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MATERIALS AND INSPECTIONS FOR REACTOR VESSEL CLOSURE STUDS

A. INTRODUCTION

General Design Criterion 1, "Quality Standards and Records," of Appendix A, "General Design Criteria for Nuclear Power Plants," to 10 CFR Part 50, "Licensing of Production and Utilization Facilities," requires, in part, that structures, systems, and components important to safety be designed, fabricated, erected, and tested to quality standards commensurate with the importance of the safety functions to be performed. Criterion 30, "Quality of Reactor Coolant Pressure Boundary," of the same appendix requires, in part, that components which are part of the reactor coolant pressure boundary be designed, fabricated, erected, and tested to the highest quality standards practical. In addition, Criterion 31, "Fracture Prevention of Reactor Coolant Pressure Boundary," requires, in part, that the reactor coolant pressure boundary be designed with sufficient margin to assure that when stressed under operating, maintenance, testing, and postulated accident conditions (1) the boundary behaves in a nonbrittle manner and (2) the probability of rapidly propagating fracture is minimized. Appendix B, "Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants," to 10 CFR Part 50 requires, in part, that measures be established for the control of special processing such as heat treating and that proper testing be performed. Section 50.55a, "Codes and Standards," of 10 CFR Part 50 requires, in part, that pressure vessels which are part of the reactor coolant pressure boundary meet the requirements for Class A or Class 1 vessels set forth in Section III of the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code.

This guide defines materials and testing procedures acceptable to the AEC Regulatory staff for implementing these criteria with regard to reactor vessel closure stud bolting[1] for 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 ASME Boiler and Pressure Vessel Code, Section III, "Nuclear Power Plant Components,"[2] and Section XI, "Rules for Inservice Inspection of Nuclear Reactor Coolant Systems,"[2] specify certain requirements associated with reactor vessel closure stud bolting. This regulatory guide supplements the requirements of the ASME code.

High-strength low-alloy reactor stud bolting may be obtained through closely controlled quenching and tempering procedures on grades of steel such as American Iron and Steel Institute (AISI) 4140 and 4340 (Ref. 1). These steels are approved by the ASME as bolting materials and are listed under Section II, "Material Specifications,"[2] of the ASME Code as SA-540 Grade B-23 and B-24 bar, SA-193 Grade B-7 bar, SA-320 Grade L-43 bar, and SA-194 Grade 7 (nuts for bolting). Additional requirements supplementing these basic materials specifications are found in SA-614 entitled "Specification For Special Requirements for Bolting Materials For Nuclear and Other Special Applications." Proper control of the tempering procedure is necessary to obtain the desired balance of

[1] Closure stud bolting is defined to include all studs (stud bolts), nuts, and washers used to fasten the pressure vessel head to the pressure vessel.

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

mechanical properties. The above-mentioned stud materials when tempered to a maximum tensile strength of 170 ksi (Ref. 2) are relatively immune to stress corrosion cracking (SCC). Above this strength level the alloy becomes increasingly susceptible to SCC. Therefore, design conservatism should be exercised in determining the sizing of the studs so that the minimum specified strength level of the material selected will not result in a measured ultimate tensile strength exceeding 170 ksi.

Use of martensitic stainless steels such as the 11-13% chromium grades should be avoided for reactor stud bolting applications. These steels (Ref. 3) require more closely controlled conditioning parameters than do carbon and low-alloy steels. Small variations in heat treatment can cause large increases in hardness and tensile strength with a corresponding decrease in corrosion resistance and fracture toughness. The tensile properties of this class of material are extremely sensitive to tempering temperatures in the 900°-1200°F range and somewhat sensitive to variations in the austenitizing treatment. Another shortcoming of this material is temper embrittlement which may result during cooling through the 750°-1000°F temperature range. Certain tempering treatments can also produce alloy compositional gradients within the structure which can strongly affect service life because of a reduction in strength and resistance to corrosion. Although martensitic stainless steels are more resistant to general corrosion, they are less resistant to stress corrosion cracking than are carbon or low-alloy steels.

