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CONTROL OF THE PROCESSING AND USE OF STAINLESS STEEL

A. INTRODUCTION

This guide describes methods that the staff of the U.S. Nuclear Regulatory Commission (NRC) considers acceptable for implementing requirements about control of the application and processing of stainless steel to avoid severe sensitization that could lead to stress-corrosion cracking. This guide applies to light-water-cooled reactors.

General Design Criterion 1, "Quality Standards and Records," and Criterion 4, "Environmental and Dynamic Effects Design Bases," as set forth in Appendix A, "General Design Criteria for Nuclear Power Plants," to Title 10, of the *Code of Federal Regulations*, Part 50, "Domestic Licensing of Production and Utilization Facilities" (10 CFR Part 50) (Ref. 1), require that components be designed, fabricated, erected, and tested to quality standards commensurate with the importance of the safety functions to be performed and that they be designed to accommodate the effects of and be compatible with the environmental conditions associated with normal operation, maintenance, testing, and postulated accident conditions. Appendix B, "Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants," to 10 CFR Part 50 requires that measures be established to ensure materials control and control of special processes, such as welding and heat treating, and to ensure performance of reliable testing programs.

This regulatory guide contains information collection requirements covered by 10 CFR Part 50 that the Office of Management and Budget (OMB) approved under OMB control number 3150-0011. The NRC may neither conduct nor sponsor, and a person is not required to respond to, an information collection request or requirement unless the requesting document displays a currently valid OMB control number. This Regulatory Guide is a rule as designated in the Congressional Review Act (5 U.S.C. 801–808). However, the NRC has determined this Regulatory Guide is not a major rule as designated by the Congressional Review Act and has verified this determination with the OMB.

B. DISCUSSION

Control of the application and processing of stainless steel to avoid severe sensitization is needed to diminish the numerous occurrences of intergranular stress-corrosion cracking in sensitized stainless steel components of nuclear reactors. Test data demonstrate that sensitized stainless steel is significantly more susceptible to intergranular stress-corrosion cracking than is nonsensitized (solution heat-treated) stainless steel. Of specific concern in this guide are the unstabilized austenitic stainless steels, which include American Iron and Steel Institute (AISI) Types 304 and 316, normally used for components of the reactor coolant system and other safety-related systems. Low carbon grade stainless steel (i.e., 304L and 316L) should be used where the material comes in contact with the reactor coolant. This guide does not cover stabilized stainless steels (e.g., AISI Types 321 and 347), which also provide some protection against sensitization.

Process controls should be exercised in accordance with good manufacturing/welding practices and knowledge gained from operating experience during all stages of component manufacturing and reactor construction to minimize exposure of stainless steel to contaminants that could lead to stress-corrosion cracking. As described in Section 5.2.3 of NUREG-0800, manufacturing processes should control cold-working and abrasive work such as grinding, to minimize the amount of cold-working, since excessive cold-working in austenitic stainless steels can increase their susceptibility to stress corrosion cracking. Because some degree of material contamination is inevitable during these operations, halogens and halogen-bearing compounds (e.g., die lubricants, marking compounds, and masking tape) should be avoided to the degree practical.

All cleaning solutions, processing compounds, degreasing agents, and other foreign materials should be completely removed at any stage of processing before any elevated temperature treatment and before hydrotests in accordance with guidelines of approved manufacturing/elevated temperature treatment procedures. Reasonable care should be taken to keep (1) fabrication and construction areas clean, (2) components protected and dry during storage and shipment, and (3) all crevices and small openings protected against contamination as identified in approved manufacturing quality assurance procedures. Pickling of sensitized stainless steel should be avoided. Special precautions should be taken to avoid surface contamination with fluorides from welding rod coatings and fluxes. The quality of water used for final cleaning or flushing of finished surfaces during installation should be in accordance with Regulatory Guide 1.37, “Quality Assurance Requirements for Cleaning of Fluid Systems and Associated Components of Water-Cooled Nuclear Power Plants” (Ref. 2).

