alloy and austenitic stainless steel welds between the following:

(1) P-No. 8 or P-No. 43 and P-Nos. 1, 3, 12A, 12B, or 12C

The references in this Case are based on the 2010 Edition with the 2011 Addenda, except where references have specific Edition or Addenda specified. For use with other Editions or Addenda, refer to the Guideline for Cross-Referencing Section XI Cases, Table 1.

P-Nos. 12A, 12B, and 12C designations refer to P-Numbers assigned by Section IX between 1967 and the Summer 1973 Addenda. In the Winter 1973 Addenda of Section IX, P-No.12A materials were reclassified P-No. 1, Gr. 1; P-No. 1, Gr. 3; P-No. 3, Gr. 1; P-No. 9A, Gr. 1; or P-No. 9B, Gr. 1; and P-No. 12B and 12C materials were reclassified P-No. 3, Gr. 3.

The Committee’s function is to establish rules of safety, relating only to pressure integrity, governing the construction of boilers, pressure vessels, transport tanks and nuclear components, and in-service inspection for pressure integrity of nuclear components and transport tanks, and to interpret these rules when questions arise regarding their intent. This Code does not address other safety issues relating to the construction of boilers, pressure vessels, transport tanks and nuclear components, and the in-service inspection of nuclear components and transport tanks. The user of the Code should refer to other pertinent codes, standards, laws, regulations or other relevant documents.
(2) P-No. 8 and P-No. 43
(3) P-No. 8 to P-No. 8

(4) Any combination of P-Nos. 1, 3, 12A, 12B, and 12C materials

(b) If a weld overlay on any of the material combinations in (a) obstructs a required examination of an adjacent P-No. 8 to P-No. 8 weld, the overlay may be extended to include overlaying the adjacent weld.

(c) Weld overlay filler metal shall be austenitic stainless steel or austenitic nickel alloy (28% Cr min., ERNiCrFe-7/7A) meeting the requirements of (f)(1) or (f)(2), as applicable. They shall be applied around the entire circumference of the item and deposited using a Welding Procedure Specification (WPS) for groove welding, qualified in accordance with the Construction Code and Owner’s Requirements identified in the Repair/Replacement Plan. As an alternative to the postweld heat treatment (PWHT) requirements of the Construction Code and Owner’s Requirements, the provisions of Appendix I may be used for ambient-temperature temper bead welding.

(1) For ferritic base materials, the Construction Code PWHT exemptions permitted for circumferential butt welds may be applied to exempt the weld overlay from PWHT, with the following clarifications:

(-a) The nominal weld thickness is defined as the maximum overlay thickness applied over the ferritic base material.

(-b) The base material thickness is defined as the maximum thickness of the ferritic material where the overlay is applied.

(2) If ambient-temperature temper bead welding is used, Appendix I shall be used.

(d) Prior to deposition of the OWOL, the surface to be weld overlaid shall be examined using the liquid penetrant method in accordance with IWA-2222 using personnel qualified in accordance with IWA-2300. Indications with major dimensions greater than \( \frac{1}{16} \) in. (1.5 mm) shall be removed or reduced in size, or repaired in accordance with the following requirements:

(1) One or more layers of weld metal shall be applied to repair surface indications only after their excavation to an acceptable size.

(2) If weld repair of indications identified in (d) is required, the area where the weld overlay is to be deposited, including any local weld repairs or initial weld overlay layer, shall be examined by the liquid penetrant method in accordance with (d). The area shall contain no indications with major dimensions greater than \( \frac{1}{16} \) in. (1.5 mm) prior to application of the structural layers of the OWOL.

(e) To reduce the potential of hot cracking when applying an austenitic nickel alloy over P-No. 8 base metal, it is permissible to apply a layer or multiple layers of austenitic stainless steel filler material over the austenitic stainless steel base metal or austenitic stainless steel weld metal. The thickness shall be considered in the design analysis required by 2(b). These filler materials shall meet the requirements (f)(1) if considered in contributing to the weld reinforcement design thickness.