It is important that bolting material possess adequate toughness throughout the reactor operating cycle. For high-strength large-diameter bolting, unusual care must be taken to assure adequate fracture toughness. Control of the tempering procedure is very important for this purpose. Fracture toughness for the AISI 4340 steel as measured by energy absorption can be moderately increased through appropriate metallurgical practices. Reactor vessel closure studs and nuts should have a Charpy V energy of 45 ft-lb or greater (Ref. 4).

Thread roots of bolts are areas of high stress concentration and are preferential sites for crack initiation. It is therefore necessary for the bolting material to possess adequate toughness so that failure will not initiate in the stud thread configuration and that if cracks are initiated, they can be readily detected by inservice inspection before they reach critical size.

Suppliers of nuclear steam systems for pressurized water reactors recommend that the vessel closure stud bolts be removed prior to raising the water level during refueling or other operations involving vessel head removal. The same suppliers also provide and recommend the use of seal plugs for insertion into the pressure vessel flange stud holes to protect against corrosion and contamination following stud removal. Provided the seal plugs are properly used and the stud bolting is maintained in an area which is free from corrosion and contamination, the above recommended procedure provides adequate protection for the stud bolting following head removal. This procedure also permits the inservice inspection to be performed on the bolting when it has been removed from the pressure vessel.

The inservice inspection as specified in Section XI, "Rules for Inservice Inspection of Nuclear Reactor Coolant Systems," of the ASME Code should be supplemented with regard to examination of the closure stud bolting. Visual and surface examinations (Ref. 5) may fail to reveal unacceptable defects, especially if the studs are examined in an untensioned condition. For these types of examinations, the reliability may be increased by examining the studs in a stud-tensioning fixture. Volumetric examination by conventional ultrasonic techniques may be difficult to perform, and the results may be inconclusive because of the chamfered ends, the recess for the lug wrench, and the threaded surfaces on the stud bolts. A technique[3] has been developed in which a transducer is lowered into the stud bolt center hole and an ultrasonic radial scan is used for the ultrasonic examination. Such a radial scan technique could be an improvement over the axial scan ultrasonic method and could increase the confidence in the inservice inspection for the determination of flaws in the thread region of the stud bolts.

Many different plating materials are available to protect reactor stud bolts and nuts from galling (Ref. 6) and corrosion; however, in certain applications, the plating can be more detrimental than helpful. Metal-plated bolts can be susceptible to fracture of the plating in the root of the thread after a short period of bolt and nut engagement. Moisture accumulation in the area of coating discontinuities can cause corrosion. The electrolytic plating process may produce hydrogen which can become entrapped in the parent metal structure and cause embrittlement. A potential combination of hydrogen in the base metal, natural notches in the bolt thread, moisture in the environment, and high stresses in the material is an ideal condition for cracking. Metallic coatings can be prone to seizing between the bolts and nuts and make bolt disassembly difficult. Examination of failed stud bolts in the LaCrosse Boiling Water Reactor (LACBWR) and Yankee Rowe has shown severe galling associated with silver-plated stud bolts and also severe corrosion damage in the thread root of the stud bolts.

Replacement stud bolts in Yankee Rowe which had a manganese phosphate surface treatment in

[3]A study being conducted at the Southwest Research Institute concerning the ultrasonic testing of the LaCrosse Boiling Water Reactor pressure vessel closure stud bolting.

combination with MoS_2 as a lubricant demonstrated superior resistance to galling when compared to the original silver-plated stud bolts. The manganese phosphate surface treatment provides only mild protection against corrosion and contaminants, and therefore the stud bolts require additional protection during venting, filling, flooding, or unusual exposure of the reactor vessel.

Because of the items mentioned in the above discussion and in order to gain the necessary assurance that the reactor pressure boundary will operate in a safe manner, some of the additional material and inspection requirements as referenced in this guide are more stringent than those stated in Section III of the ASME Code and those of Appendix G, "Fracture Toughness Requirements," to 10 CFR Part 50.

