

LEHIGH ENERGY UPDATE

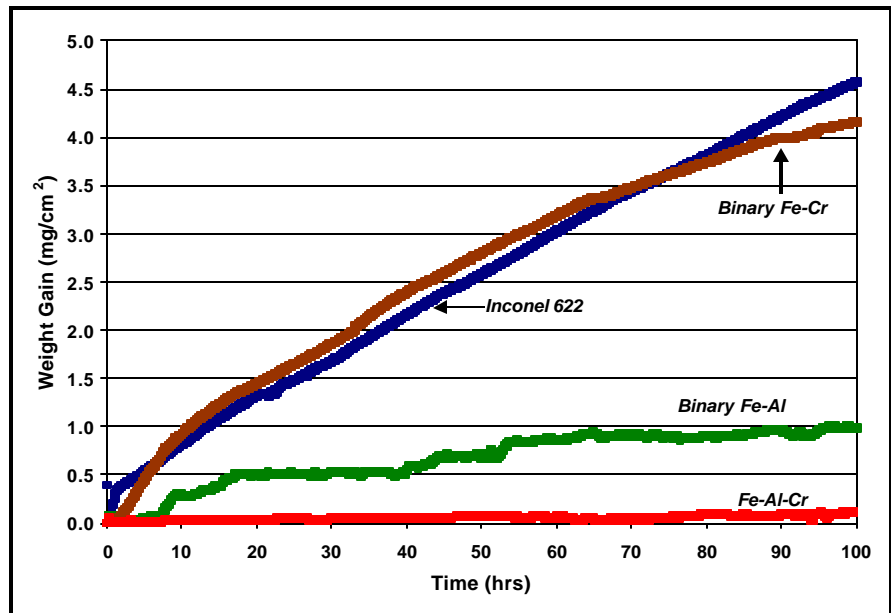


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MATERIALS RESEARCH AND PROBLEM SOLVING AT THE ENERGY RESEARCH CENTER

Proper selection and implementation of materials is important for maintaining acceptable levels of power plant availability. Forced outages can often be traced to use of the wrong material or improper fabrication or installation. Forced outages can also occur due to a change in operating conditions that renders a previously acceptable material unfit for the new conditions. The Materials Group at the Energy Research Center has been investigating materials problems for power generation companies for over 15 years and has developed a wide range of expertise and characterization tools geared towards power plant materials. Led by Professors Arnold Marder and John DuPont, the projects range from long term research in the areas of alloy development, welding, and corrosion, to short-term problem-solving activities.

High Temperature Corrosion. Over the last several years, the ERC has been particularly active in developing improved weld overlay coatings for corrosion protection in low NO_x boilers. Boilers operating with low NO_x burners present unusually harsh environments for power plant materials. A change in operating condition 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. The deposition of sulfur rich unburnt coal particles on the furnace wall exacerbates this problem even further.



Corrosion results of four weld overlay coatings exposed to a simulated low NO_x combustion gas. The Fe-Cr-Al alloy shows almost no corrosion.

Through sponsorship from a consortium of power generation companies, research has been conducted to identify commercially available alloys for use as corrosion resistant coatings. In this work, candidate alloys were exposed to a range of corrosion conditions. This included gaseous corrosion testing, to simulate direct metal attack by high temperature sulfur rich combustion gases, and solid state corrosion studies, which simulate wastage that occurs due to reactions between unburnt coal particles and the metal surface. The influence of cycles in both temperature and gas composition were also studied, since these can often have a strong influence on the corrosion mechanisms and corresponding wastage rates.

According to DuPont, "A wide range of laboratory facilities has been assembled for these evaluations. Processing facilities are available which include a completely automated welding laboratory for applying overlay coatings with any arc welding process. Laser facilities are also available for preparing laser clad coatings. A state-of-the-art high temperature corrosion laboratory has been constructed which contains two thermo-gravimetric balances. This unique equipment permits gaseous corrosion tests to be conducted at temperatures up to 1300°C in virtually any simulated combustion gas, and the temperature and/or gas composition can be cycled during the test. The equipment provides a quantitative plot of corrosion rates,

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which can be used to make direct comparisons between candidate alloys. Six high temperature corrosion furnaces are also included in the laboratory for long-term tests and for simulating corrosion which occurs due to reactions between unburnt coal particles and the metal surface. Coating microstructures are characterized in detail before and after testing using a variety of light optical and electron optical microscopes. These characterization tools permit direct identification of the corrosion products that, in turn, can be used to understand the mechanisms of corrosion responsible for the high wastage rates. Stainless steels and nickel base alloys have been evaluated under many different test conditions. This information is then used to formulate recommendations on coating selection based on what is known about the plant operating conditions.”