(f) OWOL deposits shall meet the following requirements:

(1) The austenitic stainless steel OWOL shall consist of at least two weld layers having as-deposited delta ferrite content of at least 7.5 FN. The carbon content of the stainless steel weld OWOL shall not exceed 0.035% C. The first layer of weld metal with delta ferrite content of at least 7.5 FN shall constitute the first layer of the weld reinforcement that may be credited toward the required thickness. Alternatively, layers of at least 5 FN are acceptable, provided the carbon content of the deposited weld metal is determined by prior chemical analysis of a representative sample to be less than 0.02%.

(2) The austenitic nickel alloy OWOL shall consist of at least two weld layers deposited using ERNiCrFe-7/7A filler material with a Cr content of at least 28%. The first layer of weld metal with delta ferrite content of at least 7.5 FN shall be credited toward the required thickness, provided the layer and the Cr content of the deposited weld metal is determined by chemical analysis of the production weld or of a representative coupon taken from a mockup prepared in accordance with the WPS for the production weld.

(3) A new weld overlay shall not be installed over the top of an existing weld overlay that has been in service.

2 CRACK GROWTH AND DESIGN

(a) Crack Growth Calculation of Flaws in the Original Weld or Base Metal. The size of all flaws detected or postulated in the original weld or base metal shall be used to define the life of the OWOL. Crack growth due to both stress corrosion cracking and fatigue, shall be evaluated. The fatigue crack growth law for Alloy 600 shall be addressed for the PWR reactor coolant environment. The fatigue crack growth shall be addressed using the guidance from NUREG/CR-6721 and CR-6907 for PWR applications. Flaw characterization and evaluation shall be based on the examination results or an inside-surface-

2 P-Nos. 12A, 12B, and 12C designations refer to P-Numbers assigned by Section IX between 1967 and the Summer 1973 Addenda. In the Winter 1973 Addenda of Section IX, P-No.12A materials were reclassified P-No. 1, Gr. 1; P-No. 1, Gr. 3; P-No. 3, Gr. 1; P-No. 9A, Gr. 1; or P-No. 9B, Gr. 1; and P-No. 12B and 12C materials were reclassified P-No. 3, Gr. 3.
connected postulated flaw, as described below. If the flaw is at or near the boundary of two different materials, evaluation of flaw growth in both materials is required.

(1) For repair OWOLs, the initial flaw size for crack growth in the original weld or base metal shall be based on the as-found flaw from the results of the N-770-2 (or later in accordance with 5), ultrasonic examination.

(2) For inside-surface-connected postulated flaws, the axial flaw length shall be 1.5 in. (38 mm) or the combined width of the susceptible weld plus buttering, when applicable plus any adjacent SCC susceptible material, whichever is greater. The circumferential flaw length shall be assumed to extend around the entire circumference. The depths associated with these lengths are specified in (a), (3), and (4).

(3) If no inside-surface-connected planar flaws are discovered in the N-770-2 (or later in accordance with 5) ultrasonic examination performed prior to application of the overlay, initial flaws originated from the inside surface of the weldment equal to 10% of the original wall thickness shall be assumed in both the axial and circumferential directions, and the OWOL shall be considered preemptive.

(4) For cast austenitic stainless steel (CASS) items, a 75% through-wall flaw shall be assumed in the susceptible weld material in the limiting direction. The adjacent susceptible weld material and cast material shall be examined in accordance with N-770-2 (or later in accordance with 5).

(5) Any inside-surface-connected planar flaw found during the N-770-2 (or later in accordance with 5) preservice inspection shall be used to update the life of the OWOL. The detected flaw depth shall include the postulated worst-case flaw depth in the region of the pipe wall thickness that was not examined using an ultrasonic examination meeting Appendix VIII for that region. An OWOL meeting this condition shall be considered a repair.