Solution heat treating and testing should normally be performed on starting material. However, to ensure the proper solution heat-treated condition of the surface areas of finished components, it may be preferable to perform the solution heat treating and testing operation at a later stage of component manufacturing.

Solution heat treating should include cooling rates sufficiently rapid to prevent precipitation of carbides to a degree that the material is not susceptible to intergranular stress corrosion. Water quenching

(used for simple shapes such as bars and plates) should produce an acceptable cooling rate. However, cooling by means other than water quenching is acceptable only when the cooling rate is sufficiently rapid to prevent sensitization. This determination is made by subjecting the material to a suitable intergranular corrosion test such as Practice E, "Copper–Copper Sulfate–Sulfuric Acid Test for Detecting Susceptibility to Intergranular Attack in Austenitic Stainless Steels," of American Society for Testing and Materials (ASTM) A262, "Standard Practices for Detecting Susceptibility to Intergranular Attack in Austenitic Stainless Steels" (Ref. 3).

The NRC staff considers Practice E of ASTM A262 and the accompanying screening test, Practice A, "Oxalic Acid Etch Test for Classification of Etch Structures of Austenitic Stainless Steels," to be suitable tests for verifying the nonsusceptibility of the material to intergranular stress corrosion. Although these accelerated tests use different environments than anticipated in reactors and do not provide information about susceptibility to stress-corrosion cracking in reactor environments, these tests do readily detect the presence of significant sensitization of the material, a condition that has been related to actual intergranular stress-corrosion attack in reactor environments. This regulatory guide identifies these specific tests because they are the only known tests endorsed by a consensus standard that includes acceptance criteria (acceptable/nonacceptable basis) for the material being tested. Alternate test methods that can be qualified may also be acceptable.

Specimens for the intergranular corrosion tests from material with carbon content greater than 0.03 percent should be tested in the solution heat-treated condition. Specimens from material with carbon content of 0.03 percent or less should be tested after a sensitizing treatment of one hour at 677 degrees Celsius (C) [1,250 degrees Fahrenheit (F)] plus or minus 14 degrees C (25 degrees F).

Controls should be maintained on the chemistry of the reactor coolant and auxiliary systems fluids to which the material is exposed. Chloride and fluoride ion concentrations should be specified to be less than 0.15 parts per million at all times. Dissolved oxygen concentrations should be maintained below the limiting value of 0.10 parts per million during periods when the material is at elevated temperatures. If the oxygen content exceeds this level, such as in boiling water reactor coolants during normal operation, sensitization of material that is welded without subsequent solution heat treatment should be further controlled by limiting the carbon level in the material to 0.03 percent. Carbon level control is not needed for weld metal and castings with duplex structures because these product forms with normal carbon levels have demonstrated adequate resistance to intergranular attack. Carbon level control may not be required for piping if its diameters are sufficiently small (e.g., instrument lines and control rod drive hydraulic systems) that it could withstand a single failure without an accompanying loss-of-coolant accident as defined in Appendix A to 10 CFR Part 50.

Stainless steel subjected to sensitizing temperatures [427 to 816 degrees C (800 to 1,500 degrees F)] during fabrication (except during welding) should be retested with a suitable intergranular corrosion test (such as ASTM A262) to demonstrate that the thermal treatment did not result in undue sensitization. Specimens for the retest should be subjected to a thermal treatment that duplicates the temperatures, number of cycles, holding time at each cycle, and minimum heating and cooling rate in the range of 427 to 816 degrees C (800 to 1,500 degrees F). If more than one cycle at only one temperature is to be used in production, one cycle with a holding time equivalent to the total time would be acceptable for testing purposes.

Under certain conditions, material subjected to sensitizing temperatures [427 to 816 degrees C (800 to 1,500 degrees F)] during special processing may be acceptable for intended use (e.g., nitrided control rod drive material). These conditions should include, as a minimum, assurance of the following:

- The process is properly qualified and controlled to develop a consistent and uniform product, irrespective of heat of material and equipment used.

