Callaway is a 1228-MWe pressurized water reactor near Fulton, Mo. (Photos: AmerenUE)

Modified temperbead welding requirement results in shorter outage at Callaway

Data and technical support from EPRI helped expedite a critical pressurizer repair project at AmerenUE's Callaway plant.

BY STEVE MCCRACKEN AND DAN STEPANOVIC

TO REDUCE OUTAGE duration, nuclear plants continually strive to perform repairs more quickly and efficiently, while meeting or exceeding safety and design requirements. AmerenUE has sought to apply this philosophy at Callaway, a 1228-MWe pressurized water reactor near Fulton, Mo. In the case of a structural weld overlay project on pressurizer nozzles to mitigate primary water stress corrosion cracking (PWSCC), plant staff considered new approaches that would save outage time. By teaming with the Electric Power Research Institute (EPRI) to develop the technical justification, AmerenUE received regulatory approval to modify the requirement for a 48-hour waiting period between the application of a temperbead weld and the subsequent inspection. This reduced the overall outage duration by 17 hours and kept personnel radiation exposure for the overlay project to about 14 rem.

Pressurizer repairs to address PWSCC typically involve temperbead weld overlays, applied through the methods specified in ASME Code Case N-638-1. In the temperbead process, welding beads are deposited in controlled patterns so that each successive bead provides heat tempering for the

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layer below. Temperbead welding avoids the need for post-weld heat treatment, an impractical tempering method for large components installed in the plant.

The N-638-1 temperbead rules require a delay of 48 hours after the entire weld is completed and cooled to ambient temperature before the start of nondestructive evaluation (NDE) of the weld. The intent of the delay is to provide sufficient time for any hydrogen cracking or cold cracking to occur before performing the final NDE of the weld overlay and surrounding area. The requirement for post-weld cooling, however, created a substantial cost burden to the involved utilities from the revenue loss associated with a prolonged refueling outage.

Committed to reducing outage duration, the Callaway weld overlay team submitted a relief request to the U.S. Nuclear Regulatory Commission to implement the methods of N-638-1 with a modification to the 48-hour hold requirement that would not relax safety, reliability, or structural integrity. Rather than starting the 48-hour hold time after the completed overlay weld reached ambient temperature, Callaway proposed starting the 48-hour hold after the completion of the third layer over the nozzle low-alloy steel base material.

Although ASME Code committees had passed a new code case (N-638-3) allowing

A quality control check of a weld overlay on a spray nozzle

A nozzle after the application of several weld overlays

the 48-hour hold to start sooner, the NRC had not granted any utility relief in this area. The NRC requested additional technical information from AmerenUE to address concerns regarding microstructural issues, sources for hydrogen introduction, tensile stress and temperature, and diffusivity and solubility of hydrogen in steels.

Support for starting clock sooner

The Callaway weld overlay team turned to EPRI for expert assistance in satisfying the NRC's request for information. EPRI and the industry had performed extensive research in the 1980s and 1990s related to temperbead welding on low-alloy steel and the effects of the welding on the microstructure, hardness, and toughness of this material. Through the Welding and Repair Technology Center (W&RTC), formerly the Repair and Replacement Applications Center, EPRI provides technical data to support the application of temperbead welding in nuclear power plants, and also works with industry to develop new ASME Code rules to extend temperbead welding to a broader range of applications.

W&RTC researchers directly addressed the NRC's concerns by compiling an extensive body of research results and field experience to provide the technical justification for starting the 48-hour hold following the completion of the third temperbead weld layer over the nozzle base material. The study findings are detailed in the EPRI report, *Repair and Replacement Applications Center: Temperbead Welding Applications—48-Hour Hold Requirements for Ambient Temperature Temperbead Welding* (1013558). The report addresses each of the NRC's technical concerns in detail, with the responses summarized as follows:

Microstructure: EPRI research determined that the temperbead welding process on low-alloy steels, such as the pressurizer nozzles, produces a heat affected zone (HAZ) microstructure with sufficient toughness and minimal hardness to make it resistant to hydrogen delayed cracking (sometimes referred to as cold or hydrogen induced cracking). The HAZ microstructure in the low-alloy steel, after three layers of temperbead welding, is tempered martensite or tempered bainite, with high toughness and a maximum hardness at a distance of 2 to 3 mm (80 to 120 mils) below the fusion line of less than 280 to 300 Knoop hardness number (28 to 30 Rockwell C hardness). The threshold for hydrogen delayed cracking occurs at a Rockwell C hardness of 36 or greater. In addition, after the completion of the third temperbead weld layer, the maximum temperature observed in the low-alloy steel HAZ is 900 °F, well below the low-alloy steel critical transformation temperature. This observation

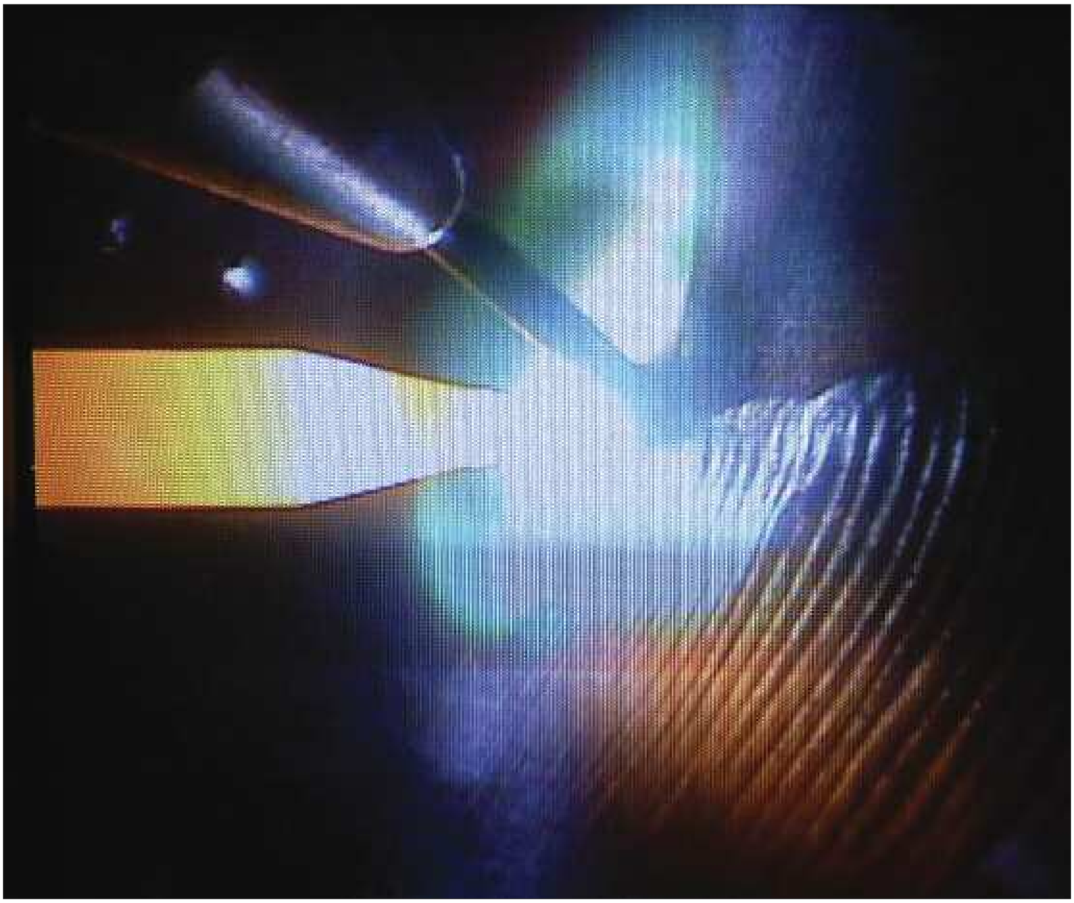
A spray nozzle after the weld overlay is completed

A geometry check being carried out on a completed nozzle

indicates that additional welding after the third layer will not produce a retransformed and untempered HAZ microstructure susceptible to hydrogen delayed cracking. Consequently, the HAZ in the low-alloy steel beneath the weld overlay after the third layer is not susceptible to hydrogen delayed cracking because of the tough tempered microstructure and low hardness.