(6) A bounding assessment of the OWOL effects on the SCC susceptible location shall be performed to satisfy (b)(8). The residual stress assessment must include the residual stresses that exist prior to application of the OWOL. Thus, the OWOL analysis includes residual stress assumed to be present due to the as-welded condition plus any machining or subsequent weld repairs that may have previously occurred. An as-welded stress distribution for a repair that is 50% through-wall in depth and extends around the entire circumference shall be assumed in the analysis. If construction records show more severe weld repairs, they shall be assumed in the analysis. Inside surface weld repairs are known to develop severe residual stress fields and provide flaw initiation sites due to grinding and weld defects and, therefore, must be accounted for in the analysis. In cases where construction records document that PWHT was performed on the susceptible weld or weld repairs, the residual stress distribution may be modified considering the effects of the PWHT.

(b) Structural Design and Sizing of the Overlay. The effects of the OWOL on the validity of the component design shall be evaluated as required by IWA-4311. In addition, the design of the OWOL shall satisfy the following requirements using the assumptions and flaw characterization requirements in (a). In addition the following requirements shall be met.

(1) The optimized structural weld overlay shall be designed such that the weld reinforcement is capable of supporting the design and service loads with consideration of the outer 25% of the wall thickness of the piping, component, or associated weld beneath the weld reinforcement in the design. An optimized structural weld overlay can be either preemptive or repair weld overlay.

(2) The axial length and end slope of the OWOL shall cover the susceptible weld including buttering where applicable and heat-affected zones on each side of the weld and the heat-affected zone on the ferritic nozzle or branch connection side of the buttering as well as any SCC-susceptible base material adjacent to the weld, and provide for load redistribution from the item into the OWOL and back into the item without violating applicable stress limits of NB-3200 or NB-3600. Any laminar flaws in the OWOL shall be evaluated in the analysis to ensure that load redistribution complies with the above. These requirements will usually be satisfied if the OWOL full thickness length extends axially beyond the SCC-susceptible material or projected flaw by at least 0.75 \( \sqrt{R_t} \) on both side(s) of the susceptible material, where \( R_t \) is the outer radius of the item and \( t \) is the nominal wall thickness of the item at the applicable side of the OWOL (i.e., \( t \) of the nozzle on the nozzle side and \( t \) of the safe-end on the safe-end side).

(3) Unless specifically analyzed in accordance with (2), the end transition slope of the overlay shall not exceed 30 degrees.

(4) The assumed flaw in the underlying base material or original weld shall be based on the limiting case of (a) and (b) that results in the larger required OWOL thickness.

(a) 75% through-wall circumferential inside surface flaw for the entire circumference.

(b) 75% through-wall axial inside surface flaw with length of 1.5 in. (38 mm), or the combined width of the weld plus buttering plus any SCC-susceptible material, whichever is greater, in the axial direction or the alternative in (c).

(c) In applying IWB-3641 allowable flaw size criteria to structural sizing of the OWOLs, the following shall be considered.

(-1) The design shall account for potential lower toughness of the underlying weld material (particularly at the fusion line with the low-alloy or carbon steel nozzle or branch connection).
(2) The limit load solution for net section collapse should use the flow stress of the lower-strength stainless steel material rather than that of the Alloy 82/182 weldment to address potential for SCC located near the stainless steel fusion line.

(3) In the design of OWOLs, the specific strength and fracture toughness properties of the underlying weldment, base material, weld layers not credited toward the OWOL in accordance with 1.2(e) and 1.2(f), and OWOL shall be used, as appropriate. Alternatively, the lower of the strength and fracture toughness properties of the underlying weldment, base material, weld layers not credited toward the weld overlay in accordance with 1.2(e) and 1.2(f), and the weld overlay shall be used for the entire OWOL assembly.

(5) The combined wall thickness at the weld overlay, including the requirements of (4), any postulated worst-case planar flaws under the laminar flaws in the OWOL, and the effects of any discontinuity (e.g., another weld overlay or reinforcement for a branch connection) within a distance of $2.5 \sqrt{Rt}$ from the toes of the OWOL shall be evaluated and shall meet the requirements of IWB-3640.

