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NEW GENERATION OF COATINGS WILL EXTEND BOILER TUBE LIFE

Boilers operating with low NO_x burners present unusually harsh environments for power plant materials. In particular, a change from normally oxidizing conditions in a standard boiler to reducing conditions in a low NO_x boiler, causes usually protective oxides to give way to severe wastage by sulfidation corrosion and erosion. This change, driven by new government regulations for reduction of NO_x emissions, has caused high rates of deterioration and, on occasion, early catastrophic failure of major boiler components such as waterwalls and burners. Investigators in the Energy Research Center are developing and evaluating several new coatings for use in boilers — coatings which will help prevent early failure of waterwall tubes. The ERC team is headed by Dr. Arnold R. Marder, Associate Director of the ERC and Professor of Materials Science and Engineering and John N. DuPont, Research Engineer in the Center.

Marder and DuPont's research on boiler tubes has been in progress for the last 10 years. Starting with a project to determine the cause of circumferential cracking in waterwall tubes, they proposed that coatings be used to prevent the initial corrosion step in the cracking degradation process. That program led to further research on various types of coatings, including chromized coatings and commercial thermal sprays. They've since expanded their effort to include weld overlays, metal matrix composite (MMC) thermal spray coatings, and electrodeposited diffusion coatings. This work deals with both commercially available coatings as well as some new coatings still in the development stage.

Graduate student Steve Banovic is using a Environmental Scanning Electron Microscope to examine the microstructure of an electrodeposited coating.

Electrodeposited Intermetallic Coatings

One way to protect boiler tubes against corrosion is to apply a thin layer of pure chromium. In an oxidizing environment, the chromium layer forms a protective oxide layer which prevents deterioration of the underlying steel tube. The process has been commercially available for several years and it has met with good success in conventional boiler conditions. Several years ago, Dr. Marder and his students studied the chromizing process to determine how to apply a chromium layer to a tube to optimize its properties as a corrosion control coating. This work led to the eventual development of a new type of coating—intermetallic aluminide— which can be applied by a low cost electro-deposition process.

The process involves codeposition of metallic elements onto the tube at room temperature in an electrodeposition bath. Upon exposure to the moderate temperature of the boiler, the metals diffuse to form a corrosion resistant intermetallic coating without affecting the underlying tube properties. Unlike other types of diffusion coatings, the time required for coating formation is short, there is no decarburization or other interaction with the underlying steel substrate and distortion is not a factor because the application occurs at room temperature.

The electrodeposited diffusion coatings effort has produced nickel aluminide coatings with superior high temperature corrosion resistance. Preliminary results show that in oxidizing environments an electrodeposited nickel aluminide coating experiences negligible oxidation. Further work is now underway to determine how well other aluminide coatings withstand low NO_x conditions.

Weld Overlay Coatings

A second method of protecting tubes involves welding a layer of material onto the surface of the steel tube. The advantage of welded coatings is that they can be applied to the surface of the boiler tubes in the boiler as well as in a shop, without the usual penalties. However, selection of proper weld alloys and control of the weld overlay process conditions are critical to producing coatings with the desired properties. The Lehigh effort involves studies to find the best way of applying a welded coating in weld overlay applications. To do this, the welded coatings are being evaluated both in the laboratory and in the field in utility boilers.

The coatings being studied include stainless steels, superalloys and newly developed iron aluminides. With the help of welding rod producers, Stoody, Lincoln Electric and McKay Welding Products, preliminary results have produced a comparative ranking of the performance of coatings subject to both erosion and corrosion attack. In addition, weldability studies have been completed which also rank coating alloy fabricability.

Laboratory studies with weld overlay coatings show that some types of weld overlays exhibit superior corrosion protection. Although sulfur-rich scales formed on the weld surfaces, there was no significant penetration of corrosion into the overlay. X-ray dot mapping results, which can be used to reveal the distribution of elements in the scale, indicate a protective scale is responsible for the outstanding corrosion resistance. Preliminary field results of selected weld overlays in a commercial fossil fired boiler indicate a significant improvement over every commercial coating previously tried by that utility. However, this type of coating presents problems with induced residual stresses and tube warping. A research project to determine the extent of the problem and evaluate potential solutions has recently been proposed (see accompanying article).

