Tips for Purchasing Welding Consumables for Nuclear Work

Here's help in determining what electrodes, wire, fluxes, and other welding consumables you need to meet the requirements of ASME Section III

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When welding under the requirements of Section III, Nuclear Components, of the ASME *Boiler and Pressure Vessel Code*, there is an industry-wide perception that one must perform the testing required by the filler metal specification for each heat/lot combination. While this may satisfy some of Section III's requirements, this thinking slights much of what Section III requires for welding consumables.

The objective of this article is to explain in simple terms how to buy electrodes, wire, flux, and other welding consumables to meet the requirements of ASME Section III.

Since the requirements in all subsections (NB, NC, ND, etc.) are the same, I will use the designation "NX" in this article. Since Subsection NB has some special requirements, those requirements are identified with "NB." This article also refers to the "Certificate Holder;" this term means any organization that has a Certificate of Authorization from ASME to manufacture nuclear components.

Demonstrating Conformance to ASME Section IX

NX-2410 requires that welding consumables be what is specified in the Welding Procedure Specifications (WPSs). That is, when the WPS specifies E7018-H4R, the welding consumable purchased must meet the requirements of that classification in the applicable "SFA" filler metal specification in ASME Section II, Part C. Those specifications say that the filler metal manufacturer certifies the material supplied conforms to the specification when the AWS classification is marked on the product or the packaging. While this is sufficient to show the material meets the requirements of the SFA specification and Section IX, Certificate Holders should have on file a Certificate of Conformance for the specific trade name material(s) they are using. A Certificate of Conformance (sometimes known as a "typical" test report) is not for the specific heat/lot combination being purchased, but from some heat/lot of that trade name consumable that was tested at some earlier date. Interpretation III-82-10 supports this approach to complying with the first part of NX-2410.

When the consumable does not conform to a specification in Section II, Part C, or it is a "G" classification (e.g., E8018-G), Section IX requires that consumable to be qualified based on trade name or other established procurement document such as a company specification, and that trade name or company identification has to be specified on the WPS. No Certificate of Conformance is needed to meet Section IX requirements for material qualified by this route since that material does not, by definition, con-

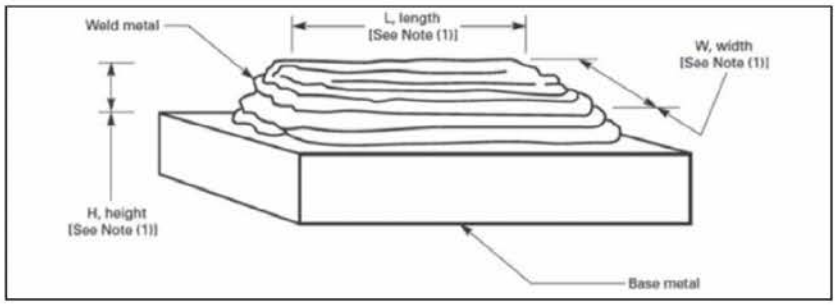

Fig. 1 — Pad for chemical analysis of undiluted weld metal (from SFA 5.1).

form to a filler metal specification, although it may be possible to obtain a certificate when the material conforms to a "G" classification.

Meeting Section III Requirements

While the above demonstrates compliance with Section IX, welding material also has to meet the rest of NX-2400, and that's where the excitement begins. In brief, NX-2400 requires testing of each heat and heat/lot combination of consumables for each welding process for which they will be used. Those test results have to meet the tensile strength and toughness requirements of the base metals be welded — not those of the filler metal specification.

Qualifying Manufacturers and Distributors of Welding Consumables

The first step is to be sure the consumables manufacturer has a manufacturing process control program that controls the raw materials and formulations that make up the consumables. NX-2420(a–h) defines welding consumable controls using the following terms:

- **Heats** of wire.
- **Chemically controlled** tube, wire, or strip.
- Batches of dry covering mixture, dry flux blends, and wet flux mixes, and chemically controlled flux mixes that are combined with individual heats of wire or with chemically controlled tube, wire, or strip to make a **lot** of covered, flux cored, or fabricated electrodes.
- **Lots** of submerged arc or electroslag flux.
- **Dry blend** of supplementary powdered filler metal.
- **Chemically controlled mix** of powdered filler metal.

These terms are defined in a sufficiently comprehensive way so that they describe the various methods that all welding consumable manufacturers use to control the raw materials that make up their products; auditors should verify and document the methods used and confirm they are appropriate to the products being made.