(6) The effects of any changes in applied loads, as a result of weld shrinkage from the entire OWOL, on other items in the piping system (e.g., support loads and clearances, nozzle loads, and changes in system flexibility and weight due to the OWOL) shall be evaluated. Existing flaws previously accepted by analytical evaluation shall be evaluated in accordance with IWB-3640.

(7) The usage factor at the location (beyond the OWOL and adjacent to the ends of the OWOL) shall be assessed. The fatigue analysis shall be conducted using the applicable requirements of Section III for Class 1 components (NB-3600 for piping and NB-3200 for vessel nozzles).

(8) The minimum thickness of the OWOL shall be sufficient to reduce residual stresses to less than 10 ksi (69 MPa) tensile at operating temperature and pressure on the internal wetted surface of all SCC-susceptible materials defined in 1.1(e).

(c) Evaluation of the Margins Beyond the Design Basis Flaw. OWOLs shall satisfy the additional structural requirement that the location exhibits Structural Factors (SFs) greater than or equal to those listed in Table 1 for an assumed limiting flaw consisting of circumferential cracking extending around the entire circumference of the item and 100% through the susceptible material of the nozzle, piping or associated weld, under the applicable design loads and service conditions.

3 EXAMINATIONS

(a) Prior Volumetric Examinations. Volumetric examinations (including examination deferrals) prior to application of the OWOL shall be performed in accordance with N-770-2 (or later in accordance with 5).

(b) Acceptance Examination. Nondestructive examination (NDE) methods shall be in accordance with IWA-2200, except as specified herein. NDE personnel shall be qualified in accordance with IWA-2300.

(I) Surface Finish. The weld overlay shall have a surface finish of 250 μin. (6.3 μm) RMS or better and contour that permits ultrasonic examination in accordance with procedures qualified in accordance with Mandatory Appendix VIII and Appendix VIII, Supplement 11. The OWOL shall be inspected to verify acceptable configuration.

(2) Surface Examination. The OWOL and the adjacent base material for at least 1/2 in. (13 mm) from each side of the OWOL shall be examined using the liquid penetrant method. The OWOL shall satisfy the surface examination acceptance criteria for welds of the Construction Code or NB-5300. The adjacent base material shall satisfy the surface examination acceptance criteria for base material of the Construction Code or NB-2500. If ambient temperature temper bead welding is performed, the liquid penetrant examination of the completed OWOL shall be conducted no sooner than 48 hr following completion of the three tempering layers over the ferritic steel.

(3) Volumetric Examination. Examination procedures, personnel and equipment shall be qualified in accordance with Appendix VIII and Appendix VIII, Supplement 11. The examination volume A-B-C-D in Figure 1, sketch (a), which includes the overlay and welds made in accordance with 1.2(d), 1.2(e), and 1.2(f), shall be ultrasonically examined to assure adequate fusion (i.e., adequate bond) with the base material and to detect welding flaws, such as interbead lack of fusion, inclusions, or cracks. The examination volume shall include the bond and heat-affected zone. If ambient temperature temper bead welding is performed, the ultrasonic examination shall be conducted no sooner than 48 hrs following completion of the three tempering layers over the ferritic steel. Planar flaws detected in the OWOL acceptance examination shall meet the preservice examination standards of IWB-3514. In applying the acceptance standards to planar indications, the thickness, $t_1$ or $t_2$ defined in Figure 1, sketch (b), shall be used as the nominal wall thickness in IWB-3514, provided the base material beneath the flaw (i.e., safe end, nozzle, or piping material) is not susceptible to SCC. For susceptible material, $t_3$ shall be used. If a flaw in the OWOL crosses the boundary between the two regions, the more conservative of the two dimensions ($t_1$ or $t_2$) shall be used. Laminar flaws in the OWOL shall meet the following requirements:
(-a) The acceptance standards of IWB-3514 shall be met, with the additional limitation that the total laminar flaw area shall not exceed 10% of the weld surface area and that no linear dimension of the laminar flaw area shall exceed the greater of 3 in. (76 mm) or 10% of the component outer circumference.

