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CONF-760514--1

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INTERNAL-BORE-WELDING OF 2 1/4 Cr-1 Mo STEEL TUBE-TO-TUBESHEET JOINTS*

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SUMMARY

The most critical weldments in an entire steam supply system for a Liquid Metal Fast Breeder Reactor (LMFBR) are those which join the steam generator tubes to the tubesheets. These welds are particularly important in the LMFBR because of the severe consequences of interaction between the two working fluids — sodium and steam. Traditionally, the tube-to-tubesheet connections have been made by passing the tubes through the tubesheet and making a fillet weld on the face side. Although this face-side welding technique is economical and generally reliable, it has the disadvantages of producing a weld which is difficult to inspect by radiography and containing a long crevice between the tube and tubesheet which may serve as a site for localized corrosion or crack initiation during service. The latter is true even if the width of the crevice is minimized by mechanical or explosive expansion of the tube inside the hole.

In order to avoid these disadvantages of the conventional face-side tube-to-tubesheet weld, the steam generators for the Clinch River Breeder Reactor Plant (a power-producing demonstration LMFBR) will be built using a relatively new technique known as internal-bore-welding (IBW). In IBW the tube does not pass through the tubesheet but rather is welded to a short stub machined on the tube side of the tubesheet. This joint has the important advantages of being inspectable

*Research sponsored by the U.S. Energy Research and Development Administration under contract with Union Carbide Corporation.

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by radiography and eliminating the crevice; however, it is much more difficult to weld than is the face-side design. Because of the close proximity of the tubes, there is not room for an orbiting-arc welding head on the outside of the tube. Consequently, this weld must be made by welding from the inside- or bore-side of the tube. This paper will present the results of the initial phases of a program undertaken at ORNL to develop improved bore-side welding equipment, to gain further understanding of this technique, and to develop mechanical property data for autogeneous welds in 2 1/4 Cr-1 Mo steel tube and tubesheet materials.

Because of the geometry of the tube stubs on the tubesheets, there is considerable concern about the number of inclusions in the tubesheet forgings, their orientation, and their behavior during welding. Although it is likely that forgings from vacuum-arc remelted (VAR) ingots will be used for CRBRP, we are including forgings from ingots made by three commercial melting practices: air melted (AM), electroslag remelted (ESR), and VAR. Our initial work has been on AM and ESR material as they were more readily available. To date, we have not observed any difference in welding behavior between these two materials.

Although there was a considerable effort in the development of the internal-bore-welding technique about 5 years ago by a number of steam generator manufacturers, this work was done on approximately 1-in.-diam tubing rather than the 5/8-in.-OD × 0.112-in. wall tubing that will be used in the CRBRP. Because of the small bore of this tubing, the feeding of filler wire (as was done in previous work) is not practicable so that autogeneous, full-penetration welds are required. A procedure has been developed for making this weld using a commercially obtained internal-welding head, which was modified to fit the smaller tube size and to allow a straight tungsten electrode to be used rather than the bent electrodes normally used. We have evaluated the following procedural variables on welding behavior and quality: (1) gas pressure, (2) gas composition,

(3) ceramic tape backing, and (4) preweld cleaning methods. All welds are made in the 5G (tube horizontal) position. The evaluation of the welds is by visual examination both internally and externally (primarily for bead contour and protrusion), by radiography using a new rod anode inserted inside the tube (for subsurface defects) and by metallographic sectioning to verify NDT results and to study the weldment microstructure. The effect of all of these variables will be discussed in the paper.

In general, we have found that gas pressure (the difference between internal and external pressure) is a critical variable as far as bead geometry is concerned. Our welding fixturing includes a slant-tube differential manometer that is used for controlling the pressure differential. We have found that a difference of 0.8 in. of water is optimum, resulting in root reinforcement of about 0.005 in.

We have evaluated both Ar and Ar-He mixtures for shield gas inside the tube and Ar and Ar-CO_2 mixtures for backing gas. We obtained considerable improvements in weld penetration with the Ar-He shield gas and got full penetration at lower currents. This is very important when using this technique as it minimizes thermal damage to the welding tip. An Ar—20% CO_2 mixture in a copper sleeve on the outside of the tube gave smoother bead contour, required a lower welding current, and did not produce any more internal defects than pure argon.

We have had limited success with one type of commercial ceramic tape used to date; however, we are obtaining other tape samples and the results of our evaluation of these materials will be included in the paper.

Our cleaning program has included both solvents such as acetone and a HNO_3-HF-H_2O solution. To date, we have found no improvement in weld quality (based on our visual and radiographic examination) by switching from the solvent to the acid cleaning technqiue. Accordingly, we would recommend the solvent cleaning method as it is much simpler.

We have conducted a preliminary study to determine the response of weldments in both AM and ESR material to variations in postweld heat treatment temperature. Sections of two welds were given 1-hr treatments in vacuum at temperatures of 1150, 1250, 1350, and 1450°F, and microhardness traces were made across the weldments into the base metal. In the as-welded condition the fusion zones were considerably harder than the base metal with the ESR fusion zone about 30 DPH harder than the AM. The hardest area in both types of material was in the HAZ near the fusion line in which the hardnesses were greater than 325 DPH as compared to base metal hardness of about 150.

Additional samples were welded for mechanical property tests, which include room- and elevated-temperature tensile, high-cycle fatigue and tube-burst tests. The results of all of these tests will be presented in the paper.

The significance of this work is that it compares 2 1/4 Cr-1 Mo steel material made by different melting practices and the response of these materials to variations in welding procedure and postweld heat treatment. The welds themselves, and thus the mechanical property data, are of interest because they were made autogeneously rather than with filler metal additions, which is more common for this alloy. Finally, the paper gives a fairly complete treatment of the internal-bore-welding technique itself, what equipment and fixturing are used, and what variables seem to have the greatest effect on weld behavior and quality.