- Adequate documentation exists that the processed material will not develop intergranular stress corrosion during its service life. Adequate documentation should include actual service experience or test data or both in simulated environments and operating conditions. Service experience should include positive evidence through destructive examination that intergranular stress corrosion did not occur.

All welding processes will result in some carbide precipitation in the weld metal and in the base metal heat-affected zone of stainless steel welds, but significant sensitization does not normally result when typical welding procedures and material chemistry are used and when no further heating of material occurs. However, there is evidence that atypical welding methods using very high heat input could result in stress-corrosion cracking in the heat-affected zone of the weld. To avoid this, the welding procedures and material chemistry (if necessary) should be controlled to prevent undue sensitization of the heat-affected zones of the weldments. Controls to prevent sensitization of the material during welding may include the following:

a. avoiding welding practices that result in the generation of high heat;

b. maintaining low heat input by controlling current, voltage, and travel speed;

c. limiting interpass temperature;

d. using stringer bead techniques and avoiding excessive weaving; and

e. limiting the carbon level of the material where section thickness makes the material more prone to sensitization.

In addition, welding procedures[1] should be qualified by passing a suitable intergranular corrosion test in all cases where the procedure is used for welding stainless steel having a carbon level greater than 0.03 percent. The qualification test should be performed using base material with the maximum carbon content anticipated and the minimum and maximum thicknesses anticipated.

At minimum, the qualification test should control the variables of heat input, interpass temperature, and welding techniques for specific section thicknesses.

C. REGULATORY POSITION

Unstabilized, austenitic stainless steel of the AISI Type 3XX series used for components that are part of (1) the reactor coolant pressure boundary, (2) systems required for reactor shutdown, (3) systems required for emergency core cooling, and (4) reactor vessel internals that are relied on to permit adequate core cooling for any mode of normal operation or under credible postulated accident conditions should meet the following criteria:

[1] "Welding procedure" means procedures qualified in accordance with the rules of Section IX, "Welding and Brazing Qualifications," of the American Society of Mechanical Engineers Boiler and Pressure Vessel Code (Ref. 4).

1. Material should be suitably cleaned and suitably protected against contaminants capable of causing stress-corrosion cracking during fabrication, shipment, storage, construction, testing, and operation of components and systems.

2. Material from which components and systems are to be fabricated should be solution heat treated[2] to produce a nonsensitized condition in the material.

3. Nonsensitization of the material[3] should be verified using ASTM A262, Practices A or E, or another method that can be demonstrated to show nonsensitization in austenitic stainless steel. Test specimens should be selected from material subjected to each different heat treatment practice and from each heat.

4. Material subjected to sensitizing temperature in the range of 427 to 816 degrees C (800 to 1,500 degrees F), subsequent to solution heat treating in accordance with Regulatory Position 2 above and testing in accordance with Regulatory Position 3 above, should be L Grade material; that is, it should not have a carbon content greater than 0.03 percent. Exceptions are the following:

a. material exposed to pressurized water reactor coolant that has a controlled concentration of typically less than 0.020 parts per million, with a limiting value of 0.10 parts per million dissolved oxygen at all temperatures above 90 degrees C (200 degrees F) during normal operation; or

b. material in the form of castings or weld metal with a ferrite content of at least 5 percent; or

c. piping in the solution annealed condition whose exposure to temperatures in the range of 427 to 816 degrees C (800 to 1,500 degrees F) has been limited to welding operations, provided it is of sufficiently small diameter so that in the event of a credible postulated failure of the piping during normal reactor operation, the reactor can be shut down and cooled down in an orderly manner, assuming makeup is provided by the reactor coolant makeup system only.