(-b) For examination volume A-B-C-D in Figure 1, sketch (a), the reduction in coverage due to laminar flaws shall be less than 10%. The unexamined volume is the volume in the OWOL underneath the laminar flaws for which coverage cannot be achieved with the angle beam examination method.

(-c) Any unexamined volume in the OWOL shall be assumed to contain the largest radial planar flaw that could exist within that volume. This assumed flaw shall meet the preservice examination acceptance standards of IWB-3514, with nominal wall thickness as defined above in (3) for the planar flaws. Alternatively, the assumed flaw shall be evaluated and meet the requirements of IWB-3640. Both axial and circumferential planar flaws shall be assumed.

(4) After completion of all welding activities, VT-3 visual examination shall be performed on all affected restraints, supports, and snubbers, to verify that design tolerances are met.

(c) Preservice and Inservice Examinations. In lieu of all other Preservice and Inservice inspections by the examination requirements in accordance with N-770-2 (or later in accordance with 5) shall be met. Alternately, the requirements of (1) through (3) below may be used to modify the provisions of N-770-2 (or later in accordance with 5).

(1) NDE qualification for procedures, equipment, and personnel shall be in accordance with Appendix VIII and Appendix VIII, Supplement 11, except that for OWOLs the qualified through-wall flaw examination depth shall be extended to the outer 50% of the base material for circumferential flaws. The qualified examination depth for axial flaws shall remain at the outer 25% of the base material.3

(2) A design requirement is added to show that Section XI, Appendix C, C-5410, eqs. (7) and (8) are met for a 100% through-wall axial flaw in the underlying material, but excluding the 75% upper bound limit of applicability of that equation.

(3) An analysis of fatigue and SCC crack growth must demonstrate that an assumed initial 75% through-wall axial flaw in the underlying material would not violate Section XI, Appendix C, C-5410, eqs. (7) and (8) during the life of the overlay.

4 PRESSURE TESTING

In lieu of meeting the requirements of IWA-4540, a system leakage test of the area affected by the repair/replacement activity shall be performed in accordance with IWA-5000, prior to or as a part of returning to service.

5 USE OF CASE N-770-2 OR LATER

(a) The revision of Case N-770 used shall be applicable, as indicated in the Applicability Index for Section XI Cases found in the Code Cases: Nuclear Components book, to the Edition and Addenda specified for the repair/replacement activity.

(b) The revision of Case N-770 used is subject to acceptance by the regulatory and enforcement authorities having jurisdiction at the plant site.

(c) The revision of Case N-770 used shall be in effect at the time of the repair/replacement activity, except as provided in (d).

(d) A revision of Case N-770 that is superseded at the time of the repair/replacement activity, but acceptable to the regulatory and enforcement authorities having jurisdiction at the plant site may be used.

### Table 1

<table>
<thead>
<tr>
<th>Structural Factors for OWOL Limiting Flaw Assumption</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Service Level</strong></td>
</tr>
<tr>
<td>-------------------</td>
</tr>
<tr>
<td>Level A (normal)</td>
</tr>
<tr>
<td>Level B (upset)</td>
</tr>
<tr>
<td>Level C (emergency)</td>
</tr>
<tr>
<td>Level D (faulted)</td>
</tr>
</tbody>
</table>

3 Additional details, including appropriate flaw size distribution, flaw location distribution, or grading unit requirements, and the demonstration acceptance criteria, may be found in a letter dated July 13, 2009 from FENOC for the Davis Besse Plant to the NRC (ML091950627).
Figure 1
Examination Volume and Thickness Definitions

(a) Examination Volume A–B–C–D

(b) Thickness \((t_1\) and \(t_2\)) for Table IWB-3514-2

GENERAL NOTES:
(a) Dimension \(b\) is equivalent to the nominal thickness of the nozzle or pipe being overlaid, as appropriate.
(b) The nominal wall thickness is \(t_1\) for flaws in E-F-G-H, and \(t_2\) for flaws in A-E-H-D or F-B-C-G.
(c) For flaws that span two examination volumes (such as illustrated in F-G) the \(t\), thickness shall be used.
(d) The weld includes the nozzle or safe end butter, where applied, plus any SCC-susceptible base material.
MANDATORY APPENDIX I
AMBIENT-TEMPERATURE TEMPER BEAD WELDING

