1. SCOPE:

1.1 This specification defines a) the minimum requirements for joining and repairing ***pressure containing and load bearing weldments*** by fusion welding, b) the minimum requirements for qualifying fusion-welding procedures, and c) the technical reasons for each set of requirements. (Parenthetical references are listed in Appendix C.)

1.2 The requirements of this specification apply to all facilities that manufacture, overhaul, or repair products for Hydril, including Hydril authorized vendors and Hydril authorized repair facilities.

2. GENERAL REQUIREMENTS

2.1 Welding of all ***pressure containing*** **and** ***non-pressure containing*** weldments exposed to well bore fluids shall be performed with procedures qualified in accordance with this specification.

2.2 Welding of all pressure containing and load bearing weldments ***not exposed to well bore fluids*** shall also be performed with procedures qualified in accordance with this specification except that the material and hardness requirements need not conform to ***NACE MR0175.***

2.3 All welders and welding operators shall be qualified in accordance with the requirements of the ***ASME Boiler & Pressure Vessel Code Section IX.***

3. APPLICABLE DOCUMENTS

3.1 Welding Specification for Fabrication / Repair of 11.1xx Materials IAW API 6A & API 16A (WS 11.100 Rev. NC)

3.2 Allowable Exceptions to WPS Specified Thickness Limits for Production Joints from 3/16" to Unlimited Thickness, Dwg X-1001742.

3.3 Allowable Exceptions to WPS Specified Thickness Limits for Production Joints from 1/16" to less than 5/8", Dwg X-1001736.

3.4 ASME Boiler & Pressure Vessel Code Section IX–Welding and Brazing Qualifications

Prepared By: Ken Fordyce Sr. Welding Engineer Date: 9/18/01	Reviewed By: Bill Carbaugh Lead Engineer Product Development Date: 9/18/01
Approved By: Ken Fordyce Sr. Welding Engineer Date: 9/18/01	Released By: A. Johnson Engineering Records Date: 9/18/01

3.5 ASME Boiler & Pressure Vessel Code Section II, Materials Part C–Specification for Welding Rods, Electrodes, and Filler Metals

3.6 ASME Boiler & Pressure Vessel Code Section VIII, Division 1–Rules for Construction of Pressure Vessels

3.7 NACE Standard MR0175–Sulfide Stress Cracking Resistant Metallic Materials for Oilfield Equipment

3.8 API Specification 6A—Specification for Wellhead and Christmas Tree Equipment

3.9 API Specification 16A—Specification for Drill Through Equipment

3.10 ASTM A 370—Standard Test Methods and Definitions for Mechanical Testing of Steel Products

3.11 ASTM E 18—Test Method for Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials

3.12 ASTM E 140—Standard Hardness Conversion Tables for Metals

4. DEFINITIONS

4.1 **Approved Welding Procedure Specification (WPS):** Any WPS that has been reviewed and approved by Hydril welding engineering as qualified to meet the required joint Welding Specifications (WSs). All WPSs, PQRs, and associated documents (PWHT charts, CMTRs, test lab reports, etc.) shall be approved before use.

4.2 **Approved Welding Process:** Any process that has been qualified in accordance with this specification and the ***ASME Boiler & Pressure Vessel Code Section IX*** to join, repair, or buildup the welds and base metals referenced in ***Section IX*** and this specification.

4.3 **Buildup Weld:** A weld that is used to add features to a part or restore mismachined, worn, or corroded surfaces to factory dimensions. A buildup weld may be a major or minor repair weld, depending on whether its thickness is the greater or lesser of 1 inch or 25% of the original base metal thickness.

4.4 **Critical PWHT Sections:** Distinct thin and thick sections of a weldment (weld metal or base metal) whose heat absorption properties and section thickness make them susceptible, respectively, to degradation in strength from overheating and excessive hardness from underheating. Critical PWHT sections shall be identified by product engineering as required.

4.5 **Critically Stressed Areas:** All areas or sections of a weldment (weld metal, base metal, heat-affected zones) whose mechanical properties must meet the minimum requirements of the base metal specification and are deemed critical to the design and safe operation of the component. Unless otherwise specified by product engineering, all areas and sections of a weldment are presumed to be "critically stressed."

4.6 **Fabrication Weld:** A weld that joins two or more pieces of metal.

4.7 **Base Metal Heat-Affected Zone (HAZ):** That portion of the weld metal or base metal, typically 1/64” to 1/4” in width, whose mechanical properties and microstructure were altered by a source of heat energy (usually welding, thermal cutting, or brazing) without melting. While the width of the HAZ depends on the energy density of the heat source and the magnitude of the temperature gradient, its mechanical properties depend on the type of weld metal or base metal, the welding process, and the welding procedure. This dependency is tied to the chemical composition of the metal and the heat-treating effect that occurs in various regions across the width of the HAZ. Consequently, the mechanical properties in the heat-affected regions vary from the original metal, and from each other, to the transformation products or microstructures that resulted from the heat treatment temperature that each region experienced separately during welding. In hardenable carbon and low alloy steels, the region near the weld interface will initially be a hard and brittle coarse-grained structure of untempered martensite or lower bainite. In regions farther away, the structure may still transform to martensite with fast cooling rates. With slower cooling rates, the HAZ will be altered but it is likely to be more like the structure of the original base metal. In regions still further away, the HAZ will be tempered but no transformation will take place (Ref. C1.1, C1.2, C1.3). Since a hard and brittle HAZ is nearly always detrimental, it must be softened to make it more ductile and better suited for design and service conditions. Consequently, postweld heat treatment is always required for the hardenable carbon and low alloy steels referenced in this specification.

4.8 **Weld Metal Heat-Affected Zone (WM-HAZ):** The same metallurgical and heat treating principles that apply to the base metal HAZ also apply to the weld metal and WM-HAZ. However, the mechanical properties of the various regions of the WM-HAZ are more dependent than the base metal HAZ on the welding conditions and the dynamic nature of certain elements on the weld-pool-solidification process. For example, the characteristics of the WM-HAZ are tied to the chemical composition of the filler metal, the amount of grain refinement that occurs from the heat of subsequent weld beads, the amount and type of base metal mixed with the weld metal, the type of flux or shielding gas used, and the influence that certain elements have on the solidification and subsequent cooling and transformation process. Since the amount of carbon present in most weld deposits is usually much lower than it is in hardenable base metals, the weld metal and the WM-HAZ do not have the hardenability or hardening power that the base metal does. Hence, the weld metal obtains its mechanical properties from other alloying elements, besides carbon, that solidify from the molten condition into austenite and then transform upon continuous cooling into a variety of constituents. Depending on the rate of cooling, these constituents range from blocky ferrite to acicular ferrite, to bainite and low carbon martensite. Thus, the structures that form in the various regions across the width of a multipass WM-HAZ are entirely different from those of the base metal, particularly the HAZ of hardenable base metals. The as-welded condition of such welds frequently exhibits a fine-grained structure that is softer than the base metal but has a high yield to tensile ratio and a strength level that is high for its composition. However, the extent of these favorable properties is greatly dependent on the size of the individual beads. Small bead sizes produce a larger percentage of fine-grained structure, while larger beads produce less. In either case, the mechanical properties of the weld metal and WM-HAZ usually diminish with increases in heat input and the number of postweld heat treatment cycles (Ref. C1.1, C1.2, C1.3).

4.9 **Major Repair Weld:** A weld that is the greater in thickness of either 1 inch or 25 percent of the original base metal thickness.

4.10 **Minor Repair Weld:** A weld that is the lesser in thickness of either 1 inch or 25 percent of the original base metal thickness.

4.11 **Procedure Qualification Record (PQR):** A PQR is a record of the welding data used to make the test weldment. It contains the actual values or ranges of the essential and supplementary essential variables used in preparing the test weldments, including the test results. The completed PQR shall document this information for each welding process used.

4.12 **Postweld heat treatment (PWHT):** Heating and cooling a weldment in a controlled manner to obtain desired properties. Specifically, PWHT means heating to a specified temperature at a specified rate, holding at temperature for specified period, and cooling at a specified rate. PWHT is required to temper or soften the hard and crack sensitive areas that welding produces in hardenable materials. PWHT thus reduces susceptibility to sulfide stress cracking and hydrogen-induced cold cracking (See Appendix D, Sections 4-6). PWHT is also required in thick weldments of all hardenability ranges to relieve residual welding and machining stresses. A production weldment has been properly postweld heat-treated when the thermal cycle is representative of that used to qualify the WPS. When the PWHT cycle is not qualified or properly controlled, weldments are susceptible to nonconforming hardness and strength values.

4.13 **Qualified WPS Postweld heat treatment (PWHT) cycle:** A WPS PWHT cycle is properly qualified when the PQR postweld heat treatment cycle is

4.13.1 ***controlled*** within the parameters specified for welding and postweld heat treating the base metals referenced in this specification,

4.13.2 ***verifiably representative*** of the production/repair ***PWHT cycle capability*** (See Section 9 of this specification),

4.13.3 ***used on the PQR*** test weldment ***that qualified the WPS*** for welding, and is

4.13.4 ***verifiably representative*** of the ***total time-at-temperature required*** to qualify WPSs ***for*** repairing ***previously postweld heat-treated weldments***. (See Sections 5.6 and 9 of this specification.)

4.14 **Welding:** The application of any one of a group of welding processes, which applies heat energy sufficient to melt and join one or more pieces of metal through localized fusion and coalescence. Welding is used to join, repair, or buildup welds and base metals using one or more qualified welding processes and procedures. Fusion welding of this type always creates heat-affected zones in the materials welded.

4.15 **Weldment:** That portion or area of a component on which welding has been performed. A weldment includes the weld metal, the heat-affected zone (HAZ), and the base metal unaffected by the heat of welding.

4.16 **Welding Procedure Specification (WPS):** A WPS is a written welding procedure that is qualified to provide direction for welding in accordance with requirements of this specification. The completed WPS shall describe the specific essential, nonessential, and supplementary essential variables required for each welding process. These variables and their meanings are defined, respectively, in Article II, QW-250 through QW-280 and Article IV of the ***ASME Boiler & Pressure Vessel Code Section IX–Welding and Brazing Qualifications***.

5. JOINT REQUIREMENTS

5.1 The minimum requirements of each weld joint, weld repair, or weld buildup in a weldment shall be defined by a ***Welding Specification (WS)*** before welding.

5.2 The WS shall be defined by Hydril product engineering in accordance with the ***Welding Specification for Fabrication / Repair of 11.1xx Materials IAW API 6A & API 16A (WS 11.100)***.

5.3 The WS shall determine the qualification requirements of all WPSs used in a production or repair weldment.

5.4 Each weld joint, weld repair, or weld buildup shall be made with WPSs that have been qualified to meet or exceed the mechanical properties specified by the WS. WPSs that are qualified to meet mechanical properties less than specified by the WS or the base metal specification may be used to weld repair low stress areas of a weldment, provided written approval is obtained from Hydril product engineering. Approval must be obtained before using procedures that are not qualified to meet the WS specified mechanical properties.

5.5 When PWHT is required, the WPSs shall be capable of producing the WS specified mechanical properties in each weld joint, weld repair, or weld buildup ***after all required production or repair postweld heat treatments***. (See Section 9 of this specification.)