NX-2420 requires the following combinations to be individually tested for each welding process in which they will be used:

- Each lot of covered, flux cored, or fabricated electrodes.
- Each heat of bare electrodes, rods, or wires for use with the oxyfuel gas (OF), gas metal arc (GMA), gas tungsten arc (GTA), plasma arc (PA), and electrogas (EG) welding processes.
- Each heat of consumable inserts.
- Each combination of heat of bare electrodes or lot of fabricated electrodes and lot of submerged arc flux.
- For each combination of heat of bare electrodes or lot of fabricated electrodes, and dry blend of supplementary powdered filler metal, and lot of submerged arc flux.

The reason for requiring testing of heats, lots, and combinations of consumables is simple; there is significant interaction between the arc, flux, and weld metal during welding. The arc is really a small, traveling electric furnace that leaves a trail of weld metal in its wake. In the same manner as the fluxes used in steelmaking affect the properties of the steel, so the welding arc, wire, and flux interact, controlling the properties of the weld metal. While flux may not be a "material" by ASME's definition of material, the flux and wire compositions definitely affect the properties of the weld metal, so each combination has to be tested.

The first step in purchasing welding consumables is to verify the suppliers of those consumables control raw materials and consumables manufacturing as required by NX-2420(a–h). That can be done two ways:

1. ASME can issue a Quality System Certificate to the welding consumable manufacturer. ASME auditors who grant these Certificates have verified control as required by NX-2420(a–h). The purchase order must specify that the product be manufactured under the manufacturer's Quality System Certificate.

2. The Certificate Holder can audit the manufacturer as permitted by NCA-3811(b) for a limited scope quality program demonstrating control as required by NX-2420(a–h). The purchase order must specify that consumable manufacturing be controlled as specified in NX-2420.

If the consumable manufacturer is going to weld test coupons and do the heat/lot/batch testing required to meet NX-2400, control over that aspect must also be part of its quality program.

My opinion is that welding consumables cannot be purchased from a manufacturer that has not been audited per the above because it is not possible to satisfy NCA-3855.5 (unqualified source material) since one could not be sure of the pedigree of a single length of wire because that length could have a splice in it.

If welding consumables pass through distributors who store the material, their quality system for control of storage and identification also needs to be audited.

Welding of Consumable Test Coupons

NX-2420 requires each heat, lot, and combination of welding consumables to be tested. While NX-2410(b) provides a list of information required to be supplied to the organization doing the testing of the consumable, that organization could be the Certificate Holder itself, so don't read that list as a requirement to have the consumable manufacturer do the testing.

Chemical Analysis of the Weld Metal

When welding P-Numbers 1, 3, 4, 5A, 5B, 5C, 6, 7, 9, and 11 base metals, NX-2431 requires mechanical testing of the weld metal (tension and impact testing). However, the following are exempt from mechanical testing:

- Austenitic stainless steel and nonferrous welding materials
- Consumable inserts
- Welding materials used for GTAW root

deposits with a maximum of two layers.

The only testing required for these materials is chemical analysis for the elements specified in Table NX-2432 and for the elements specified in the filler metal specification or WPS. When either specifies compositional limits, the weld metal has to meet those requirements. When filler metals will be deposited using GTAW, PAW, and GMAW (except for A-8 deposits), the wire may be analyzed directly (see Table NX-2432.1-1). For other processes, undiluted weld deposits must be prepared as specified by the applicable SFA specification. Figures 1 and 2 show typical test assemblies.

For austenitic stainless steels (A-number 8 or 9 materials), the delta-ferrite also has to be reported; that can be determined by the chemical composition of the weld metal or wire for GTAW as applied to the WRC ferrite diagram in NX-2433.1-1 or by magnetic testing of a weld pad following AWS A4.2.

Mechanical Testing of the Weld Metal

All other welding consumables used to join P-Numbers 1, 3, 4, 5A, 5B, 5C, 6, 7, 9, and 11 base metals have to be mechanically tested. This means a test assembly similar to that shown in Fig. 2 has to be welded using each heat, lot, or combination of consumables that will be used in production. NX-2431.1 spells out the required testing, specifically that tension and impact test specimens have to be removed as shown in Fig. 2 for all processes.