I-1 GENERAL REQUIREMENTS

(a) This Mandatory Appendix applies to dissimilar austenitic filler metal welds between P-Nos. 1, 3, 12A, 12B, and 12C materials and their associated welds and welds joining P-No. 8 or 43 materials to P-Nos. 1, 3, 12A, 12B, and 12C materials with the following limitation. This Mandatory Appendix shall not be used to repair SA-302 Grade B material unless the material has been modified to include from 0.4% to 1.0% nickel, quenching, tempering, and application of a fine grain practice.

(b) The maximum area of an individual weld overlay based on the finished surface over the ferritic base material shall be 1,000 in.² (650 000 mm²).

(c) Repair/replacement activities on a dissimilar metal weld in accordance with this Mandatory Appendix are limited to those along the fusion line of a nonferritic weld to ferritic base material on which 1/8 in. (3 mm) or less of nonferritic weld deposit exists above the original fusion line.

(d) If a defect penetrates into the ferritic base material, repair of the base material, using a nonferritic weld filler material, may be performed in accordance with this Mandatory Appendix, provided the depth of repair in the base material does not exceed 3/8 in. (10 mm).

(e) Prior to welding, the area to be welded and a band around the area of at least 1 1/2 times the component thickness or 5 in. (130 mm), whichever is less, shall be at least 50°F (10°C).

(f) Welding materials shall meet the Owner’s Requirements and the Construction Code and Cases specified in the Repair/Replacement Plan. Welding materials shall be controlled so that they are identified as acceptable until consumed.

(g) Peening may be used, except on the initial and final layers.

I-2 WELDING QUALIFICATIONS

The welding procedures and operators shall be qualified in accordance with Section IX and the requirements of I-2.1 and I-2.2.

I-2.1 Procedure Qualification.

(a) The base materials for the welding procedure qualification shall be of the same P-Number and Group Number as the materials to be welded. The materials shall be postweld heat treated to at least the time and temperature that was applied to the materials being welded.

(b) The maximum interpass temperature for the first three layers of the test assembly shall be 150°F (66°C).

(c) The weld overlay shall be qualified using groove weld coupon. The test assembly groove depth shall be at least 1 in. (25 mm). The test assembly thickness shall be at least twice the test assembly groove depth. The test assembly shall be large enough to permit removal of the required test specimens. The test assembly dimensions on either side of the groove shall be at least 6 in. (150 mm). The qualification test plate shall be prepared in accordance with Figure I-1.

(d) Ferritic base material for the procedure qualification test shall meet the impact test requirements of the Construction Code and Owner’s Requirements. If such requirements are not in the Construction Code and Owner’s Requirements, the impact properties shall be determined by Charpy V-notch impact tests of the procedure qualification base material at or below the lowest service temperature of the item to be repaired. The location and orientation of the test specimens shall be similar to those required in (e), but shall be in the base metal.

(e) Charpy V-notch tests of the ferritic heat-affected zone (HAZ) shall be performed at the same temperature as the base metal test of (d). Number, location, and orientation of test specimens shall be as follows:

(1) The specimens shall be removed from a location as near as practical to a depth of one-half the thickness of the deposited weld metal. The coupons for HAZ impact specimens shall be taken transverse to the axis of the weld and etched to define the HAZ. The notch of the Charpy V-notch specimen shall be cut approximately normal to the material surface in such a manner as to include as much HAZ as possible in the resulting fracture.

(2) If the material thickness permits, the axis of a specimen shall be inclined to allow the root of the notch to be aligned parallel to the fusion line.