5.6 When it is necessary to repair defects or machining errors in ***previously postweld heat-treated weldments***, the ***weldments shall be capable*** of meeting the WS specified requirements after all PWHT cycles. (See qualified WPS PWHT cycle definition in Section 4.13 and PWHT requirements in Section 9.) Capability shall be established by qualifying WPSs for both, the shortest and longest PWHT cycle times at temperature using the same parameters used in the original WPSs (base metal, filler metal, process, etc.). For the ***hardenable materials*** referenced in this specification, the shortest PWHT cycle shall be 4 hours at temperature. The longest PWHT cycle shall be 4 hours plus 4 hours multiplied by the number of 4-hour cycles necessary to equal or exceed the aggregate time-at-temperature to which the weldment would be exposed. When the weld metal hardness is below the minimum required by the WS, or the parameters used in the original WPS are unknown, the ***entire weld shall be removed and rewelded*** with WPSs qualified in accordance with this specification.

When it is not possible to qualify WPSs for the required number of 4-hour PWHT cycles (aggregate of several or one single exposure), an appropriate disposition shall be made by Hydril product engineering or the owner, as applicable, before any welding is performed.

6. BASE MATERIAL REQUIREMENTS

6.1 The base metals used to manufacture or repair Hydril products shall be defined by ***Hydril Engineering and Material Specifications (HEMPS)*** or other approved standards (ASME, ASTM, SAE, AMS, MIL STD).

6.2 The base metals to be used in Hydril products shall be specified by Hydril product engineering.

6.3 The base metals to be used for procedure qualification test coupons shall conform to a HEMPS or other approved standard and shall meet or exceed the minimum mechanical properties specified by the WS for the material combination to be qualified. (See Joint requirements and ***WS 11.100, Welding Specification for Fabrication / Repair of 11.1xx Materials IAW API 6A & API 16A*****.)**

6.4 The base metals of all products to be weld repaired or built up shall be positively identified by an appropriate means before weld repairs are performed. The chemical composition of the base metal shall be traceable by serial number, engineering drawing, manufacturing or repair records, or other means, to a certified mill test report (CMTR) or chemical analysis report. When positive identification by chemical analysis is required, a qualified laboratory using industry-accepted practices and techniques shall perform the analysis. Care should be taken to ensure that the analysis is made from one or more samples (chips or cuttings) of the ***original base metal***. This includes the substrate of previous weld repairs, buildups, or other areas that are not previously deposited weld metal. A suitable etchant, such as specified in ASME IX QW-470, should be used to substantiate that these areas are in fact original base metal. The areas from which chips or cuttings are removed for chemical analysis shall be in accordance with pre-approved locations defined by the product engineer or the ***Overhaul and Repair Manual*** and shall be restored by welding with an approved WPS when required.

6.5 Equivalent P-Number (EP) groupings for the purpose of procedure qualification are not permitted for any of the ***hardenable materials*** referenced in this specification (8630M, 4130, F22). These materials have differences in hardenability, temper resistance, and product heat-treat conditions that require different PWHT cycles. Consequently, the component members of weldments produced from combinations of these materials will possess unequal mechanical properties with the same PWHT cycle. Thus, ***welding combinations of 8630M, 4130, or F22 to each other is not recommended.*** However, when the mechanical properties of each component member need not be equal, then combinations of these materials may be welded, provided the WPSs used to weld them are qualified separately. In other words, a separate PQR test weld shall be made and postweld heat-treated with the higher of the two PWHT temperatures required for welding each of the two materials to themselves. In this case, the criteria for qualification shall be that the mechanical properties of the joint (weaker member, weld metal, and stronger member) shall meet the requirements of the WS after PWHT. For example, welding 4130 material to itself requires WPSs qualified for a minimum of 4 hours at 1210°F (±15F°), whereas 4 hours at 1225°F (±15F°) is the minimum required for 8630M materials. Consequently, the WPSs used to weld these materials to each other must be qualified with the higher of the two PWHT temperatures. This is necessary to ensure that the HAZ of the more temper resistant and hardenable material (8630M) meets the maximum hardness requirement of HRC 22 and to ensure that the mechanical properties of the joint meets design requirements. Thus, when hardenable materials like 4130, F22, and 8630M are welded to each other, the weldment design must account for the mechanical properties differences that will result when they are postweld heat treated together.

6.6 WPSs to be used for welding products manufactured from AISI 8630 modified material, condition IV or lower (HEMPS 2.535, 2.501, and 2.555) shall be qualified on base metals that meet HEMPS 2.535-04 (95 ksi tensile/ 80 ksi yield).

6.7 WPSs to be used for welding products manufactured from AISI 4130, condition IV or lower (HEMPS 2.522, 2.600, 2.707, 2.709) shall be qualified on base metals that meet HEMPS 2.707-04 (95 ksi tensile/ 80 ksi yield).

6.8 WPSs to be used for welding products manufactured from HEMPS 2.580 or HEMPS 2.581 condition IX materials (ASTM A 182 Grade F22 or ASTM A 182 Grade F22 modified) shall be qualified on base metals that meet HEMPS 2.580-09 (110 ksi tensile/ 95 ksi yield).

6.9 WPSs to be used for welding products manufactured from HEMPS 2.580 materials, condition X or lower (ASTM A 182 Grade F22) and HEMPS 2.581 (ASTM A 182 Grade F22 modified) shall be qualified on base metals that meet HEMPS 2.580-10 (100 ksi tensile/ 85 ksi yield).

6.10 The P-Number metals listed in ***ASME IX QW-422*** and ***WS 11.100*** shall be used to qualify procedures for welding the P-Number material combinations specified in ***WS 11.100***. Procedures qualified with P-Number materials are thus qualified to weld all P-Number and S-Number metals of the same grouping. However, the S-Number materials listed in QW-422, for example, ASTM A 513 Grade 10XX, ASTM A 519 Grade 10XX, API 5L XX, shall not be used to qualify procedures (See ASME IX, QW-420.2).

6.11 Metals that do not appear in ***ASME IX*** QW-422 as either an S-Number or a P-Number metal are considered “unassigned metals” and shall be qualified separately, except as otherwise permitted in QW-420.1 for base metals having the same UNS numbers. Unassigned metals shall be identified in the WPS and on the PQR by specification, type, and grade or by chemical analysis and mechanical properties.

6.12 When the WS calls for welding materials of different mechanical properties (heat treatment condition, strength levels, etc.), the material with the lesser properties shall meet or exceed the mechanical properties specified in the WS.

7. FILLER METAL REQUIREMENTS

7.1 Welding rods, electrodes, fluxes, filler metals, and carbon and low-alloy steel welding consumables containing more than 1% nickel shall not be used for welding products required to meet ***NACE MR0175*** (as indicated by a WS specified maximum joint hardness of 22 HRC). Welding consumables containing more than 1% nickel may be used otherwise.

7.2 AWS/ASME classified filler metals that are qualified with the WPS for a given number of postweld heat-treat cycles shall be listed in the WPS by either the trade name or the classification number. Unclassified filler metals, which are so qualified, shall also be listed on the WPS and PQR by trade name or nominal chemical composition of the weld deposit. The nominal chemical composition of such deposits shall be taken from either the PQR test weld or the manufacturer's certificate of compliance. The certificate of compliance for SAW filler metals shall show that the deposit was made with the same flux as that used on the original PQR test weld.

7.3 The ASME/AWS ***SAW flux classification system shall not be used*** to document the SAW flux-wire combinations used on WPSs that are qualified for welding any of the ***hardenable materials*** referenced in this specification (8630M, 4130, F22). These WPSs shall identify both the flux and the wire separately by brand name and the manufacturer's designation (e.g. Thyssen UV420 TTRC flux & Oerlikon OE-S3NiMo-1 wire). If the wire is classified and the flux is not, then the flux must be identified on the WPS by the manufacturer's designation. On the other hand, either the electrode classification number or the manufacturer's designation (e.g. LINCOLNWELD LA-71 wire and all other electrodes conforming to the requirements for ASME/AWS A5.17 Class EM14K wires) may identify solid wire electrodes.

7.4 The ASME/AWS SAW flux classification system is inappropriate for use in welding ***hardenable materials*** in accordance with this specification because the purpose of the testing for classification is different than it is for procedure qualification. For example, SAW fluxes are classified by ASME/AWS according to the weld metal mechanical properties they produce with some certain classification of electrode, under the specific test conditions called for in the ASME/AWS specification. ***The conditions are standardized for purposes of comparing flux-wire combinations and are not representative of the welding and postweld heat treating conditions required by this specification,*** particularly time at temperature. For example, an ASME/AWS SAW flux classification like F9P10-EF3-F3 refers to a flux-wire combination that will produce a minimum all-weld-metal-tensile strength of 90-110 ksi. and Charpy impact properties of 20 ft-lb. @ -100°F after only a ***1-hour postweld heat treatment at 1150°F***. However, the ***mechanical properties*** of weld metal subjected to this heat treatment ***cannot be compared with those obtained from*** single or multiple postweld heat treatments of ***4 hours at 1225°F (8630M), 4 hours at 1210°F(4130), or 4 hours at 1180°F (F22)***. See Section 9 of this specification.

7.5 ASME/AWS SAW flux classifications like F9P6-EG-G are not acceptable for use on WPSs qualified in accordance with this specification because the "EG" indicates an unspecified chemical composition. Hence, the classification gives no assurance a) that the deposit will meet the 1% maximum nickel requirement of ***NACE MR0175***, or b) that the F9P6-EG-G deposit will develop the required mechanical properties after more than 1-hour postweld heat treatment. Unless prohibited elsewhere in this specification, SAW flux classifications may be used on P-Number 1 Group 1 and 2 materials, provided they conform to the ASME/AWS classification system. (See SFA-5.17 or SFA-5.23 of ***Section II, Part C Materials—ASME Boiler & Pressure Vessel Code Specification for Welding Rods, Electrodes, and Filler Metals.)***

7.6 The deposited weld metal mechanical properties (after post-weld heat treatment, if applicable) shall meet or exceed the minimum specified mechanical properties of the WS, including yield strength. Therefore, except for WPSs qualified with the ***prequalified filler metals listed in Appendix B***, the weld metal mechanical properties shall be demonstrated with all-weld metal tensile specimens removed from the procedure qualification test weld. WPSs qualified with filler metals and consumables other than those listed in Appendix B shall be requalified. Requalification may be performed using the prequalified filler metals without all-weld metal tensile testing or by performing the all-weld metal tensile tests on other filler metal deposits as part of the procedure qualification-testing regime. ***Note that yield strength values obtained from transverse (cross-weld) tensile tests are invalid and will not be accepted.*** The lack of uniform strain over the gage length of such tests prohibits reliable measures of yield strength. ***See Appendix D, Section 1, for a complete explanation.***

8. MECHANICAL TESTING FOR PROCEDURE QUALIFICATION

8.1 The mechanical tests required for qualifying WPSs with and without postweld heat treatment are outlined in Appendix A. Test welds requiring postweld heat treatment shall be postweld heat treated in accordance with Section 9 of this specification before testing.

8.2 When WPSs are to be qualified for a WS specified maximum joint hardness of 22 HRC (as required by ***NACE MR0175*** for low-alloy and martensitic stainless steels), a hardness traverse across the base metal, heat affected zone and weld metal shall be performed in accordance with Figure A1.