Test assemblies have to be welded using each process with which the consumable will be used; this means that a single heat of ER70S-2 that will be used for both GTAW and GMAW has to be tested with each process. Welding also has to be done within the range of preheat and interpass temperatures that will be used in production welding, not the range in the SFA specification (e.g., 225°–350°F in the case of SFA-5.1).

If the production weld will be heat treated, the tension and impact specimens must be heat treated for at least 80% of the time the component will be heat treated. This means the Certificate Holder must anticipate any postweld heat treatment (PWHT) that will be performed on the weld metal, including those heat treatments performed during shop welding, field welding, and repairs, including repairs the owner performs after installation. NX-4622.1 requires that the design specification provide the extent of such additional heat treatments, so when the engineer who wrote the specification balks at giving you a PWHT holding time, point to that paragraph — it's a code requirement.

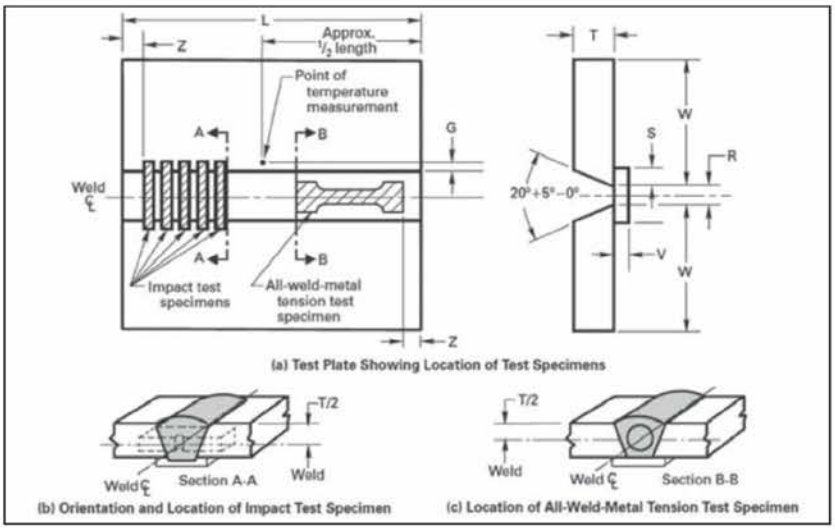

Fig. 2 — Groove weld test assembly for mechanical properties and soundness of weld metal.

Tensile Strength Requirements

The tensile strength of the filler metal must meet the specified minimum tensile strength of the base metals it will join, or the lower of the two if the tensile strengths are different. Tensile testing has to be done in the as-welded condition if the production weld will be left as-welded and in the heat-treated condition if the production weld will be heat treated.

Toughness Testing Requirements

Just as the tensile strength of the weld metal has to meet that of the base metal, the weld metal has to be tested at or below the test temperature of the base metal that it will join. It must also meet the same acceptance criteria as that base metal or the lower of the two if the acceptance criteria are different; however, unlike tensile strength, impact acceptance criteria for the base metal depend upon its thickness and the lowest service temperature of the component being built. Impact testing has to be done in the as-welded condition if the production weld will be left in the as-welded condition and in the heat-treated condition if the production weld will be heat treated.

When welding Subsection NB piping, pumps or valves thicker than 2½ in. (64 mm) or a vessel of any thickness, NB-2300 requires the material manufacturer to perform a series of drop-weight tests to establish the lowest no-break temperature "T_{NDT}" for that material. The manufacturer then has to perform Charpy impact testing at 60°F (33°C) above T_{NDT}. If 35 mils (0.89 mm) lateral expansion and 50 ft-lb (68 J) absorbed energy are achieved, T_{NDT} + at 60°F becomes the lowest service temperature (LST) for that lot of base material. This exercise is performed for all materials in a component, and the highest T_{NDT} determined for all the materials used determines the LST for that component.

Since weld metal toughness has to equal or exceed that of the base metal, welding consumables must undergo drop weight testing followed by impact testing, except that it's only necessary to do the drop-weight testing 10°F (5°C) below the highest T_{NDT} determined per the above. Since the Certificate Holder will purchase the materials discussed in the previous paragraph, the Certificate Holder will determine and advise whomever will be testing the welding consumables of the T_{NDT} required.

