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CONTROL OF STAINLESS STEEL WELD CLADDING OF LOW-ALLOY STEEL COMPONENTS

A. INTRODUCTION

This guide describes methods that the staff of the U.S. Nuclear Regulatory Commission (NRC) considers acceptable for the selection and control of welding processes used for cladding ferritic steel components with austenitic stainless steel to restrict practices that could result in underclad cracking. This guide is limited to forgings and plate material and does not apply to other product forms such as castings and pipe. Adequate resistance to underclad cracking for these latter items should be ensured on a case-by-case basis. This guide applies to light-water-cooled reactors.

General Design Criterion 1, "Quality Standards and Records," of 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), requires that components important to safety be designed, fabricated, erected, and tested to quality standards commensurate with the importance of the safety function to be performed. 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 control of special processes such as welding and that proper testing be performed.

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B. DISCUSSION

The presence of intergranular cracking in low-alloy steel under stainless steel weld cladding has been observed in reactor vessels and other components for nuclear systems in varying degrees, depending on the material and the cladding processes (Refs. 2–4). This condition has been reproduced experimentally using specific materials and welding processes common to the reactor components (Ref. 5). Two types of underclad cracking have been identified.

Underclad cracking (or "hot" underclad cracking) has been reported only in forgings and plate material of American Society of Mechanical Engineers (ASME) SA-508, "Specification for Quenched and Tempered Vacuum Treated Carbon and Alloy Steel Forgings for Pressure Vessels," Grade 2 Class 1 (formerly known as SA-508 Class 2) composition (Ref. 6) made to coarse-grain practice. High-deposition-rate welding processes, such as the submerged-arc wide-strip (i.e., greater than 60 millimeters or 2.36 in) process and the submerged-arc 6-wire process, result in coarse grains in the weld metal. Reheat underclad cracking occurs when the adjacent layer of high-heat-input cladding is added, which reheats the heat-affected zone (HAZ) in the carbon steel, causing a liquid phase along the grain boundaries and grain boundary separation upon cooling. Reheat underclad cracking was not observed in ASME SA-508 Grade 2 Class 1 materials clad by low-heat-input processes controlled to minimize heating of the base metal. Further, cracking was not observed in clad ASME SA-533 Grade B Class 1 plate material, which is produced to fine-grain practice, regardless of the welding process used. In addition, the use of fine-grain forgings is a method to avoid underclad cracking regardless of welding process used.

Characteristically, the underclad cracking occurs only in the grain-coarsened region of the base metal HAZ at the weld bead overlap. The subsurface location and size of these cracks 0.5 inch (1.3 centimeters) long by 0.165 inch [(4.2 millimeters) deep, maximum] make them challenging to detect using nondestructive examination. Also, nondestructive examination should be performed following postweld heat treatment because underclad cracking can grow during postweld stress relief heat treatment. Detection often requires destructively removing the cladding to the weld fusion line and examining the exposed base metal either with metallographic techniques or with liquid penetrant or magnetic particle testing methods.

From the results of certain analytical evaluations, it has been concluded that cracks of this nature will have no detrimental effect on the structural integrity of components under operating conditions. However, because uncertainties exist about assumptions made in the analyses and about the combined effects of strain concentration and cyclic loading on crack growth, the presence of these cracks is undesirable, and they should be avoided to the extent practical. Accordingly, fabrication processes known to produce this condition should be controlled.

Welding processes known to induce underclad cracking, such as the high-heat-input processes indicated above, should not be used for cladding material susceptible to underclad cracking, such as ASME SA-508 Grade 2 Class 1 forgings or plate material of similar composition. This restriction need not apply to the cladding of ASME SA-533 Grade B Class 1 plate material made to fine-grain practice and heat-treated to refine the grain structure because such material has been demonstrated to exhibit resistance to underclad cracking.

Because welding procedures for a given cladding process may vary significantly among manufacturers, the essential variables of these procedures must be qualified to Section IX, "Welding and Brazing Qualifications," of the ASME Boiler and Pressure Vessel Code (Ref. 7). This qualification includes a test for soundness of the weldment, but this test is not adequate for establishing resistance to underclad cracking because it may be performed using material resistant to underclad cracking, such as ASME SA-533 Grade B Class 1 plate, and because it is not designed to detect cracks that have the location and orientation of typical underclad cracking. Therefore, supplementary criteria are needed for the cladding procedure qualification, including suitable tests to demonstrate that underclad cracking is not induced.

When crack-susceptible materials are involved, the weld qualification test specimen should be made using material that is representative of production material. A postweld heat treatment comparable to the appropriate production heat treatment should be applied before any testing, because such a heat treatment may contribute to the formation or growth of cracks. The area examined must be sufficiently large to ensure that the test includes overlap regions where cracking occurs.

Although a standard test for determining susceptibility to underclad cracking does not exist at this time, several test methods developed for this purpose are considered satisfactory for determining the existence of cracks. One such test method includes the removal of cladding to the fusion line and examination of the base material for cracks using one of the following examination methods: metallography, liquid penetrant, or magnetic particle. This is followed by progressive grinding and examination through the HAZ until the cracks are completely revealed. Another test method is to make a minimum of three cross section specimens in the through thickness direction either transverse or parallel to the weld and examine the weld, HAZ and base metal for cracks.