Hydrogen introduction: The introduction of diffusible hydrogen during the welding process can cause hydrogen delayed cracking in a HAZ microstructure with low toughness and high hardness. Hydrogen can be introduced into the weld area from various sources, including moisture; a poor grade of shielding gas; drawing compounds; contaminated base metal; and lubricants, coatings, or paints inadvertently in contact with the weld wire. EPRI research results demonstrate that the introduction of deleterious levels of diffusible hydrogen is unlikely with the gas tungsten arc welding (GTAW) process. Hydrogen delayed cracking, therefore, is not probable when the GTAW process is employed with adequate cleanliness controls.

Tensile stress: Hydrogen delayed cracking occurs in low-alloy steels at ambient temperatures under conditions of high localized tensile stress in microstructures with low fracture toughness and high hardness, such as untempered martensite. High



Arc welding in progress

restraint conditions combined with the localized distortion and shrinkage that occurs in the weld area during the heat cycles of welding can promote high tensile residual stress. If this high residual stress occurs in a low-alloy steel HAZ with low toughness and high hardness, such as untempered martensite, hydrogen delayed cracking is possible. Conversely, if the fracture toughness in the HAZ exceeds the induced tensile residual stress, the microstructure is not susceptible to cracking. EPRI research demonstrates that the temperbead welding process produces a HAZ microstructure in the low-alloy steel that exhibits high toughness with adequate resistance against hydrogen delayed cracking. Finally, a review of experience in the nuclear industry reveals no cases of hydrogen delayed cracking in low-alloy steels where temperbead welding procedures were used.

Hydrogen in steel: The diffusion rate of hydrogen is greater in ferrite (i.e., low-alloy and carbon steel materials) than in austenite (i.e., austenitic stainless steel and nickel alloy materials). Furthermore, the solubility of hydrogen is approximately five times greater in austenite than in ferrite, and seven to eight times greater in austenite than in martensite. Consequently, during welding at high temperatures, hydrogen that may have been introduced into the weld will diffuse out of the low-alloy steel and into the austenitic overlay weld metal, which is essentially immune to hydrogen delayed cracking. The hydrogen will then remain in the austenitic weld metal and not diffuse back into the low-alloy HAZ due to the lower diffusion and higher solubility of hydrogen in an austenitic microstructure. Furthermore, during temperbead welding, and during installation of non-temperbead weld layers, temperatures are sufficiently high for hydrogen to diffuse out of the low-alloy steel HAZ by either escaping to the environment or diffusing into the austenite, where it can be held in much greater quantities.

On the whole, the study found no technical basis for waiting 48 hours after cooling to ambient temperature before the start of NDE of the completed weld. The report also noted that more than 20 temperbead weld overlays have been applied to nuclear power plant low-alloy steel nozzles and more than 100 temperbead repairs have been made to other low-alloy steel components. The initial overlays have been in service for more than 20 years, and NDE inspections performed after the 48-hour hold and during subsequent in-service outages have found no indication of hydrogen cracking.

Saving time, reducing exposure

The W&RTC study and assistance enabled AmerenUE to gain the NRC's permission to modify the 48-hour hold requirements of N-638-1. By using the modified requirements, Callaway personnel eliminated approximately 17 hours of critical path refueling outage time, while successfully implementing six pressurizer nozzle-to-safe-end piping weld overlays with no recordable indications (inspection readings that might indicate flaws). These 17 hours were integral to the schedule success of the pressurizer weld overlay project and other refueling outage activities.

Callaway achieved a significant dose reduction as well. AmerenUE originally estimated personnel exposure at 26 rem. With the 48-hour hold modification, Callaway was able to remove the informational NDE tests that would have been performed in the original 48-hour hold window, which helped reduce the final personnel exposure for the pressurizer overlay project to a total of about 14 rem. NN