8.3 When all-weld metal tensile tests are required, the specimens shall be removed from the top longitudinal center of the PQR test weld grooves of each filler metal and process weld deposit to be qualified (Figure A4). At least one standard 0.500” (12.7 mm) diameter round tension test specimens shall be used. The testing shall be performed in accordance with the requirements of ASTM A 370, and yield strength shall be measured with a 0.2% offset. Alternatively, two small-size specimens with dimensions proportional to the standard may be used.

9. PRODUCTION / REPAIR / PQR POSTWELD HEAT TREATMENTS

9.1 When a weldment requires postweld heat treatment, it shall be performed in accordance with WPSs that are qualified to meet the WS specified requirements after all required production or repair PWHT cycles.

9.2 WPSs to be used for welding ***hardenable materials*** (8630M, 4130, F22) ***that have not been previously postweld heat treated*** shall be qualified with the following PWHT cycle:

9.2.1 ***First Cycle:*** Weldment A (Figure A2) shall be postweld heat treated one time. The time at temperature shall be 4 hours, and the temperature shall be ***15 F° below*** the PWHT temperature given for the specific materials to be welded. Heating and cooling rates above 800°F shall be 100 to 150F° (56 to 83C°) per hour.

9.3 WPSs to be used to repair or correct defects or machining errors in ***previously postweld heat-treated weldments of hardenable materials*** shall be qualified for the first postweld heat treat cycle plus one or more of the following cycles, as required by Sections 4.13 and 5.6 of this specification:

9.3.1 ***Second and succeeding Cycles:*** Weldment B shall be postweld heat treated a minimum of two times at temperature (2 x 4 hours each) ***if the part to be welded has been postweld heated one time previously.*** However, if the part to be welded has been previously postweld heat treated more than once, Weldment B shall be postweld heat treated such that the ***minimum aggregate time at temperature equals or exceeds 4 hours plus 4 hours multiplied by the number of cycles previously postweld heat treated.*** The temperature shall be ***15 F° above*** the PWHT temperature given for the specific materials to be welded. Heating and cooling rates above 800°F shall be 50 to 80F° (28 to 44C°) per hour.

9.4 WPSs that are qualified with the above-specified PWHT cycles or meet the requirements of Section 9.6 need not be validated with a furnace survey. However, ***WPSs that are qualified with PWHT cycles different than*** the PWHT cycles specified above ***or do not meet the requirements of Section 9.6***, ***shall be validated with a furnace survey*** in accordance with Section 9.5.

9.5 When a furnace survey is required to validate the production/repair PWHT cycle (in accordance with Section 9.4), it shall be performed as follows. The ***survey shall be made on a weldment that represents the largest weldment on which the WPSs will be used.*** Therefore, if the WPSs were to be qualified for welding Hydril's largest annular BOP, the survey would be made on a GX18 ¾-10M ABOP body, which weighs approximately 30,000 pounds. Similarly, if the WPSs were to be qualified for welding Hydril's largest ram BOP, the survey would be made on an 18 ¾-15M RBOP body which weighs approximately 20,000 pounds. In addition, the survey shall be conducted with ***thermal couples attached directly to each weld joint, buildup, and critical PWHT section in the weldment***. A thermal couple attachment-unit (TAU) of the capacitor-discharge type and redundant thermocouples should be used to ensure that accurate readings are obtained in these critical areas. (TAU attachments shall not be made to finished-machined surfaces or in areas that are outside the heated zone of subsequent postweld heat treatments.)

9.6 The PQR postweld heat treatment cycle shall be considered sufficiently representative of the production postweld heat treat cycle if a comparison of the PQR PWHT chart with the production PWHT chart shows that:

9.6.1 ***all welds and critical PWHT sections*** reached the soak temperature specified in the WPS (±15F°) at the same time (±15 minutes) and were held within the allowable temperature range for the time range specified in the WPS (as shown by the thermal cycle of the weld in Figure D4.), or

9.6.2 the ***last weld*** to reach temperature was held within the allowable temperature range for the ***minimum time specified*** in the WPS, the ***first weld*** to reach temperature was held within the allowable temperature range no longer than the ***maximum time specified*** in the WPS, and ***none of the critical PWHT sections*** exceeded the allowable temperature range at any time. (Welds 1, 3, and 4 of Figure D3 meet these criteria for a WPS qualified to the 8-hour cycle but not the 4-hour cycle.)

9.7 Postweld heat treating equipment shall be properly calibrated and meet the requirements specified by the equipment manufacturer, the applicable code, or the user, which ever is more stringent.

9.8 Postweld heat treatment may be performed locally or in a furnace. When it is performed locally on a circumferential girth or buildup weld, the minimum width of the heated zone centered on the weld shall equal or exceed the widest portion of the weld plus two times the thickness of the joint. When spot repairs of finished-machined parts are postweld heat treated locally, special fixturing and pre- and post-heat treating procedures should be used to minimize the distortion that can occur, particularly on finished-machined cylindrical parts having a low ratio of wall thickness to diameter. Distortion occurs on such parts when unbalanced thermal strains and weld shrinkage forces cause elastic and plastic strains about the neutral axis of the weldment cross section. These effects can be minimized when background heating is applied to the entire circumference of the part during the postweld heat treat cycle. The background heating should be slow and controlled at temperatures between 800°F and 1000°F. Seventy to one-hundred Fahrenheit degrees per hour is recommended, whereas the background heat should not exceed 1000°F. Note that all local pre- and postweld heat treatments must be in accordance with one or more WPSs qualified to make the repairs.

9.9 The WPSs used to make welds thicker than 1.5 inches on ASME P-No.1 Group 1 and 2 materials shall be qualified with a postweld heat treat cycle of 7 hours at 1100°F (Heating and cooling rates above 800°F shall be 80-150F° per hour). The WPS would thus be qualified with multiple postweld heat treatments ranging from a minimum of 0.25 hours to a maximum of 8.75 hours, depending on weld thickness (See Table A1). Hydril material specifications that fall into this category include HEMPS 2.511, 2.524, 2.545, 2.547, 2.561, and 2.562.

9.10 The following postweld heat-treat time-at-temperature cycles shall be used in accordance with Sections 9.2 and 9.3 above (and Tables A2 through A4) to qualify WPSs for welding the ***hardenable materials*** referenced in this specification. The use of ***other hardenable materials*** not referenced in this specification is not permitted without engineering approval. (See Section 6 of this specification.)

9.10.1 The WPSs used to join or repair materials meeting HEMPS 2.535, 2.501, and 2.555 (AISI 8630 modified) shall be qualified with a minimum time of 4 hours at 1225°F.

9.10.2 The WPSs used to join or repair materials meeting HEMPS 2.580 (ASTM A 182 Grade F22) and HEMPS 2.581 (ASTM A 182 Grade F22 modified) shall be qualified with a minimum time of 4 hours at 1180°F.

9.10.3 The WPSs used to join materials meeting HEMPS 2.522, 2.600, 2.707, and 2.709 (AISI 4130) shall be qualified with a minimum time of 4 hours at 1210°F.

9.11 When the thickest weld in the production/repair weldment is less than or equal to 5 inches, the PQR test weld shall be postweld heat-treated 4 hours. The ***WPS*** would thus be ***qualified from 4 to 5 hours at temperature***.

9.12 When the ***thickest weld*** in the production/repair weldment is ***less than*** or equal to ***5 inches***, and ***two postweld heat treatments*** are required, the PQR test weld shall be postweld heat-treated ***twice for 4 hours each*** at temperature. The WPS would thus be qualified for ***two 4-hour cycles*** at temperature or ***one 8-hour cycle*** at temperature. The maximum time qualified for each 4-hour cycle would be 5 hours, and the ***maximum*** time qualified for the one 8-hour cycle would be 10 hours.

9.13 When the thickest weld in the production/repair weldment is less than or equal to 5 inches, and ***three postweld heat treatments*** are required, the PQR test weld shall be postweld heat-treated three times for 4 hours each at temperature. The WPS would thus be qualified for three 4-hour cycles at temperature or one 12-hour cycle at temperature. The maximum time qualified for the each 4-hour cycle would be 5 hours, and the maximum time qualified for the one 12-hour cycle would be 15 hours.

9.14 When the ***thickest weld*** in the production/repair weldment is ***greater than 5 inches*** but less than or equal to 8 inches, the PQR test weld shall be postweld heat-treated 8 hours. The ***WPS*** would thus be ***qualified from 8 hours to 10 hours at temperature***.

9.15 When the thickest weld in the production/repair weldment is greater than 5 inches but less than or equal to 8 inches, and ***two postweld heat treatments*** are required, the PQR test weld shall be postweld heat-treated twice for 8 hours each at temperature. The WPS would thus be qualified for two 8-hour cycles at temperature or one 16-hour cycle at temperature. The maximum time qualified for each 8-hour cycle would be 10 hours, and the maximum time qualified for the one 16-hour cycle would be 20 hours.

9.16 When the thickest weld in the production/repair weldment is greater than 5 inches but less than or equal to 8 inches, and ***three postweld heat treatments*** are required, the PQR test weld shall be postweld heat-treated three times for 8 hours each at temperature. The WPS would thus be qualified for three 8-hour cycles at temperature or one 24-hour cycle at temperature. The maximum time qualified for each 8-hour cycle would be 10 hours, and the maximum time qualified for the one 24-hour cycle would be 30 hours.

9.17 When the ***thickest weld*** in the production/repair weldment is ***greater than 8 inches***, the PQR test weld shall be qualified on base metal of the same thickness to be welded, and the test weld shall be postweld heat-treated 1 hour for each inch of weld thickness. The WPS would thus be qualified for that time plus 25% at temperature. The maximum base metal and deposit thicknesses qualified would be 1.33 times the PQR thickness.

10. EQUIPMENT REQUIREMENTS:

10.1 All welding equipment (power sources, ram manipulators, rotating tables, power rolls, and other manual, semi-automatic, mechanized, and machine welding equipment) shall be capable of reproducing settings of all specified variables.

10.2 All instruments used to verify welding machine and equipment settings and postweld heat treatment furnace settings (ammeters, voltmeters, temperature measuring devices, flowmeters, rotational and linear travel speed measuring devices, etc.) shall be calibrated in accordance with the manufacturer’s recommendations or applicable codes, whichever is more stringent.

11. QUALITY ASSURANCE REQUIREMENTS

11.1 The equipment, materials, and services used in the manufacture of weldments conforming to this specification shall be consistent with the welding and inspection requirements of the quality plan, purchase order specification, or other procurement documents.

APPENDIX A—MINIMUM TESTING REQUIREMENTS

12. TEST WELD COUPON DETAILS

12.1 A minimum of ***one PQR test weld*** (Weldment A in Figure A2) shall be made to qualify a WPS ***for*** welding ***hardenable materials*** that have ***not*** been ***previously postweld heat-treated***.

12.2 A minimum of ***two PQR test welds*** (Weldments A & B in Figure A2) shall be made to qualify a WPS ***for*** welding ***hardenable materials*** that have been ***previously postweld heat-treated.*** Note that Weldment B shall be postweld heat treated a minimum of two times at temperature (2 x 4 hours each) ***if the part to be welded has been postweld heated only one time previously.*** However, if the part to be welded has been postweld heat treated more than once previously, Weldment B shall be postweld heat treated such that the ***minimum aggregate time at temperature equals or exceeds 4 hours plus 4 hours multiplied by the number of cycles previously postweld heat treated.*** (See Section 13.2 below.)

