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REGULATORY GUIDE

DIRECTORATE OF REGULATORY STANDARDS

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

A. INTRODUCTION

General Design Criterion 1, "Quality Standards and Records," of Appendix A to 10 CFR Part 50, "General Design Criteria for Nuclear Power Plants," requires that components important to safety be designed, fabricated, and tested to quality standards commensurate with the importance of the safety function to be performed. Appendix B to 10 CFR Part 50, "Quality Assurance Criteria for Nuclear Power Plants and Fuel Processing Plants," requires that measures be established to assure control of special processes such as welding and that proper testing be performed. This guide describes acceptable methods of implementing these requirements with regard to 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 assured on a case-by-case basis. 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

The presence of intergranular cracking in low-alloy steel under stainless steel weld cladding has been observed[1,2] in reactor vessels and other components for nuclear systems in varying degrees depending on the material and the cladding processes. This condition has been reproduced experimentally[3] using specific materials and welding processes common to the reactor components.

Underclad cracking has been reported only in forgings and plate material of SA-508 Class 2 composition[4] made to coarse-grain practice when clad using high-deposition-rate welding processes identified as "high-heat-input" processes such as the submerged-arc wide-strip and the submerged-arc 6-wire processes. Cracking was not observed in SA-508 Class 2 materials clad by "low-heat-input" processes controlled to minimize heating of the base metal. Further, cracking was not observed in clad SA-533 Grade B Class 1 plate material, which is produced to fine-grain practice, regardless of the welding process used.

Characteristically, the cracking occurs only in the grain-coarsened region of the base metal heat-affected zone at the weld bead overlap. The subsurface location and size of these cracks (0.5 in. x 0.165 in. maximum) make them relatively insensitive to detection using standard nondestructive examination methods. Detection normally requires destructively removing the cladding to the weld fusion line and examining the exposed base metal either by metallographic techniques or with liquid penetrant or magnetic particle testing methods.

[1] Westinghouse Nuclear Energy Systems Report WCAP 7733 "Reactor Vessels Weld Cladding–Base Metal Interaction," by T. R. Mager, et. al., April 1971.

[2] Oak Ridge National Laboratory, Heavy Section Steel Technology Program, 6th Annual Information Meeting, April 25-26, 1972, Paper No. 5, PVRC Task Group Report on "Under-Clad Cracking," by R. D. Wylie, Southwest Research Institute.

[3] Babcock and Wilcox Nuclear Power Generation Report B&W 10013 "Study of Intergranular Separations in Low-Alloy Steel Heat Affected Zones Under Austenitic Stainless Steel Weld Cladding," by P. S. Ayres, et. al., December 1971.

[4] SA-508, "Specification for Quenched and Tempered Vacuum Treated Carbon and Alloy Steel Forgings for Pressure Vessels," does not cover plate. However, plate with composition similar to SA-508 Class 2 has been reported to have underclad cracking.

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 concerning assumptions made in these analyses as well as concerning the combined effects of strain concentrations 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 SA-508 Class 2 forgings or plate material of similar composition. This restriction need not apply to the cladding of SA-533 Grade B Class 1 plate material made to fine-grain practice and heat-treated to refine the grain structure since such material has been demonstrated to exhibit resistance to underclad cracking.

Since welding procedures for a given cladding process may vary significantly among manfacturers, the essential variables of these procedures are required to be qualified to Section IX, "Welding Qualifications," of the ASME Boiler and Pressure Vessel Code.[5] This qualification includes a test for soundness of the weldment which is not adequate for establishing resistance to underclad cracking because it may be performed using material resistant to underclad cracking, such as SA-533 Grade B Class 1 plate, and because the qualification test 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 post-weld heat treatment comparable to the appropriate production heat treatment should be applied prior to 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 overlap regions where cracking occurs are included in the test.

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 examining 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 heat-affected zone until the cracks are completely revealed.

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.

Production weld cladding for safety-related components should comply with the fabrication requirements specified in Section III, "Nuclear Power Plant Components," as well as Section IX, "Welding Qualifications," of the ASME Boiler and Pressure Vessel Code.[5] Complying with these requirements and with the supplementary criteria for the procedure qualification identified herein 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 SA-533 Grade B Class 1 plate made to fine-grain practice and heat-treated to develop a fine-grained structure. Weld cladding practices used in the fabrication of low-alloy steel safety-related components should be conducted in accordance with the following guidelines:

1. For weld cladding of SA-508 Class 2 forgings made to coarse-grain practice and plate material of similar composition:

a. "High-heat-input" welding processes that induce underclad cracking such as the submerged-arc wide-strip welding process 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 C.2. below.

2. The weld cladding procedure described in regulatory position C.1. should be qualified for use by a performance test to demonstrate that it does not induce

[5] Copies may be obtained from American Society of Mechanical Engineers, United Engineering Center, 345 East 47th Street, New York, N.Y. 10017.

excessive underclad cracking. The test should include the following:

a. Base material for the test should be of the same grade as that to be used in production. A minimum of three representative heats of material should be tested. 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 post-weld heat-treated at temperatures and times at least as great as those encountered in production heat treatment prior to removal of specimens.

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

e. The following indications on any one-inch length of evaluation test specimen should be the basis for rejection of the welding procedure:

(1) any fissures greater than 1/32 inch in length or 0.010 inch in depth.

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

3. Production welding should be monitored to verify compliance with the limitations on essential variables established by the procedure qualification. In the event that the production welding procedure 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 or the cladding procedure should be requalified in accordance with regulatory position C.2. above.