(3) If the test material is in the form of a plate or forging, the axis of the weld shall be oriented parallel to the principal direction of rolling or forging.
The Charpy V-notch test shall be performed in accordance with SA-370. Specimens shall be in accordance with SA-370, Fig. 11, Type A. The test shall consist of a set of three full-size 10 mm × 10 mm specimens. The lateral expansion, percent shear, absorbed energy, test temperature, orientation, and location of all test specimens shall be reported in the Procedure Qualification Record.

(f) The average lateral expansion value of the three HAZ Charpy V-notch specimens shall be equal to or greater than the average lateral expansion value of the three unaffected base metal specimens. However, if the average lateral expansion value of the HAZ Charpy V-notch specimens is less than the average value for the unaffected base metal specimens and the procedure qualification meets all other requirements of this Mandatory Appendix, either of the following shall be performed:

1) The welding procedure shall be requalified.

2) An Adjustment Temperature for the procedure qualification shall be determined in accordance with the applicable provisions of NB-4335.2 of Section III, 2001 Edition with the 2002 Addenda. The RTNDT or lowest service temperature of the materials for which the welding procedure will be used shall be increased by a temperature equivalent to that of the Adjustment Temperature.

I-2.2 Performance Qualification. Welding operators shall be qualified in accordance with Section IX.

I-3 WELDING PROCEDURE REQUIREMENTS

The welding procedure shall include the following requirements:

(a) The weld metal shall be deposited by the automatic or machine GTAW process.

(b) Dissimilar metal welds shall be made using A-No. 8 weld metal (QW-442) for P-No. 8 to P-No. 1, 3, 12A, 12B, or 12C weld joints or F-No. 43 weld metal (QW-432) for P-No. 8 or 43 to P-No. 1, 3, 12A, 12B, or 12C weld joints.

(c) The area to be welded shall be buttered with a deposit of at least three layers to achieve at least \( \frac{1}{8} \) in. (3 mm) overlay thickness with the heat input for each layer controlled to within ±10% of that used in the procedure qualification test. The heat input of the first three layers shall not exceed 45 kJ/in. (1.8kJ/mm) under any conditions. Particular care shall be taken in the placement of the weld layers of the austenitic overlay filler material at the toe of the overlay to ensure that the HAZ and ferritic base metal are tempered. Subsequent layers shall be deposited with a heat input not exceeding that used for layers beyond the third layer in the procedure qualification.

(d) The maximum interpass temperature for field applications shall be 350°F (180°C) for all weld layers regardless of the interpass temperature used during qualification. The interpass temperature limitation of QW-406.3 need not be applied.

(e) The interpass temperature shall be determined as follows:

1) Temperature measurement (e.g., pyrometers, temperature-indicating crayons, and thermocouples) during welding. If direct measurement is impractical, interpass temperature shall be determined in accordance with (2) or (3).

2) Heat-flow calculations, using at least the variables listed below:

\(-a\) welding heat input
\(-b\) initial base material temperature
\(-c\) configuration, thickness, and mass of the item being welded
\(-d\) thermal conductivity and diffusivity of the materials being welded
\(-e\) arc time per weld pass and delay time between each pass
\(-f\) arc time to complete the weld

3) Measurement of the maximum interpass temperature on a test coupon that is no thicker than the item to be welded. The maximum heat input of the welding procedure shall be used in welding the test coupon.

(f) Particular care shall be given to ensure that the weld region is free of all potential sources of hydrogen. The surfaces to be welded, filler metals, and shielding gas shall be suitably controlled.

---

2 P-Nos. 12A, 12B, and 12C designations refer to P-Numbers assigned by Section IX between 1967 and the Summer 1973 Addenda. In the Winter 1973 Addenda of Section IX, P-No.12A materials were reclassified P-No. 1, Gr. 1; P-No. 1, Gr. 3; P-No. 3, Gr. 1; P-No. 9A, Gr. 1; or P-No. 9B, Gr. 1; and F-No. 12B and 12C materials were reclassified P-No. 3, Gr. 3.
GENERAL NOTE: Base metal Charpy impact specimens are not shown. This figure illustrates a dissimilar metal weld.