12.3 The test weld shall conform to one of the following:

12.3.1 Option 1: one single-V-groove weld

12.3.2 Option 2: one double-V-groove weld

12.4 The single- or double-V-groove options (Figures A2 & A4) may be used, respectively, to qualify one or more welding processes. Each welding process must deposit a ¾ inch (19-mm) thick deposit in order to qualify for the maximum thickness permitted by ASME IX and the PWHT time and temperature qualified. Deposit thicknesses less than ¾ inches are limited to 2 times the PQR deposit thickness.

12.5 Tack welds (or other means) shall be used to secure the PQR test weldment such that the joint is fully constrained during welding.

13. PWHT & MECHANICAL TESTING OF PQR TEST WELDS

13.1 The mechanical testing required for test weldments that do not require postweld heat treatment is the same as that required for weldments requiring postweld heat treatment. See Figures A1 through A4 and the following Sections.

13.2 The PWHT cycle for test weldments of hardenable materials (8630M, 4130, F22) shall be qualified using PQR test Weldments A and B as follows (Figure A2).

APPENDIX A—MINIMUM TESTING REQUIREMENTS (continued)

13.2.1 ***First PWHT Cycle:*** Weldment A shall be postweld heat treated one time. The time at temperature shall be 4 hours, and the temperature shall be ***15 F° below*** the PWHT temperature given for the specific materials to be welded. Heating and cooling rates above 800°F shall be 100 to 150F° (56 to 83C°) per hour. (See Sections 9.2 and 9.3.)

13.2.2 ***Second and Succeeding PWHT Cycles:*** Weldment B shall be postweld heat treated a minimum of two times at temperature (2 x 4 hours each) ***if the part to be welded has been postweld heated one time previously.*** However, if the part to be welded has been postweld heat treated more than once, Weldment B shall be postweld heat treated such that the ***minimum aggregate time at temperature equals or exceeds 4 hours plus 4 hours multiplied by the number of cycles previously postweld heat treated.*** The temperature shall be ***15 F° above*** the PWHT temperature given for the specific materials to be welded. Heating and cooling rates above 800°F shall be 50 to 80F° (28 to 44C°) per hour. (See Section 9.3 of this specification.)

13.3 Macroetch Hardness Survey

13.3.1 A macroetch hardness specimen shall be removed from the location shown in Figure A2 and prepared for hardness testing.

13.3.2 The faces of the macroetch specimen shall be ground flat and parallel to a 63-microinch finish (or better). If needed, a minimum of 1/32” shall be ground from the surfaces tested to ensure removal of PWHT scale and decarburized material.

13.3.3 The macroetch shall be etched with a suitable etchant to reveal the weld deposit, HAZ, and base metal unaffected by the heat of welding.

13.4 The hardness survey shall be performed IAW Figure A1 as follows:

13.4.1 Readings ≥ 20 HRC shall be made & reported in the “C” scale per ASTM E 140.

13.4.2 Readings ≤ 100 HRB shall be made & reported in the “B” scale per ASTM E 140.

13.4.3 Any reading greater than 22 HRC shall be re-tested as follows: Make one reading on each side of the high reading (R_0) at the same distance from the fusion line and from each other in accordance with ASTM E 18. The results shall be acceptable if the average of the two is less than or equal to 22 HRC and neither reading is greater than 24 HRC (e.g. $R_1 = 24$, $R_2 = 20$, average = $(R_1 + R_2)/2 = 22$).

13.4.4 The Vickers method of hardness testing shall not be used.

13.5 Tensile testing—Weld Joint

APPENDIX A—MINIMUM TESTING REQUIREMENTS (continued)

13.5.1 Two transverse RSTs shall be performed IAW ASME IX QW-151.1.

13.5.2 The specimens shall meet the minimum specified tensile strength permitted by ASME IX QW-153 for the applicable P-Number base metal or the Joint Welding Specification (WS) for unassigned metals (8630M, 4130, F22). Note that yield strength measurements taken from transverse tensile specimens should not be taken for reasons given in Section 7.6 and Appendix D, Section 1.

13.6 Tensile testing—Base Metal

13.6.1 One 0.500 inch (12.8 mm) ϕ BMT (base metal tensile specimen) shall be removed from the ¼ T location (Figure A2) and tested IAW ASTM A 370.

13.6.2 The specimens shall meet or exceed the minimum specified tensile properties of the WS or the applicable base metal specification (tensile, yield, percent elongation in 2”, percent reduction of area). See Section 6 of this specification.

13.7 Guided-bend Testing

13.7.1 Four transverse side-bend test specimens shall be removed from the locations shown in Figure A2.

13.7.2 The specimens shall be prepared and tested IAW applicable sections of QW-160.

13.8 Charpy Impact Testing

13.8.1 Charpy impact tests shall be performed as follows in accordance with ASTM A 370 and ASTM E 23 using the test temperature specified in the WS. The specimens shall be removed at the ¼ T and ¼ t locations shown in Figures A2 and A3:

13.8.2 One set (3 specimens per set) from each weld deposit.

13.8.3 One set from the HAZ of each different base metal.

13.8.4 One set from the base metal of each different base metal unaffected by the heat of welding.

13.8.5 The tested specimens shall meet or exceed the minimum energy value specified in the WS. Shear and lateral expansion shall be reported for informational purposes.

APPENDIX A—MINIMUM TESTING REQUIREMENTS (continued)

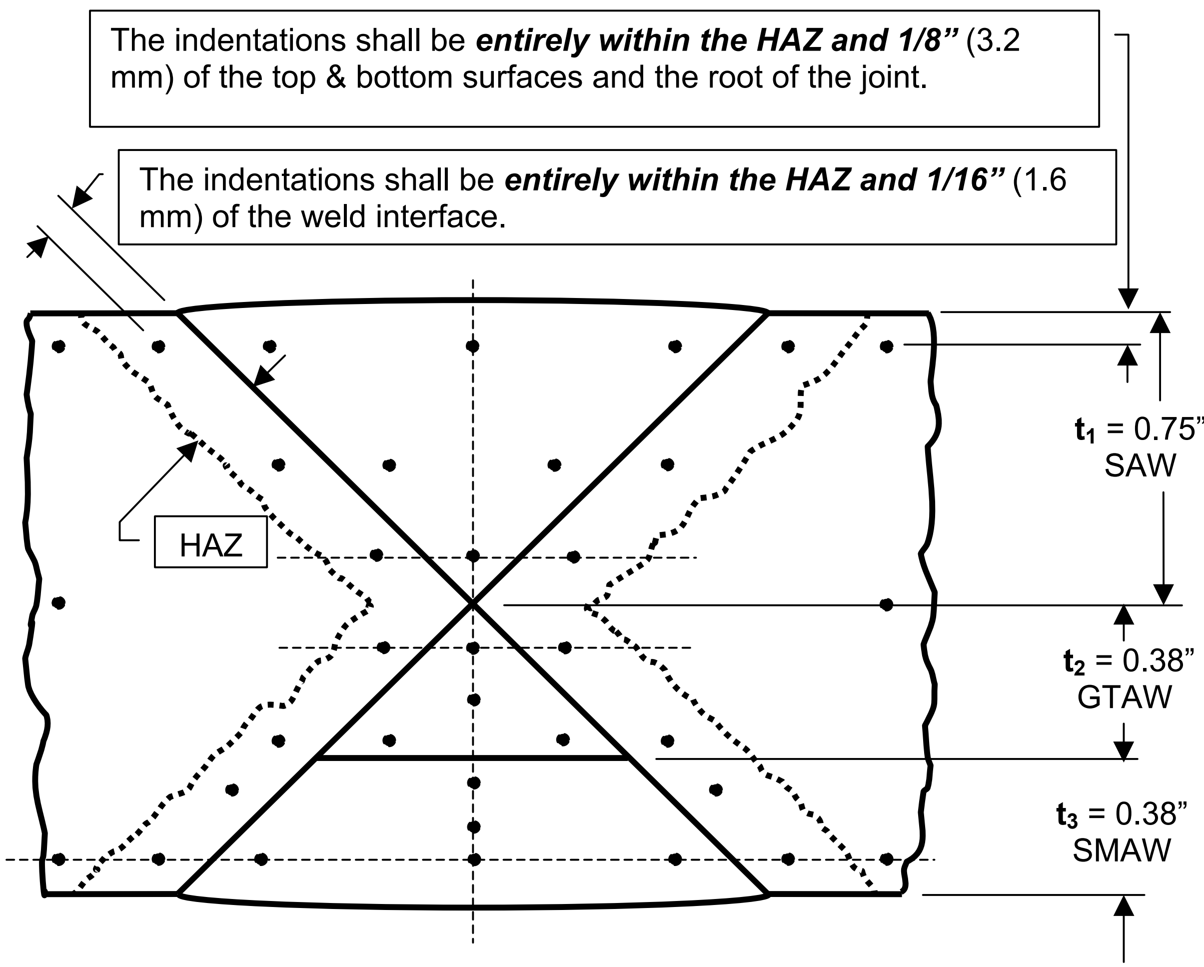

Figure A1—Typical for Multiple Process Hardness Testing

Note 1: The number of indentations shall be as shown for each weld deposit.

APPENDIX A—MINIMUM TESTING REQUIREMENTS (continued)

