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REGULATORY GUIDE

DIRECTORATE OF REGULATORY STANDARDS

REGULATORY GUIDE 1.44

CONTROL OF THE USE OF SENSITIZED STAINLESS STEEL

A. INTRODUCTION

General Design Criteria 1 and 4 of Appendix A to 10 CFR Part 50, "General Design Criteria for Nuclear Power Plants," 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 to 10 CFR Part 50, "Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants," requires that measures be established to assure materials control and control of special processes such as welding and heat treating and to assure performance of reliable testing programs. This guide describes acceptable methods of implementing the above requirements with regard to 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. The Advisory Committee on Reactor Safeguards has been consulted concerning this guide and has concurred in the regulatory position.

B. DISCUSSION

Control of the application and processing of stainless steel to avoid severe sensitization is needed to diminish the numerous occurrences of stress corrosion cracking in sensitized stainless steel components of nuclear reactors. Test data demonstrate that sensitized stainless steel is significantly more susceptible to stress corrosion cracking than non-sensitized (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. This guide does not cover stabilized stainless steels (e.g., AISI types 321 and 347) which also provide some protection against sensitization, since these materials are not currently being selected for use in light-water-cooled reactors.

Process controls should be exercised during all stages of component manufacturing and reactor construction to minimize exposure of stainless steel to contaminants that could lead to stress corrosion cracking. Since 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 prior to any elevated temperature treatment and prior to hydrotests. 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. 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.

Solution heat treating and testing should normally be performed on starting material. However, in order to assure 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 of American Society for Testing and Materials (ASTM) A 262-70.[1]

Practice E of ASTM A 262-70, "Copper–Copper Sulfate–Sulfuric Acid Test," and the accompanying screening test Practice A, "Oxalic Acid Etch Test," are considered suitable tests for verifying non-susceptibility of the material to intergranular stress corrosion. Although these accelerated tests use different environments than anticipated in reactors and do not provide information relating directly to susceptibility to stress corrosion cracking in reactor environments, these tests do readily detect the presence of significant sensitization of the material, a condition which has been related with actual intergranular stress corrosion attack in reactor environments. These specific tests are identified here because they are the only known tests endorsed by a consensus standard that includes acceptance criteria (acceptable–non-acceptable basis) for the material being tested. Alternate test methods that can be qualifed are also 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 1250°F ± 25°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 (ppm) at all times. Dissolved oxygen concentrations should be maintained below 0.10 ppm during periods when the material is at elevated temperatures. When the oxygen content regularly exceeds this level, such as occurs in BWR 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 since 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) so that it could withstand a single failure without an accompanying loss-of-coolant accident as defined in 10 CFR Part 50, Appendix A.

Stainless steel subjected to sensitizing temperatures (800 to 1500°F) during fabrication (except during welding) should be retested with a suitable intergranular corrosion test (such as ASTM A 262-70) 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 800 to 1500°F range. 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 (800 to 1500°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 that:

1. The process is properly qualified and controlled to develop a consistent and uniform product, irrespective of heat of material and equipment used; and
2. Adequate documentation exists that the processed material will not develop intergranular stress corrosion during its service life. Adequate documentation should include actual service experience and/or test data 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 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: (1) avoiding welding practices that result in the generation of high heat, (2) maintaining low heat input by controlling current, voltage, and travel speed, (3) limiting interpass temperature, (4) using stringer bead techniques and avoiding excessive weaving, and (5) limiting the carbon level of the material where section thickness makes the material more prone to sensitization.

[1] ASTM Standard A 262-70, "Recommended Practices for Detecting Susceptability to Intergranular Attack in Stainless Steels," may be obtained from ASTM, 1916 Race Street, Philadelphia, Pennsylvania 19103.

In addition, welding procedures[2] 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 having the maximum carbon content anticipated and the minimum and maximum thicknesses anticipated.

As a minimum, the variables tthat should be controlled in the qualification test are 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 upon to permit adequate core cooling for any mode of normal operation or under credible postulated accident conditions should meet the following:

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[3] to produce a non-sensitized condition in the material.

3. Non-sensitization of the material[4] should be verified using ASTM A 262-70, "Recommended Practices for Detecting Susceptibility to Intergranular Attack in Stainless Steel," Practices A or E, or another method that can be demonstrated to show non-sensitization 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 800 to 1500°F, subsequent to solution heat treating in accordance with subparagraph C.2. above and testing in accordance with subparagraph C.3. above, should be L Grade material; that is, it should not have a carbon content greater than 0.03 percent. Exceptions are:

(a) Material exposed to reactor coolant which has a controlled concentration of less than 0.10 ppm dissolved oxygen at all temperatures above 200°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 800 to 1500°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 800 to 1500°F during heat treating or processing other than welding, subsequent to solution heat treating in accordance with subparagraph C.2. above, and testing in accordance with subparagraph C.3. above, should be retested in accordance with subparagraph C.3. above, to demonstrate that is not susceptible to intergranular attack, except that retest is not required for:

(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 800 to 1500°F for less than one hour; or

(c) Material exposed to special processing, provided 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.

Specimens for the above retest should be taken from each heat of material and should be subjected to a thermal treatment that is 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. An intergranular corrosion test, such as specified in subparagraph C.3. above, should be performed for each welding procedure to be used for welding material having a carbon content of greater than 0.03 percent.

[2] Welding procedure means procedures qualified in accordance to the rules of Section IX of the American Society of Mechanical Engineers Boiler and Pressure Vessel Code.

[3] 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.

[4] 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 the solution heat treatment is followed by water quenching.