5. Material subjected to sensitizing temperatures in the range of 427 to 816 degrees C (800 to 1,500 degrees F) during heat treating or processing other than welding, subsequent to solution heat treating in accordance with Regulatory Position 2 above and testing in accordance with Regulatory Position 3 above, should be retested in accordance with Regulatory Position 3 to demonstrate that it is not susceptible to intergranular attack, except that retest is not required for the following:

a. cast metal or weld metal with a ferrite content of 5 percent or more; or

b. material with a carbon content of 0.03 percent or less that is subjected to temperatures in the range of 427 to 816 degrees C (800 to 1,500 degrees F) for less than one hour; or

c. material exposed to special processing, provided that the processing is properly controlled to develop a uniform product, and provided that adequate documentation exists of service experience and/or test data to demonstrate that the processing will not result in increased susceptibility to intergranular stress corrosion.

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[2] "Solution heat treated" means heating to a suitable temperature, holding at that temperature long enough to cause all carbides to enter into solution, and then cooling rapidly enough to keep the carbon in solution.

[3] Material of product forms with simple shapes not subject to distortion during heat treatment, such as plate, sheet, bars, pipe, and tubes, need not be tested provided that water quenching follows the solution heat treatment.

Specimens for the retest should be taken from each heat of material and should be subjected to a thermal treatment representative of the anticipated thermal conditions that the production material will undergo.

6. Welding practices and, if necessary, material composition should be controlled to avoid excessive sensitization of base metal heat-affected zones of weldments. Controls to prevent sensitization of the material during welding include maintaining low heat input and limiting the interpass temperature.

7. An intergranular corrosion test, such as specified in Regulatory Position 3 above, should be performed for each welding procedure to be used for welding material having a carbon content greater than 0.03 percent.

D. IMPLEMENTATION

The purpose of this section is to provide information to applicants and licensees regarding the NRC's plans for using this regulatory guide. The NRC does not intend or approve any imposition or backfit in connection with its issuance.

In some cases, applicants or licensees may propose or use a previously established acceptable alternative method for complying with specified portions of the NRC's regulations. Otherwise, the methods described in this guide will be used in evaluating compliance with the applicable regulations for license applications, license amendment applications, and amendment requests.

REFERENCES

1. 10 CFR Part 50, "Domestic Licensing of Production and Utilization Facilities," U.S. Nuclear Regulatory Commission, Washington, DC.[1]

2. Regulatory Guide 1.37, "Quality Assurance Requirements for Cleaning of Fluid Systems and Associated Components of Water-Cooled Nuclear Power Plants," U.S. Nuclear Regulatory Commission, Washington, DC.[2]

3. ASTM A262, "Standard Practices for Detecting Susceptibility to Intergranular Attack in Austenitic Stainless Steels," American Society for Testing and Materials, West Conshohocken, PA.[3]

4. ASME Boiler and Pressure Vessel Code, American Society of Mechanical Engineers, New York, NY.[4]

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[1] All NRC regulations listed herein are available electronically through the Public Electronic Reading Room on the NRC's public Web site, at http://www.nrc.gov/reading-rm/doc-collections/cfr/part050. Copies are also available for inspection or copying for a fee from the NRC's Public Document Room at 11555 Rockville Pike, Rockville, MD; the PDR's mailing address is USNRC PDR, Washington, DC 20555; telephone (301) 415-4737 or (800) 397-4209; fax (301) 415-3548; e-mail pdr.resource@nrc.gov.

[2] All regulatory guides listed herein were published by the U.S. Nuclear Regulatory Commission. Where an ADAMS accession number is identified, the specified regulatory guide is available electronically through the NRC's Agencywide Documents Access and Management System (ADAMS) at http://www.nrc.gov/reading-rm/adams.html. All other regulatory guides are available electronically through the Electronic Reading Room on the NRC's public Web site, at http://www.nrc.gov/reading-rm/doc-collections/reg-guides/.

[3] Copies of ASTM standards may be purchased from the American Society for Testing and Materials, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, Pennsylvania 19428-2959; phone (610) 832-9585. Purchase information is available through the ASTM Web site at http://www.astm.org.

[4] Copies may be purchased from the American Society of Mechanical Engineers, Three Park Avenue, New York, NY 10016-5990; phone (212) 591-8500; fax (212) 591-8501; www.asme.org.