For all other construction — Subsection NB piping or other components equal to or less than 2½ in. thick and all vessels, piping, pumps, valves, and other components built to other Subsections — materials have to be tested at a temperature no higher than the LST as established

Table 1 — Impact Testing Requirements for Piping, Pumps, and Valves (Table NB-2332(a)-1 Modified)

Nominal Wall Thickness in. (mm) (Note 1)	Lateral Expansion mils (mm)
⅝ (16) or less	No test required
Over ⅝ to ¾ (16 to 19) inclusive	20 (0.50)
Over ¾ to 1½ (19 to 38) inclusive	25 (0.64)
Over 1½ to 2½ (38 to 64) inclusive	40 (1.00)
If over 2½ in. (64)	Drop weight testing and Charpy testing

Note 1: For pumps, valves, and other components, use the thickness of the connecting piping.

in the Design Specification (NX-3211). NC 2311(b) is typical of the other subsections, and it states the following:

"The Design Specification shall state the Lowest Service Temperature for the component."

Accordingly, when working to other subsections, be sure the Design Specification gives you the LST.

The acceptance criteria for the base metal is a function of the thickness of the component being welded as shown in Table 1; the weld metal needs to meet the same toughness criteria as the base metal it will join.

While Subsection NB specifies only lateral expansion acceptance criteria for piping, pumps, and valves as shown in Table 1, Subsection NC and others also have ft-lb acceptance criteria (see Table NC-2332.1-2). The Certificate Holder can use either mils or ft-lb criteria, but, since lateral expansion criteria are the same in all subsections, and the ft-lb criteria are a function of the yield strength of the base material to be welded, I recommend using mils acceptance criteria when preparing your specification for purchasing welding consumables.

The typical SFA specification requires that five impact specimens be prepared, but NX-2321.2 requires only three. Three test specimens should be tested, not five. NX-2350 has provisions for retesting if one specimen falls below the required toughness.

Practical Observations Regarding Impact Testing

The Design Specification defines the LST for most Section III construction, and the Owner or the Engineer has to provide it to the Certificate Holder. When I worked for an NPT stamp holder back in the 1970s, we ordered welding materials and qualified our WPSs at 32°F (0°C) since the plant operating fluid was water whereas containment structures and spent fuel transport casks can have very low service temperatures, but a lower temperature (e.g., –20°F (–29°C) as is commonly found in the filler metal specifications) can be used if the acceptance criteria can be met. We also postweld heat treated filler metal and WPS qualification test pieces for 16 h, qualifying them for 20 h. Those writing specifications for purchasing welding consumables should be aware that the lowest service temperature or the acceptance criteria that one has to meet can be modified by the results of qualifying WPSs in accordance with NX-4335, so be sure to check the WPSs you will follow when specifying the impact testing requirements for welding consumables.

Summary

The manufacturer needs to control welding consumables so that the metal and fluxes that make up those consumables are uniquely identified by heat, lot, batch, and blend; that control needs to be verified by the Certificate Holder. Each heat, lot, batch, or blend combination must be tested and must meet the same tensile and impact test requirements as the base metal that that consumable will be used to join — and those requirements are different from those of the filler metal (SFA) specifications.

Mechanical testing has to be done in the same heat treatment condition as the production weld.

Chemical composition of the weld metal has to meet the requirements of the filler metal specification, and austenitic stainless steel weld metal has to exhibit a minimum ferrite number (FN) of 5. ◆

A Welding Consumables Purchasing Checklist

NX-2410(b) gives you the following checklist of what you need to know before purchasing welding consumables for nuclear work.

1. Welding process to be used.
2. SFA specification and classification, or other identification if no SFA specification applies.
3. Minimum tensile strength in the as-welded or heat-treated condition or both
4. Drop weight test for material in the as-welded or heat-treated condition or both if the base metal is drop weight tested; the lowest service temperature must be known.
5. The Charpy V-notch test temperature and the lateral expansion or the absorbed energy requirements based on the impact test requirements of the base metal to be welded in the as-welded or heat-treated condition or both.
6. The preheat and interpass temperatures to be used during welding of the test coupon based on a WPS that will be followed in production welding.
7. Postweld heat treatment time, temperature range, and maximum cooling rate if the production weld will be heat treated.
8. Elements for which chemical analysis is required per the SFA specification or WPS and NX-2432.
9. Minimum delta-ferrite for A-numbers 8 or 9 weld metal.
10. Shielding gas when using GMAW or EGW to produce A-number 8 or 9 weld metal.

This list is useful not only as a checklist of requirements but also as a list the Certificate Holder can use to push the Engineer to provide the required base metal toughness test temperature, acceptance criteria, and PWHT holding time when they have not been provided in the design specification.