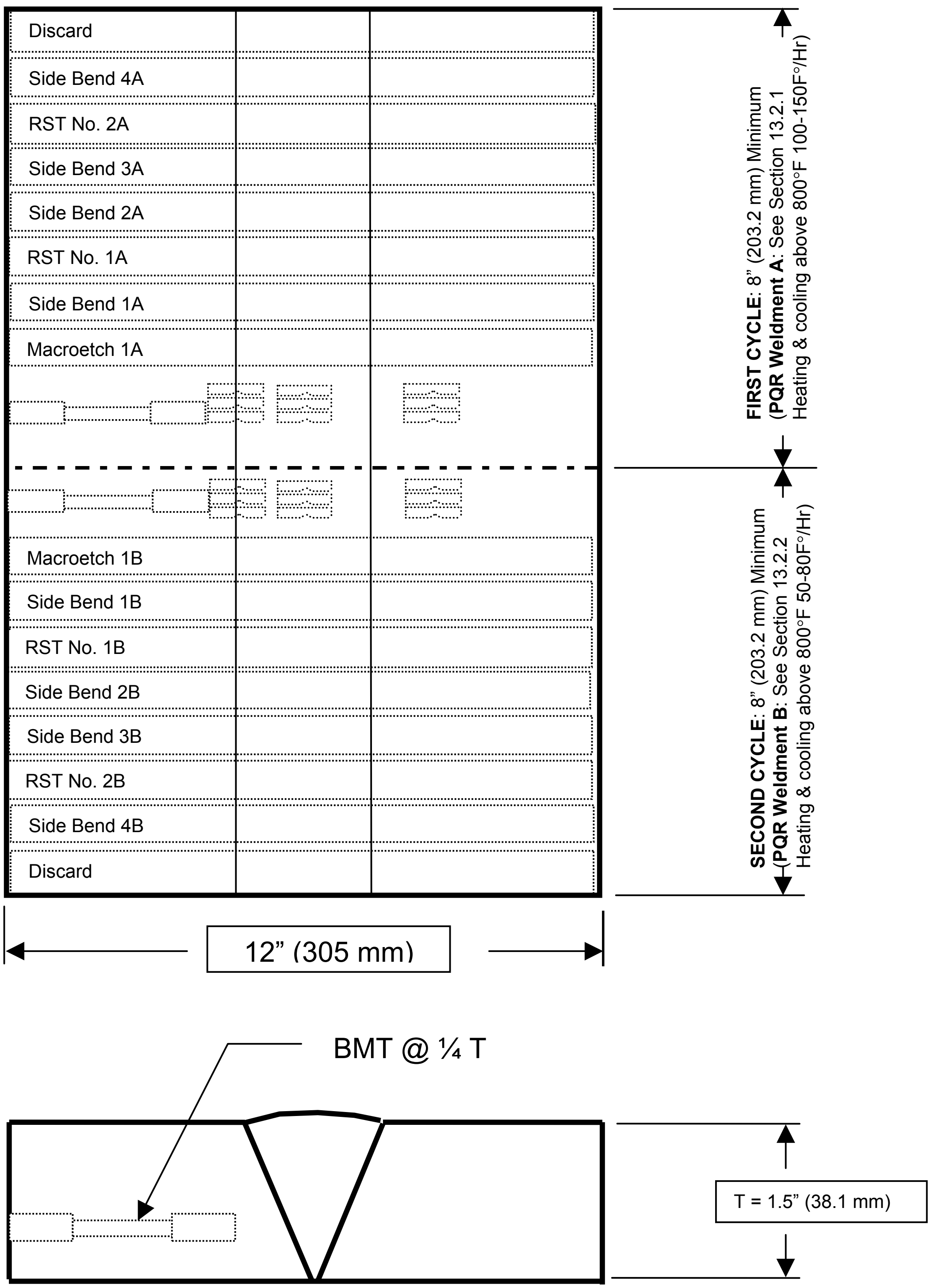

Figure A2—Typical for Single-V-Groove Welds

APPENDIX A—MINIMUM TESTING REQUIREMENTS (continued)

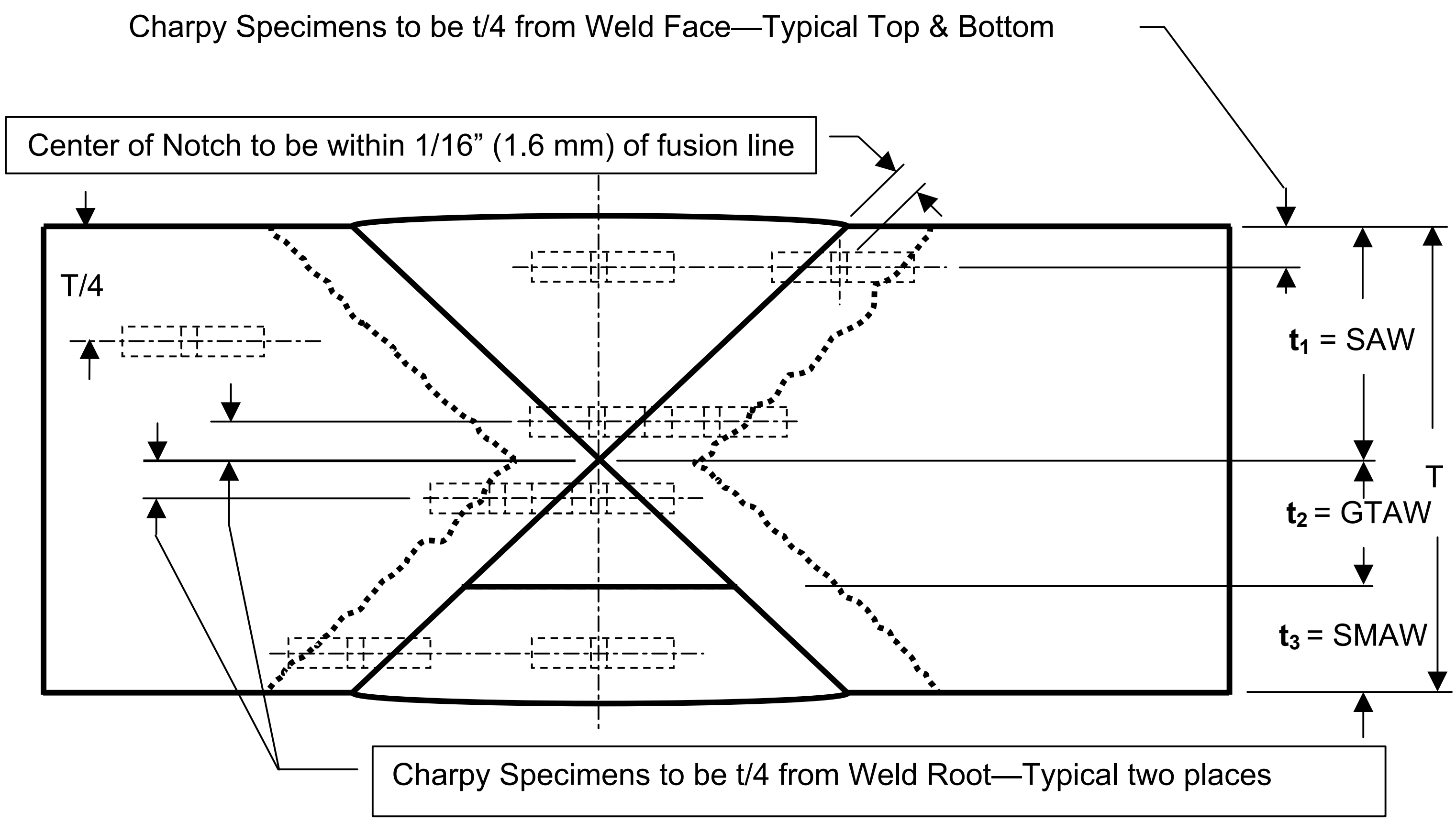

Figure A3—Typical for Multiple Process Impact Testing

APPENDIX A—MINIMUM TESTING REQUIREMENTS (continued)

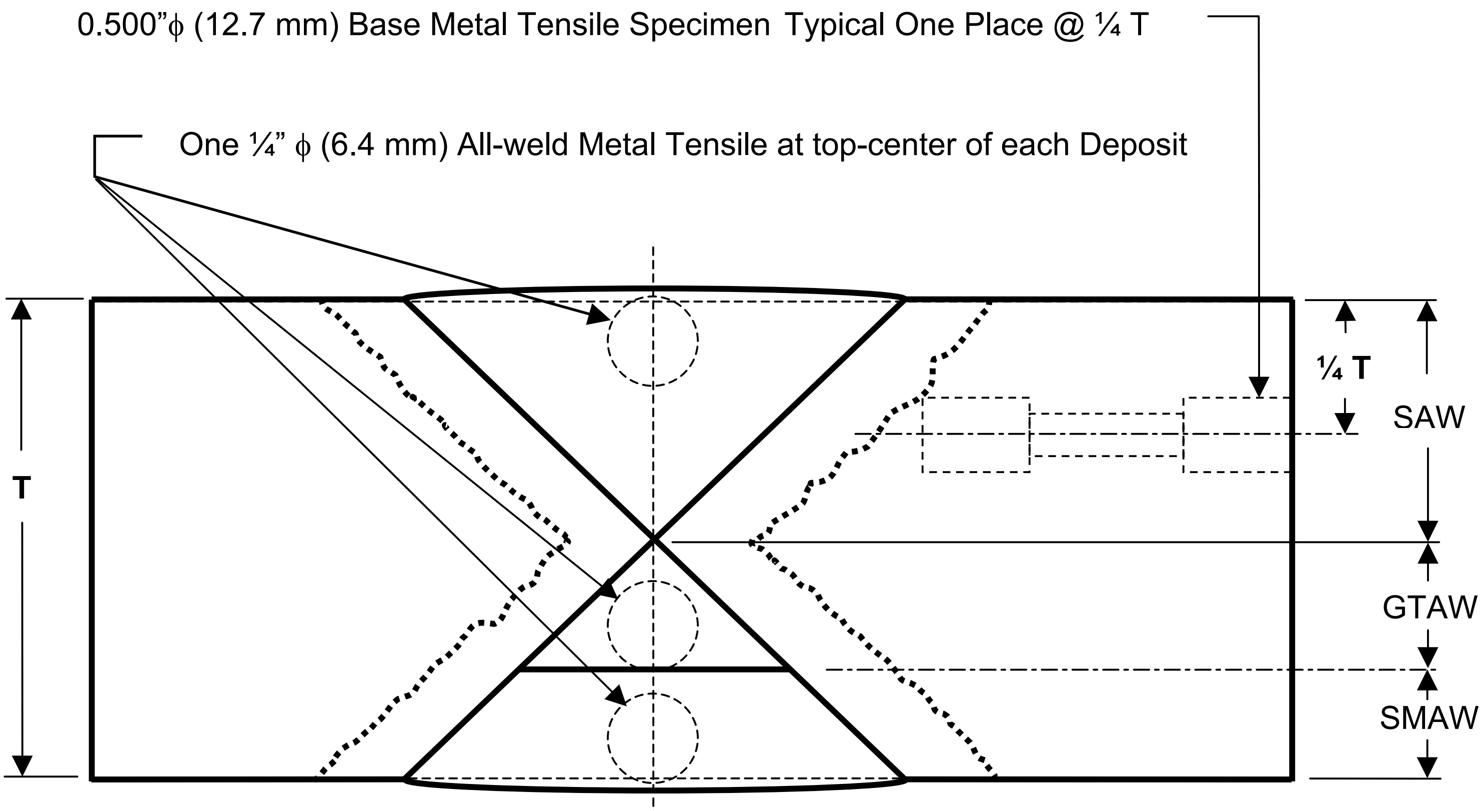

Figure A4—Typical for Multiple Process All-Weld Metal Tensile Tests (When Required by Section 7.6)

APPENDIX A—MINIMUM TESTING REQUIREMENTS (continued)

TABLE A1

DETERMINATION OF PWHT TIMES FOR PRODUCTION/REPAIR WELDMENTS OF P-NO. 1 GROUP 1 & 2 STEELS (SEE SECTION 9.11 FOR PQR PWHT REQUIREMENTS)

The minimum PWHT time shall be determined as shown below by the greatest weld thickness in the weldment that has not been previously postweld heat-treated. For example, the minimum PWHT time for a weldment that has a 5” thick groove weld would be 2 hours plus 3 x 15 minutes or 2.75 hours. Similarly, the minimum time for an 8” thick groove weld would be 2 hours plus 6 x 15 minutes or 3.5 hours. Note, however, that if the weldment contains welds of varying thicknesses, such as ¾”, 5”, and 8”, the minimum PWHT time for all three would also have to consider the method of heat treatment. For instance, if the weldment in this example was postweld heat treated in a furnace, then each of the three welds would have to be subjected to the same PWHT time (3.5 hours, in this example). On the other hand, if each weld could be postweld heat-treated locally, such that the heat cycle of each one could be controlled individually without significantly affecting the other, then each weld could be postweld heat treated according to the minimum PWHT time appropriate for each one. In this case, the respective minimum PWHT times would be 0.75 hours for the ¾” thick weld, 2.75 hours for the 5” thick weld, and 3.5 hours for the 8” thick weld. Note that PWHT holding time need not be continuous. It may also be an intermittent accumulation of multiple PWHT cycles. As such, the maximum number of times that a production weldment can be postweld heat treated is determined by dividing the required PWHT time into the maximum PWHT time qualified. For example, if a 2” thick weld was made with a WPS that was qualified with a PQR PWHT of 7 hours, the WPS would be qualified for a maximum PWHT time of 8.75 hours or PQR PWHT time plus 25% (in accordance with essential variable QW-407.2 of ASME IX). Thus, the 2” thick weld could be postweld heat-treated 4 times (8.75 hours ÷ 2 hours = 4.38). Compare this with an 8” thick weld, which could only be postweld heat-treated 2 times (8.75 hours ÷ 3.5 hours = 2.5). In this example, note also that there are 1.75 hours remaining after 2 PWHT cycles, which may be used for a repair (8.75 hours minus 7 hours = 1.75 hours). Hence a repair weld up to 1.75” deep in the original 8” thick groove weld could be postweld heat treated within the limits qualified with a 7 hour PQR postweld heat treatment (8.75 hours).