Thermal Spray Coatings

In the application of a thermal spray coating, a metal powder is heated to a high temperature and propelled toward the boiler tube surface with a high velocity gas or plasma jet. Once at the surface, the particles form a coating. Thermal spray coatings have the advantage of being applied in-situ in the boiler and as a consequence, they are more easily repaired after exposure. However, these coatings do not metallurgically bond to the boiler tube substrate and, therefore, they run the risk of flaking after exposure to corrosion and erosion attack or due to thermal cycling. Previous studies of thermal spray coatings have shown corrosion of the underlying boiler tube is dependent on the density and structure of the coating. In the present effort, FeCrAlY - Cr_3C_2 (Iron Craly-Carbide) and Fe-Al (Iron Aluminide) coatings have been evaluated for erosion control. Preliminary results show there is a critical amount of second phase, carbide and oxide, necessary in order to optimize the erosion resistance of these alloys. Furthermore, plasma spray and HVOF processes have also been compared and it has been shown that high velocity oxy fuel (HVOF) produces the most dense coating. Other comparison factors are presently being evaluated.

An Array of Laboratory Tools

The ERC team uses a wide-range of laboratory facilities to fully characterize and compare coatings. Processing facilities include an automated welding laboratory for developing weld overlay coatings and an electrodeposition laboratory for applying electrodeposited intermetallic coatings. The thermal spray coatings evaluated by the group are prepared by National Laboratories and commercial thermal spray vendors.

A state-of-the-art high temperature corrosion facility is used to evaluate materials in both sulfidation and oxidation corrosion environments. The corrosion laboratory facility includes a thermogravimetric (TG) corrosion test unit for quantitative kinetic studies and furnaces dedicated to sulfidation, oxidation and mixed environments. Of special value to the project is a unique Environmental Scanning Electron Microscope which makes it possible to directly observe high temperature corrosion and oxidation processes in real time under actual environmental conditions. The erosion resistance of coatings is measured in a special test facility specifically built for this application. This facility is capable of evaluating erosion velocities between 20 and 90 m/s (impact velocities are measured by a laser velocimeter), temperatures up to 500°C, a range of impact angles from 20° to 90°, and a variety of erodents from hard alumina particles to simulated fly ash.

Coating microstructures are characterized both before and after exposure in a boiler in the University's microscopy laboratories. These include light optical microscopy with quantitative image analysis for measurement of coating constituents, a variety of scanning electron microscopes for higher magnification of planar and cross-sectional analysis and several analytical electron microscopes for precise measurement of the chemical constituents in the coatings.

Consortium Approach

The Lehigh effort on boiler tube coatings is funded by a consortium of utility companies, coatings suppliers, National Laboratories and the Department of Energy. Industrial members of the consortium include: Allegheny Power System, Centerior Energy Corporation, Ohio Edison Company, Pennsylvania Power & Light Company, Public Service Electric & Gas Company, Virginia Power, Welding Services Incorporated and SprayMasters. Ames National Laboratory, Idaho National Engineering Laboratory and Sandia National Laboratory are all contributing manpower, equipment and facilities to the program. In addition, DOE is sponsoring three research projects associated with the coatings program. These include a project on iron aluminide weld overlay coatings sponsored by the Oak Ridge National Laboratory, a project on optimization of thermal spray coatings for erosion resistance sponsored by DOE, and a DOE equipment grant that made it possible to purchase the Environmental Scanning Electron Microscope.

A team of eight graduate research assistants is involved in the ERC coatings program. Boris Levin and Bruce Lindsley head up the effort in solid particle erosion. Kevin Luer, with six years of industrial thermal spray experience, has recently returned to Lehigh for post-graduate work and has joined Brian Schorr in the study of thermal spray coatings. Along with Megan Slusser, Kevin has assumed responsibility for the corrosion laboratory facilities. Jesse Nawrocki and Steve Banovic are working with John DuPont on the weld overlay coatings and Don Susan leads the effort in the electrodeposited diffusion coatings. •