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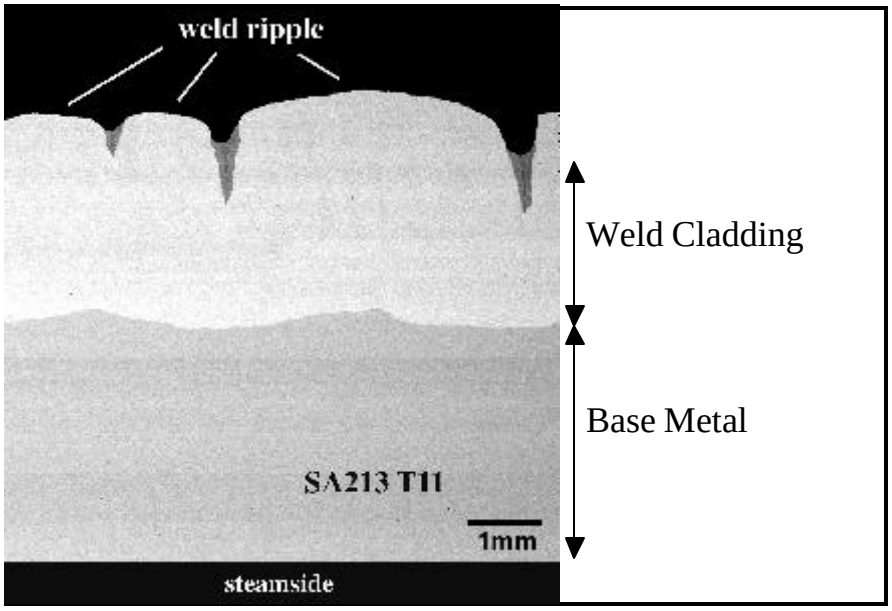
LEHIGH RESEARCHERS STUDY CRACKING OF WELD OVERLAY COATINGS

Since the early 1990's, U.S. utilities have been making major modifications to their fleets of coal-fired boilers to comply with NO_x regulations. In many cases, this involved installation of low NO_x burners and overfire air registers, often resulting in oxygen deficient regions in the vicinity of the burners. Some of the coal-fired utility boilers, which were converted to low NO_x operating conditions, subsequently experienced increased rates of waterwall corrosion. In response, some utilities turned to weld overlay coatings for corrosion protection. In 1998, reports began drifting back to the ERC that some boilers with weld overlay coatings were experiencing circumferential cracking of coated waterwall tubes. Since then, researchers at the Center have been working to determine why these coating failures are occurring.

The materials research team, led by Drs. Arnold Marder and John DuPont has been studying coatings for boiler tubes for more than a decade. Their work has included investigations into the mechanisms of waterwall corrosion and the effects of furnace conditions and alloy composition on corrosion rate. They have looked at different types of coatings, including weld overlay, thermal spray and chromized. Their research has included laboratory experimentation, laboratory evaluation of tube specimens obtained from the field, and computer simulations.



Cross Section View of Circumferential Cracks in a Weld Cladding

As part of this activity, they recently completed a research program that evaluated the corrosion resistance of commercial weld overlay coatings in a range of oxidizing/sulfidizing environments and various slag compositions. With these results they were able to better define the corrosion mechanism in low NO_x boilers through accelerated tests that included cyclic gas experiments. They have also looked at the stresses and strains which arise during the application of weld overlay coatings. Teaming with Dr. Herman Nied, a specialist in stress analysis and fracture mechanics, they investigated the effects of welding procedures on the quality of the weld overlay coating and on the potential for waterwall tube panel buckling.

In 1998, the group obtained five tube samples from three utilities, all with Inconel 625 weld cladding. Laboratory analysis showed the weld clad coatings were not visibly thinned, but they did contain longitudinal and circumferential cracks which were quite severe on four of the five tubes. The cause of the longitudinal cracks was attributed to improper welding procedures and recommendations were made on ways of avoiding these types of cracks.

The circumferential cracks found across the weld cladding are of greater concern since they are related to boiler operating environment. These ranged from

minor to very severe, with almost half the circumferential cracks having fully penetrated the cladding, and in some cases, into the tube material beneath the cladding. Detailed chemical analysis showed each circumferential crack contained a sulfur "spine" which extended all the way down to the crack tip.

Comparison of cracks to those found in an earlier study of chrome moly low-alloy boiler tube steels showed a striking similarity. In the 1989 study, the materials group characterized circumferentially cracked low alloy steel tubes retrieved from service in several pulverized coal boilers. There were approximately 20 to 25 circumferential cracks per inch. Just as with the cracks recently found in weld overlay claddings, each crack was filled primarily with an iron oxide corrosion product, but each also possessed an iron sulfide "spine" running down to the crack tip.

According to Marder, "Our research suggests the circumferential cracks are caused by a combined process of corrosion and thermal fatigue. Stresses in the tube walls can be caused by temperature gradients, resulting from fluctuations due to slag falls, sootblower operation and changes in the flame. These stresses are magnified, in some cases, due to a thermal expansion mismatch between the cladding material and the base metal. In general, corrosion can be caused by both oxidation and sulfidation mechanisms. However, sulfidation is a more severe factor in coal-fired boilers because of the role which the sulfur plays in the crack propagation process. Susceptible locations on the cladding surface act as thermal stress concentrators and are potential sites for crack initiation and propagation. Corrosive sulfur species diffuse to the crack tip and react with the steel alloy at the tip. This weakens the alloy and permits continued growth of the crack with time."

DuPont adds, "Now that we think we know the causes of cracking of weld clad coatings, we are continuing our studies to determine why some weld overlay coatings experience circumferential cracking and others don't. Some coating alloys are obviously more susceptible to corrosion attack. There may also be some features of the weld overlay process which lead to initiation of corrosion induced cracking. Our goal is to be able to specify which alloys to use and how to perform the welding process to minimize the potential for failure."

Marder adds, "Based on discussions with our utility sponsors, we've developed proposals for two new research projects that we think will help power companies cope with waterwall degradation in low NO_x boilers. One project, "Development of Low Cost Weld Overlay Coatings for Low NO_x Waterwall Tubes," will apply material design principles to develop low cost core wire compositions for weld overlay coatings. The other project, "Remaining Life Assessment of Circumferentially Cracked Weld Overlay Coatings" will estimate remaining life of circumferentially cracked tubes as a function of stress level, coating composition and corrosion environment. Together, these two programs will enable utility companies to overcome the circumferential cracking problem found in certain existing weld overlay coatings and apply a new generation of low cost weld overlay coatings for the more stringent requirements expected in the future." •

For more information on weld overlay coatings research, please contact Dr. Arnold Marder at (610) 758-4197 or arm0@lehigh.edu.