C. REGULATORY POSITION

1. Bolting Materials

a. Reactor vessel closure stud bolting should be fabricated from materials which have adequate toughness throughout the life cycle of the reactor. Stud bolting should meet the requirements set forth in Subsection NB, "Requirements for Class 1 Components," Section III of the ASME Code. Bolting materials should meet the requirements of one of the following ASME specifications:

(1) SA-540 Grade B-23 and B-24 bar (AISI 4340).

(2) SA-193 Grade B-7 bar (AISI 4140, 4142, 4145).

(3) SA-194 Grade 7 (nuts for bolting) (AISI 4140, 4142, 4145).

(4) SA-320 Grade L-43 bar (AISI 4340).

b. The requirements of the specification in paragraph C.1.a. should be supplemented by the following:

(1) The maximum measured ultimate tensile strength of the stud bolting material should not exceed 170 ksi.

(2) Charpy V impact testing should be performed according to ASME SA-370, "Methods and Definitions for Mechanical Testing of Steel Products," and to be acceptable, the results must satisfy the requirements of Paragraph IV.A.4. of Appendix G to 10 CFR Part 50.

In case a test fails, one retest may be conducted according to subsubarticle NB-2350 of Section III, ASME Code.

(3) Stud bolting should not be metal-plated unless it has been demonstrated that the plating will not degrade the quality of the material in any significant way (e.g., corrosion, H_2 embrittlement) or reduce the quality of results attainable by the various required inspection procedures. The stud bolting may have a manganese phosphate (or other acceptable) surface treatment. Lubricants for the stud bolting are permissible provided they are stable at operating temperatures and are compatible with the bolting and vessel materials and the surrounding environment.

2. Inspection. The nondestructive examination of the stud bolts and nuts should be performed according to subsubarticle NB-2580 of Section III of the ASME code as supplemented by the following:

a. The stud bolts and nuts should be ultrasonically examined after final heat treatment and prior to threading.

b. The ultrasonic examination (paragraph NB-2584) should be conducted according to ASME Specification SA-388, "Ultrasonic Examination of Heavy Steel Forgings."

c. The calibration standard used to establish the first back reflection for the ultrasonic testing should be based on good sound representative material. To assure that the material is representative, the selection of the standard should be based on a preliminary ultrasonic examination of a number of specimens (a minimum of three per standard).

d. The magnetic particle or liquid penetrant examination (paragraph NB-2583) should be performed on the studs and nuts after final heat treatment and threading.

e. The requirements of paragraph NB-2585 should be applied to all closure stud bolts and nuts.

3. Protection Against Corrosion. During venting and filling of the pressure vessel and while the head is removed, the stud bolts and stud bolt holes in the vessel flange should be adequately protected from corrosion and contamination.

4. Inservice Inspection. The inservice examination of the pressure vessel stud bolting should be performed in accordance with the requirements of Section XI of the ASME Code as supplemented by the following:

a. The inservice inspection should include a surface examination which should be in accordance with paragraph NB-2545 or NB-2546 of Section III of the ASME Code. For this inspection the studs should be removed from the pressure vessel.

b. Selection of the bolting material for each required inservice inspection should be based on a representative sample and on a reasonable geometric distribution.

REFERENCES

1. Aerospace Structural Metals Handbook, Code 1206, Vol. 1, "Ferrous Alloys," Syracuse University Press.

2. J. H. Gross, "The Effective Utilization of Yield Strength," Transactions of the ASME, Paper No. 71-PVP-11.

3. "ASM Metals Handbook," Vol. 2, p. 245-248, 1964.

4. "PVRC Recommendations on Toughness Requirements for Ferritic Materials," Welding Research Council Bulletin No. 175, p. 14-16, August 1972.

5. A. G. Pickett and H. C. Burghard, Jr., "An Investigation of the Failure of LACBWR Pressure Vessel Closure Studs," Southwest Research Institute SWRI-2154-20, December 1971.

6. R. L. Scott and P. H. Harley, "Failure of Threaded Fittings and Fasteners at Nuclear Facilities," Nuclear Safety, Vol. 13, No. 1, Jan-Feb. 1972.