POSTWELD HEAT TREATMENT REQUIREMENTS FOR P-NO. 1 GROUP 1 & 2 STEELS (HOURS @ 1100°F)

Greatest Weld Thickness	Minimum Required PWHT Time
Up to 2”	1 hour per inch, 15 minutes minimum
Over 2” to 5”	2 hours plus 15 minutes for each additional inch over 2”
Over 5”	2 hours plus 15 minutes for each additional inch over 2”

TABLE A2— PQR PWHT REQUIREMENTS FOR WELDING HEMPS 2.535, 2.501, 2.555 (8630M) MATERIALS		
NO. OF CYCLES REQUIRED FOR PART TO BE PRODUCED OR REPAIRED MULTIPLIED BY THE MINIMUM NO. HRS REQUIRED FOR WELD THICKNESS (t) ON 8630M MATERIALS[1]		
t ≤ 5”	**5” < t ≤ 8”**	**t > 8”**
One 4-hour cycle @ 1210°F[2]	One 8-hour cycle @ 1210°F [2]	One cycle x 1 hour per inch @ 1210°F[2]
Two 4-hour cycles @ 1240°F[3]	Two 8-hour cycles @ 1240°F [3]	Two cycles x 1 hour per inch @ 1240°F[3]
Three 4-hour cycles @ 1240°F	Three 8-hour cycles @ 1240°F	Three cycles x 1 hour per inch @ 1240°F
Four 4-hour cycles @ 1240°F	Four 8-hour cycles @ 1240°F	Four cycles x 1 hour per inch @ 1240°F
Five 4-hour cycles @ 1240°F	Five 8-hour cycles @ 1240°F	Five cycles x 1 hour per inch @ 1240°F

TABLE A3—PQR PWHT REQUIREMENTS FOR WELDING HEMPS 2.580 & 2.581 (F22M) MATERIALS		
NO. OF CYCLES REQUIRED FOR THE PART TO BE PRODUCED OR REPAIRED MULTIPLIED BY THE MINIMUM NO. HRS REQUIRED FOR WELD THICKNESS (t) ON F22 MATERIALS[1]		
t ≤ 5”	**5” < t ≤ 8”**	**t > 8”**
One 4-hour cycle @ 1165°F[2]	One 8-hour cycle @ 1165°F[2]	One cycle x 1 hour per inch @ 1165°F[2]
Two 4-hour cycles @ 1195°F[3]	Two 8-hour cycles @ 1195°F[3]	Two cycles x 1 hour per inch @ 1195°F[3]
Three 4-hour cycles @ 1195°F	Three 8-hour cycles @ 1195°F	Three cycles x 1 hour per inch @ 1195°F
Four 4-hour cycles @ 1195°F	Four 8-hour cycles @ 1195°F	Four cycles x 1 hour per inch @ 1195°F
Five 4-hour cycles @ 1195°F	Five 8-hour cycles @ 1195°F	Five cycles x 1 hour per inch @ 1195°F

[1] See Section 9 of this specification.
[2] PWHT temperature for the first cycle shall be 15F° below the set point temperature required for the respective material. Heating & cooling rates for the first cycle shall be 100 to 150F° (56 to 83C°) per hour above 800°F or as determined by Section 9.4.
[3] PWHT temperature for the second and succeeding cycles shall be 15F° above the set point temperature required for the respective material. Heating & cooling rates for the second and succeeding cycles above 800°F shall be 50 to 80F° (28 to 44C°) per hour or as determined by Section 9.4.

TABLE A4—PQR PWHT REQUIREMENTS FOR WELDING HEMPS 2.522, 2.600, 2.707 & 2.709 (AISI 4130) MATERIALS		
NO. OF CYCLES REQUIRED FOR THE PART TO BE PRODUCED OR REPAIRED MULTIPLIED BY THE MINIMUM NO. HRS REQUIRED FOR WELD THICKNESS (t) ON 4130 MATERIALS[4]		
t ≤ 5”	**5” < t ≤ 8”**	**t > 8”**
One 4-hour cycle @ 1195°F[5]	One 8-hour cycle @ 1195°F[5]	One cycle x 1 hour per inch @ 1195°F[5]
Two 4-hour cycles @ 1225°F[6]	Two 8-hour cycles @ 1225°F[6]	Two cycles x 1 hour per inch @ 1225°F[6]
Three 4-hour cycles @ 1225°F	Three 8-hour cycles @ 1225°F	Three cycles x 1 hour per inch @ 1225°F
Four 4-hour cycles @ 1225°F	Four 8-hour cycles @ 1225°F	Four cycles x 1 hour per inch @ 1225°F
Five 4-hour cycles @ 1225°F	Five 8-hour cycles @ 1225°F	Five cycles x 1 hour per inch @ 1225°F

[4] See Section 9 of this specification.
[5] PWHT temperature for the first cycle shall be 15F° below the set point temperature required for the respective material. Heating & cooling rates for the first cycle shall be 100 to 150F° (56 to 83C°) per hour above 800°F or as determined by Section 9.4.
[6] PWHT temperature for the second and succeeding cycles shall be 15F° above the set point temperature required for the respective material. Heating & cooling rates for the second and succeeding cycles above 800°F shall be 50 to 80F° (28 to 44C°) per hour or as determined by Section 9.4.

APPENDIX B—PREQUALIFIED WELDING CONSUMABLES

Table B1—Prequalified Filler Metals for F22 (PWHT 4-12 hours @ 1180°F ±15F°)

SAW		SMAW	GTAW	FCAW
FLUX	**WIRE**	**ELECTRODE**	**WIRE**	**WIRE**
Thyssen UV420TTRC	Thyssen S3 NiMo-1	E10018-D2	Oerlikon CarboRod SD3 1Ni ½ Mo	E100T5-D2
Thyssen UV420TTRC	Oerlikon S3 NiMo-1		Oerlikon S3 NiMo-1	Devasco 8022N
Oerlikon OP42TT	Oerlikon S3NiMo-1		Thyssen S3 NiMo-1	
Oerlikon OP121TT	Oerlikon S3NiMo-1			

Table B2—Prequalified Filler Metals for 4130 (PWHT 4-12 hours @ 1210°F ±15F°)

SAW		SMAW	GTAW	FCAW
FLUX	**WIRE**	**ELECTRODE**	**WIRE**	**WIRE**
Thyssen UV420TTRC	Thyssen S3 NiMo-1	E10018-D2	Techalloy Raco AK10	E100T5-D2
Thyssen UV420TTRC	Oerlikon S3 NiMo-1			Devasco 8022N

Table B3—Prequalified Filler Metals for 8630M (PWHT 4-12 hours @ 1225°F ±15F°)

SAW		SMAW	GTAW	FCAW
FLUX	**WIRE**	**ELECTRODE**	**WIRE**	**WIRE**
Thyssen UV420TTRC	Thyssen S3 NiMo-1	E10018-D2	Techalloy Raco AK10	E100T5-D2
Thyssen UV420TTRC	Oerlikon S3 NiMo-1			Devasco 8022N

APPENDIX B—PREQUALIFIED WELDING CONSUMABLES (CONTINUED)

Table B4—Prequalified Filler Metals for P-No. 1 Groups 1 & 2 (without PWHT)

SAW		SMAW	GTAW	FCAW
FLUX	**WIRE**	**ELECTRODE**	**WIRE**	**WIRE**
Lincoln 882	Lincoln L61	E7018-1	ER70S-6	E71T-1-MJ H8
F7A6-EM12K				

Table B5—Prequalified Filler Metals for P-No. 1 Groups 1 & 2 (PWHT 7 Hrs @ 1100°F)

SAW		SMAW	GTAW	FCAW
FLUX	**WIRE**	**ELECTRODE**	**WIRE**	**WIRE**
Lincoln 882	Lincoln LA71	E7018-1	ER70S-6	E71T-1-MJ H8

1. APPENDIX C—REFERENCES

1.1 **Welding Handbook,** Vol. 1, Eight Edition, pp.90-124

1.2 ***Weldability of Steels,*** Welding Research Council, 4th Ed., pp. 47-117

1.3 ***ASM Metals Handbook***, Vol. 6, 10th Edition, pp. 416-428

1.4 ***Welding Handbook***, Vol. 1, Eight Edition, pp.386-389

1.5 ***Weldment Evaluation Methods***, Defense Metals Information Center, Battelle Memorial Institute, DMIC Report 244 August 1968

1.6 ***ASME Boiler & Pressure Vessel Code Section VIII, Division 1–Rules for Construction of Pressure Vessels, Section UHT-81***

APPENDIX D—EXPLANATION OF REQUIREMENTS

1. TENSILE TESTS

Yield strength values obtained from transverse (cross-weld) tensile tests are unacceptable and will not be accepted for procedure qualification. The lack of uniform strain over the gage length of such tests prohibits reliable measures of yield strength. Excerpts follow from selected references, which elaborate on this point: Mechanical tests of welds are similar to the mechanical tests applied to base metal, but allowances must be made to account for the heterogeneity, anisotropy, and residual stress of the weldment. To obtain an accurate assessment of the strength and ductility of weldments, several different specimens may be used. The ***all-weld metal specimen is used to evaluate the deposited weld metal ultimate tensile strength, yield strength and elongation.***

APPENDIX D—EXPLANATION OF REQUIREMENTS (Continued)

The transverse-weld specimen is generally used for evaluating joint efficiency, defined as the ratio of the ultimate tensile strength of the welded specimen to the specified tensile strength of the base metal. Yield strength and elongation are normally not determined during a transverse-weld test because of the different strength and ductilities usually present in the various regions of the weldment. For example, if the weld metal yield and tensile strengths exceed those of the base metal and heat-affected zone, most of the plastic straining and final failure will occur outside the weld metal region. Such a test does not give any indication of the weld ductility. Additionally, it is not possible to obtain a reliable measure of yield strength, because the conventional definition of yield strength depends on uniform deformation within the entire gage length. The transverse tensile test, however, does indicate whether the ultimate tensile strength equals or exceeds the base metal tensile strength or some other specified minimum value, and as such is used quite widely in various codes. Therefore, to evaluate both weldment strength and ductility, the transverse-weld specimen is used in conjunction with the longitudinal-weld specimen (Ref. C1.2).