An alternative test method includes the use of standard guided bend tests in which the bend specimens are oriented approximately parallel (deviations not greater than 15 degrees) to the direction of welding. In this test, the tensile face must be located at the weld-bead-overlap area. The maximum tensile stress should be applied to the fusion line area and HAZ.

Production weld cladding for safety-related components should comply with the fabrication requirements specified in Section III, "Rules for Construction of Nuclear Power Plant Components," as well as Section IX, of the ASME Boiler and Pressure Vessel Code. Complying with these requirements and with the supplementary criteria for the cladding procedure qualification identified in this regulatory guide is considered reasonable assurance that underclad cracking will be avoided in production weld cladding. Deviation from the qualification procedure during production welding should be accompanied by additional assurance that underclad cracking has not resulted, such as the removal of a section of cladding followed by a suitable examination or a requalification of the procedure to include the actual conditions used in production.

C. REGULATORY POSITION

Controls should be exercised to limit the occurrence of underclad cracking in low-alloy steel safety-related components clad with stainless steel. Welding processes that induce underclad cracking by generating excessive heating and promoting grain coarsening in the base metal should not be used for cladding any grade of material that has a known susceptibility to underclad cracking. Welding procedures used for cladding these grades of material should be qualified for use to demonstrate that underclad cracking is not induced. These controls need not be applied to the cladding of materials demonstrated to be resistant to underclad cracking, such as ASME SA-533 Grade B Class 1 plate made to fine-grain practice and heat-treated to develop a fine-grained structure. Weld cladding Class 1 and 2 vessels and components should comply with Sections III and IX of the ASME Boiler and Pressure Vessel Code, supplemented by the following:

1. For weld cladding of ASME SA-508 Grade 2 Class 1 forgings made to coarse-grain practice and plate material of similar composition, the following apply:

a. High-heat-input welding processes that induce underclad cracking, such as the submerged-arc wide-strip welding process (i.e., greater than 60 millimeters or 2.36 inch) and the submerged-arc 6-wire process, should not be used.
b. Weld cladding procedures should be qualified for use in accordance with Regulatory Position 2, below.

2. The weld cladding procedure described in Regulatory Position 1 should be qualified for use by a performance test to demonstrate that it does not induce excessive underclad cracking. The test should include the following:

a. Base material for the test should be of the same grade and class as that to be used in production. A minimum of three representative heats of material should be tested. In cases where less than three heats of material are used in production, these heats may be tested in lieu of the three representative heats.

b. The qualification block from which test specimens are to be taken should be of sufficient size and thickness to develop thermal restraint conditions typical of those developed in production welding.

c. The qualification block from which test specimens are to be taken should be suitably postweld heat-treated at temperatures and times at least as great as those encountered in production heat treatment before removal of specimens.

d. A minimum of two weld-clad-overlap areas per test specimen should be evaluated.

e. The following indications on any 1-inch length of evaluation test specimen or over the area of review of the polished surface should be the basis for rejection of the welding procedure:

(1) any fissures greater than 0.030 inch (0.76 millimeter) in length or 0.010 inch (0.25 millimeter) in depth, or

(2) more than three fissures 0.005 inch (0.13 millimeter) to 0.010 inch (0.25 millimeter) in depth.

3. Production welding should be monitored to verify compliance with the limitations on essential variables. Essential variables are based on the procedure qualification in accordance with Section IX of the ASME Boiler and Pressure Vessel Code. If production welding does not conform to these limitations, an examination for cracking should be performed on the production part from which a section of cladding has been removed, and the cladding procedure should be requalified in accordance with Regulatory Position 2, above.

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. WCAP-7733, "Reactor Vessels: Weld Cladding-Base Metal Interaction," by T.R. Mager, E. Landerman, and C.J. Kubit, Westinghouse Nuclear Energy Systems Report, April 1971.

3. R.D. Wylie, "Under-Clad Cracking," Paper No. 5, PVRC Task Group Report, Oak Ridge National Laboratory, Heavy Section Steel Technology Program, 6th Annual Information Meeting, April 25–26, 1972.

4. WCAP-15338, "A Review of Cracking Associated with Weld Deposited Cladding in Operating PWR Plants," by W. Bamford and R.D. Rishel, Westinghouse Electric Company Report, March 2000.

5. B&W 10013, "Study of Intergranular Separations in Low-Alloy Steel Heat Affected Zones Under Austenitic Stainless Steel Weld Cladding," by P.S. Ayres, I. Barnes, and G.N. Emmanuel, Babcock and Wilcox Nuclear Power Generation Report, December 1971.

6. ASME SA-508, "Specification for Quenched and Tempered Vacuum Treated Carbon and Alloy Steel Forgings for Pressure Vessels," American Society of Mechanical Engineers, New York, NY.[2]

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

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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] 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.