Interpretation of test results for a welded joint, as a whole, is not possible in the transverse weld specimen. The reduced section of this specimen contains base metal, heat-affected zones, and weld metal. When all of these materials are simultaneously subjected to the same stress, the one with the lowest strength will elongate and break. ***Thus, this test should not be used to make quantitative comparisons of weld metals*** (Ref. C1.4).

Transverse weld tension tests provide limited information on the mechanical properties of fusion welds. Test results must be interpreted with great care because of the variations in properties resulting from inhomogeneous structures along the gage length. These tests are used chiefly to obtain strength data from which joint efficiency may be calculated and to obtain information on fracture characteristics. ***Because the structures found in weldments are heterogeneous, the transverse-weld tension test does not provide a quantitative measure of weld-joint ductility.*** In this test, each zone of the composite specimen is loaded to the same stress (assuming a uniform specimen cross section). The stress-strain behavior in the weld, heat-affected-zones and the base metal is likely to be different, however. When the weld-metal strength significantly exceeds the strength of the base metal ***(overmatching)***, nearly all of the plastic strain and fracture occurs outside the weld in the heat-affected zone or unaffected base metal. ***The ultimate strength, yield strength, reduction of area, and elongation will be equivalent to that of the base metal and give little or no indication of weld-metal properties.*** Small defects in the weld metal may have no effect since the specimens usually fail outside the weld metal. When the weld-metal strength is significantly lower than that of the heat-affected zone or parent metal ***(undermatching)***, plastic strain and failure occur chiefly in the weld metal. ***The test, therefore, may fail to disclose undesirable features in the heat-affected zone or parent metal.*** In addition, for undermatching, elongation occurs almost entirely in the weld metal. ***Therefore, percent elongation based on the entire gage length is erroneous and meaningless*** (Ref. C1.5).

2. WPS THICKNESS LIMITS

ASME IX permits welding of base metal and weld metal thicknesses up to 8 inches (203.2 mm) when the PQR base metal is 1.5 inches (38.1 mm) thick and the weld deposit is 0.75 inches (19

APPENDIX D—EXPLANATION OF REQUIREMENTS (Continued)

mm) or more in thickness. However, the ***maximum weld metal thickness*** of joints in hardenable metals (such as 4130, F22, 8630M), which must meet ***NACE MR0175***, is also limited by the minimum PWHT time at temperature that the test weld will meet the maximum hardness requirements. For example, assume that a WPS is qualified on 1.5 inch (38.1-mm) thick F22 base metal with a 0.75-inch (19 mm) thick deposit. Assume also that the test weld was qualified for impacts with a postweld heat treatment of 4 hours at 1180°F. As such, the WPS would be qualified for welding base metals 5/8 inches (15.9 mm) and over in thickness, but the weld deposit would only be qualified for a maximum thickness of 5 inches. Note also that the WPS would only be qualified for a fixed PWHT time range 4 to 5 hours. Although at first glance these thickness and time limits might seem unreasonable, they are consistent with the rules of ASME IX, API 16A, MR0175, and the technical and metallurgical principles involved. For instance, the PWHT time for carbon and low alloy base metals is commonly determined as a function of the material thickness multiplied by one hour per inch of thickness. This formula was derived on the presumption that the full thickness of the material must be heated, and that it takes one hour per inch to reach PWHT temperature throughout the thickness (when heating occurs from one side). However, unlike non-welded materials, the primary areas of concern in welding hardenable low alloy steels, like 8630M, F22, and 4130, are the strength and hardness in the welds and contiguous base metal heat affected zones (HAZ) after PWHT. Therefore, a WPS that is qualified with a 4-hour PWHT cannot be used to postweld heat treat production welds less than 4 hours or more than 5 hours. The PWHT time cannot be any less than 4 hours because any lesser time might not soften the HAZ sufficiently to meet the hardness requirements of ***NACE MR0175***. Moreover, the PWHT time cannot be more than 5 hours because any greater time would exceed the supplementary essential variable requirements of ***ASME IX*** for impacts, which limits PWHT time to a maximum of the time qualified plus twenty-five percent.

3. EFFECTS OF PWHT TIME ON LOW TEMPERATURE TOUGHNESS

The maximum PWHT time at temperature of a single cycle is determined by the supplementary essential variable (SEV) of ASME IX QW-407.2. This SEV requires that the PQR test weld be subjected to PWHT essentially equivalent to that encountered in the fabrication of production welds, including at least 80% of the aggregate times at temperature (s). The reason for this requirement is to ensure that low temperature toughness is maintained, since this property also varies up or down depending on the PWHT cycle and material type. This requirement is based on empirical findings, which show that improvements in notch toughness of weld metal are inconsistent and complex. For example, filler metals that obtain their strength through hardenability and are softened by the tempering action of PWHT do not lose or may even gain notch toughness when postweld heat-treated. However, filler metals that resist softening during PWHT (because of their carbide-forming elements) exhibit sensitivity to embrittlement from PWHT (Ref. C1.2, p112). The above reasons show, therefore, that WPSs have specific limitations that must be clearly documented on the WPS, particularly those that are qualified for notch toughness with postweld heat treatment.

APPENDIX D—EXPLANATION OF REQUIREMENTS (Continued)

4. CONSEQUENCES OF INADEQUATE PWHT

It is possible to qualify different welding processes with different PWHT cycles. However, when different processes are used to produce a weldment that is to be postweld heat treated in a furnace, they shall be qualified for the same time at temperature and the same number of cycles. The principal reasons for this are as follows: 1) A WPS cannot be used outside its limits of PWHT qualification (PQR time plus 25% maximum, as noted above). 2) The thermal effect that is required to sufficiently soften the base metal HAZs of high heat input processes (like SAW) is less than it is for lower heat input processes (like SMAW, GTAW, and GMAW). 3) The effects of multiple post weld heat-treat cycles on the strength and hardness of weldments produced by each WPS must be quantified.

Since the deposit is usually low in carbon and is the beneficiary of the tempering and grain refining effects of subsequent weld beads, weld metal HAZ hardness is rarely a concern. Nonetheless, the minimum PWHT times and temperatures are critical for some filler metals, as noted above. In addition, it is important to note that the weld and base metal HAZs contain residual stresses and may contain hard and brittle transformation products that have not been tempered by the heat of welding. If residual stress and hardness in these areas are not sufficiently reduced, the weldment will be susceptible to sulfide stress cracking and hydrogen embrittlement and will not meet ***NACE MR0175.*** Note that ***NACE MR0175*** requires all low alloy and martensitic stainless steel weldments to be postweld heat-treated at a temperature of no less than 1150°F. (See the definition of the weld metal heat affected zone in Section 4.)

5. VALID PWHT TEMPERATURE TOLERANCE

PWHT temperature tolerance is critical for the same reasons. For example, the production PWHT temperature should not vary from the setpoint temperature by more than a valid PWHT tolerance. ***The WPS must be capable of producing weldments, which meet requirements at known PWHT temperatures above and below the setpoint temperature.*** If this is not achieved, the mechanical properties in certain areas of the weldment cannot be substantiated, and some areas are not likely to meet requirements. For instance, some welds in the part may be overheated and some may be underheated, depending on the size and shape of the part and the heating characteristics of the furnace. Those areas that are below a valid tolerance at the start of soak temperature may not be sufficiently tempered and hard spots in excess of the requirement will result. Discounting the strength degradation that will result from multiple PWHT cycles, those areas that are above a valid tolerance at the start of soak temperature may be softened too much. The result may be base metal or weld metal that is below design strength requirements at the end of soak temperature. It is for these reasons that a valid PWHT tolerance must be established. Such a tolerance will ensure that the strength and hardness of a weldment will consistently meet requirements at the extremes of the metal temperature variations that inevitably exist in any post weld heat treating operation. ***These principles cannot be overstated because the usable life of a weldment is governed primarily by the number of times it can be stress relieved and still***

APPENDIX D—EXPLANATION OF REQUIREMENTS (Continued)

maintain the mechanical properties that are required for the design and service environment.

6. CONSEQUENCES OF PRODUCTION & PQR PWHT CYCLE VARIATIONS

As alluded to above, the mechanical properties obtained by post weld heat treating a massive production part can vary drastically between the properties obtained by post weld heat treating small PQR test weldments. Variations in any of the three phases of the PWHT cycle (heating, soaking, and cooling) can change the mechanical properties in direct proportion to the temper resistance of the material. Not all materials and weld deposits have equivalent temper resistance or exhibit the same change with changes in PWHT cycle. Most construction codes and standards recognize the effects that PWHT has on material properties by placing material specific limits on the PWHT cycle. For example, in addition to the PQR testing of the welding procedures, heat treatment verification tests are required by ASME VIII for each heat of a quenched and tempered vessel material. The tests are required to verify that the initial heat treatment and all subsequent thermal treatments, like PWHT, have not reduced material properties below requirements (Ref. C1.6). These requirements are consistent with other codes (ASME IX, AWS D1.1, ANSI B31.1, and ANSI B31.3) which make PWHT an essential variable for qualifying welding procedures.

Nonetheless, PWHT variables (heating, soaking, cooling) are not controlled in the same manner by the construction codes that apply to the manufacture and repair of valves and blow out preventers (API 6A and API 16A). For this reason, post weld heat treating practice varies widely, and the differences between the PWHT cycles used to PWHT PQR test welds and massive BOPs is pronounced. Take metal temperature variations, for example. The metal temperature variations that can occur in thin and thick sections and the top and bottom of massive BOPs of production PWHT cycles do not occur during the PWHT cycle of PQR test welds. Huge differences in heating and cooling rates are common. The potential consequences associated with variations in production PWHT include the following: 1) Temperatures too far below the soak temperature can leave hard spots in the welds. 2) Temperatures too far above or too long at the soak temperature can reduce mechanical properties to unacceptable levels. 3) Heating and cooling rates that are too high can cause thermal stress cracks in thin sections, untempered heat affected zones, or unacceptable distortion in machined parts. 4) Heating and cooling rates that are too slow can over temper the material by keeping it longer at or near-soak temperatures.

Thus, as illustrated in Figure D3, the solution is to qualify the welding procedures with multiple PQR PWHT cycles that match the shortest thermal cycle with the fastest heating & cooling rates and the longest thermal cycle with the slowest heating and cooling rates of the actual production PWHT cycle. Otherwise, the procedure qualification process serves no useful purpose. WPSs used to manufacture BOPs to be used in sour service must be qualified with PWHT cycles that accurately predict a BOP’s strength after multiple PWHT cycles. At the same time, the qualification must ensure that the production welds will not have hard spots that make them susceptible to sulfide stress cracking and hydrogen embrittlement. Examples of these types of failures are shown in Figures D1 and D2.

APPENDIX D—EXPLANATION OF REQUIREMENTS (Continued)

Figure D1

APPENDIX D—EXPLANATION OF REQUIREMENTS (Continued)

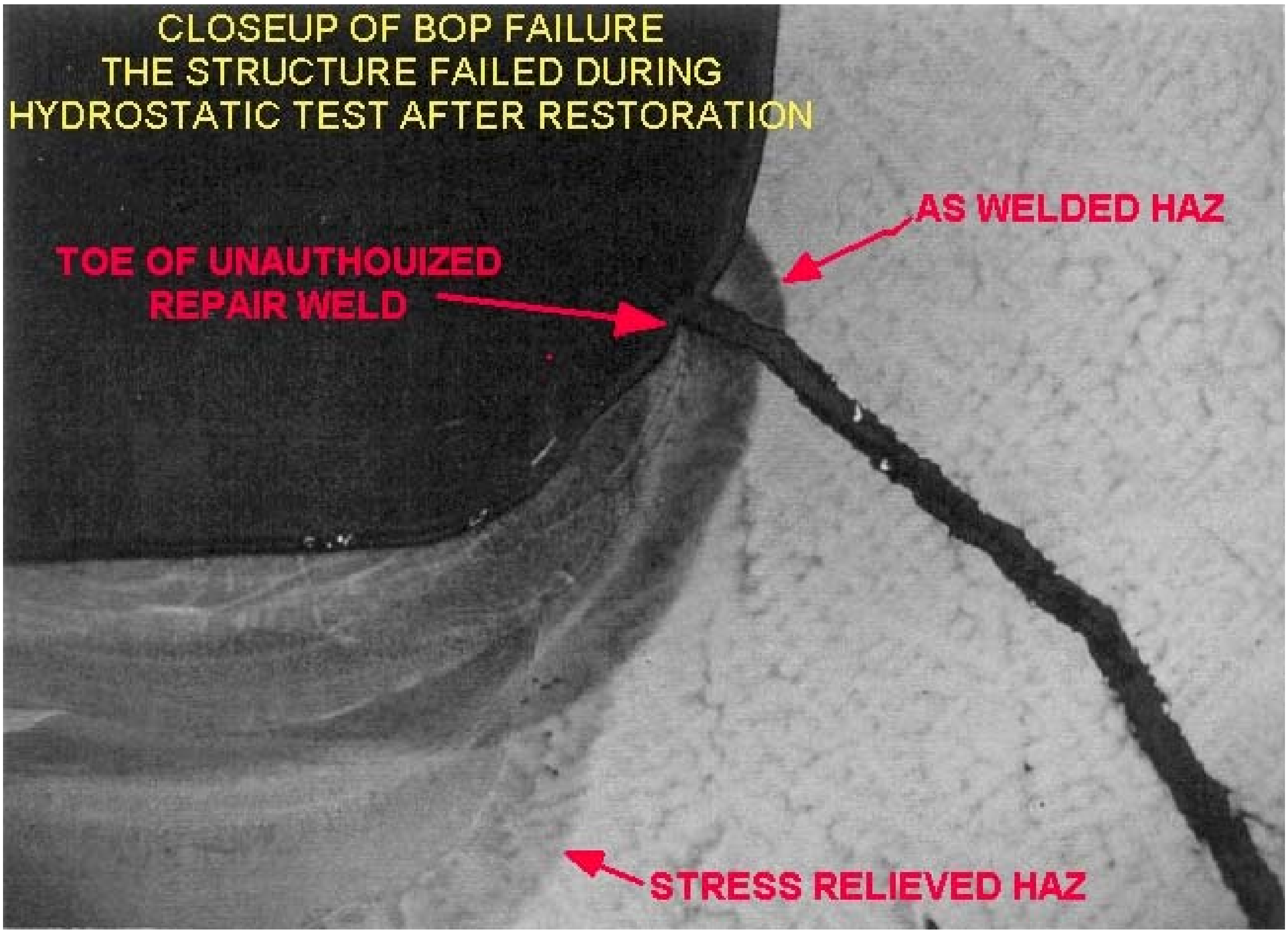

Figure D2

APPENDIX D—EXPLANATION OF REQUIREMENTS (Continued)

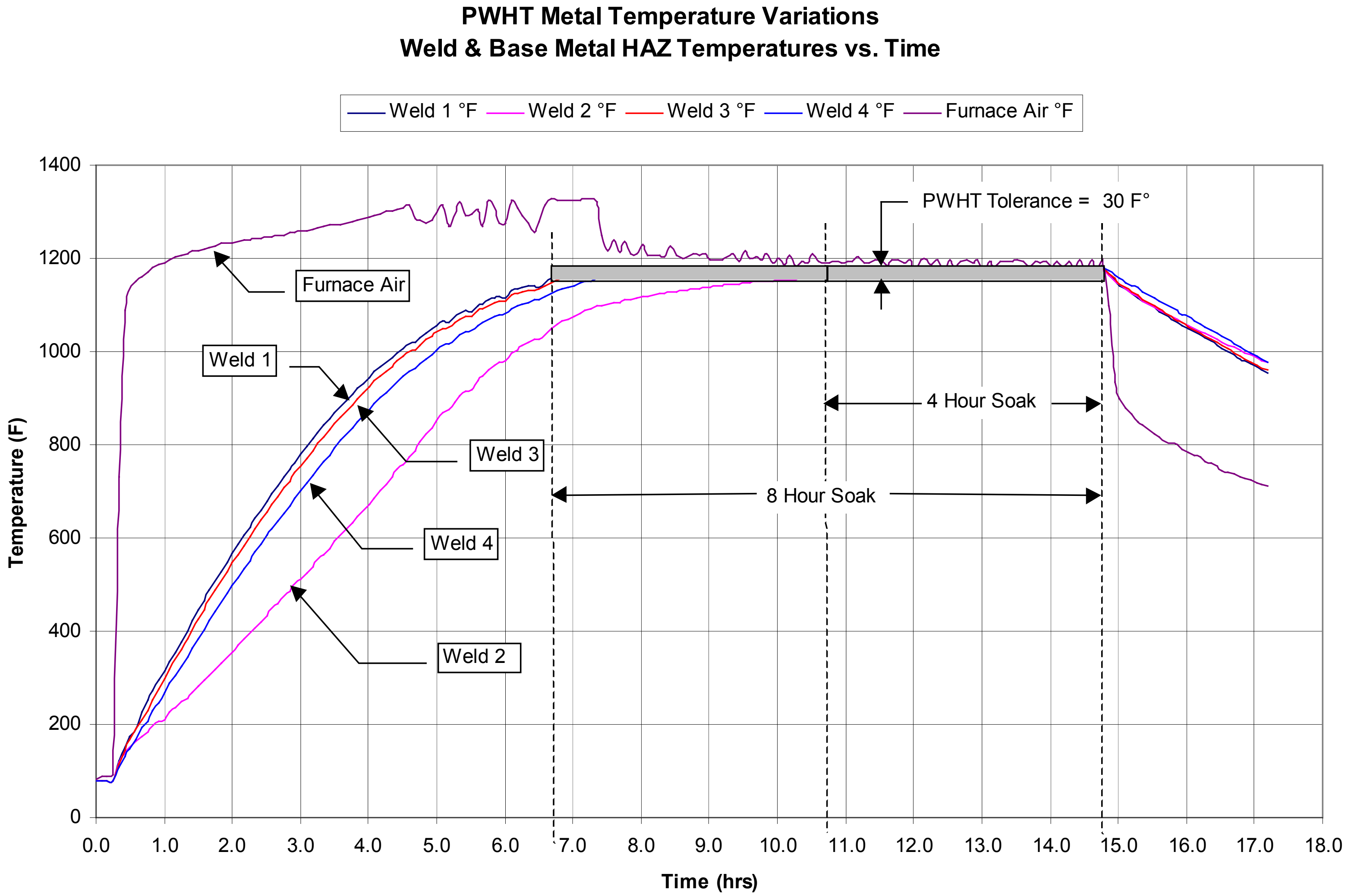

Figure D3

APPENDIX D—EXPLANATION OF REQUIREMENTS (Continued)

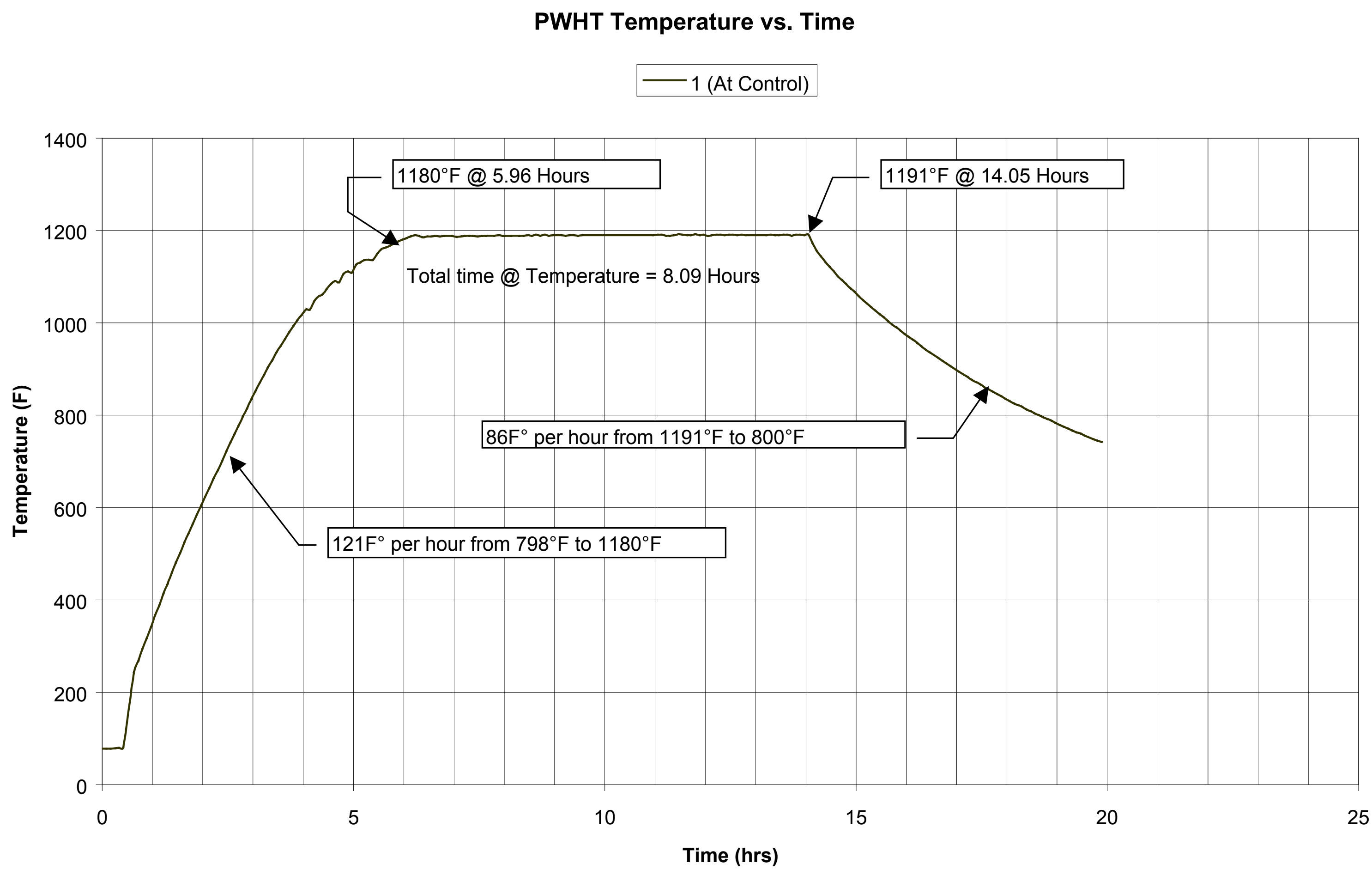

Figure D4