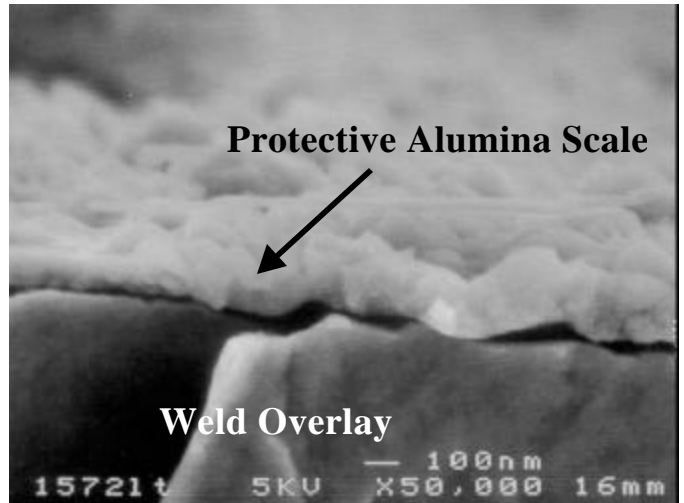
Marder adds, “The latest coating research project at the ERC is developing a low cost/high performance weld overlay that is specifically designed for corrosion protection in low NO_x conditions. The alloys currently being used by the industry were actually developed for other applications. For example, the nickel-based alloys such as IN622 and IN625 were originally developed for high temperature strength. As a result, they contain many additional alloying elements that add to the cost of the alloy and adversely affect corrosion resistance, weldability, or both. In addition, most of these alloys rely on the use of Cr as an oxide former, so they are expensive. Up to now, no attempt has been made to use all the information gained about the low NO_x operating conditions and associated corrosion mechanisms to design an alloy that specifically fits the intended need.”

Marder continues, “We are also developing FeCrAl alloys for corrosion resistant weld overlay coatings for low NO_x conditions. These alloys rely mainly on Al with only small amounts

of Cr for corrosion protection. Aluminum has been found to be a much more efficient oxide former than Cr under low NO_x conditions, so it provides much better corrosion protection. In addition, Al is much cheaper than Cr so that the alloys are less expensive. Small amounts of Cr (about 5%, compared to 20%

present in commercial alloys) are added to improve the corrosion resistance even further. The graph on Page 1 shows a typical example of recent progress in this area. This plot shows the weight gain as a function of time for four weld overlays – IN622, FeCr, FeAl, and a FeCrAl alloy. These tests were conducted in a mixed oxidizing/sulfidizing gas at 500°C, and the slopes of the curves give an indication of the corrosion rate. A large weight gain indicates the material is being corroded rapidly. Note that the IN622 and FeCr overlays have the highest corrosion rates. The corrosion rate is significantly reduced when Cr is replaced with Al, while the corrosion rate is negligible when both Cr and Al are added. Microscopic examination of the FeCrAl overlay showed that the excellent corrosion resistance can be attributed to the formation of a thin, protective alumina (Al₂O₃) layer on the alloy surface. Work is on-going to determine the optimal amounts of Al and Cr that are needed for good weldability and corrosion resistance in a variety of environments, and this work will include field installations.”

Welding of New Power Plant Alloys. Conventional 2.25Cr-1Mo steel (Alloy 22) is used extensively in power plants at metal temperatures up to approximately 700°C.



Scanning electron microscope photograph showing the protective alumina scale that forms on FeCrAl weld overlays.

Components fabricated with this alloy usually require welding during installation and in-service repair. Conventional Alloy 22 steel requires a post-weld heat treatment (PWHT) to improve the mechanical properties of the heat-affected zone (HAZ) and reduce susceptibility to hydrogen cracking. The PWHT step is typically time consuming and expensive. A new power plant steel, designated as Alloy 23 by the ASME code, has recently been developed in attempt to reduce or avoid problems associated with PWHT. This alloy has been reported to exhibit improved mechanical properties and resistance to hydrogen cracking relative to Alloy 22 even without the application of a PWHT. The weldability was improved by reducing the carbon content. The lower carbon level, however, decreases the strength. Therefore, the strength was improved by the addition of strong carbide-forming elements such as tungsten, vanadium, and niobium.

DuPont explains, “Although Alloy 23 exhibits good weldability and mechanical properties without a PWHT, there are still many applications which will require a PWHT during actual use. A PWHT will be required when the alloy is used above a certain wall thickness and diameter or when welded to an

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existing alloy steel that requires a PWHT. Current ASME welding codes apply the same PWHT schedules to each alloy. The implicit assumption with this approach is that the alloys respond similarly to the PWHT thermal cycle. However, the reduced carbon content and presence of strong carbide forming elements in Alloy 23 may cause significant differences in microstructural

evolution and resultant mechanical properties between the two alloys during PWHT. One of our research projects determined the effect of PWHT time and temperature on the hardness and microstructure of Alloy 23 so that PWHT schedules for this relatively new alloy can be optimized.

Our research showed that although the heat treatment response of the two alloys at 575°C is similar, Alloy 23 retains significantly higher hardness at all other times and temperatures compared to Alloy 22. High resolution electron microscopy results showed that this difference in heat treatment response was attributed to formation of fine carbides that do not form in Alloy 22. The PWHT data was translated into a master tempering curve by the use of a tempering parameter that permits estimation of the heat affected zone hardness for any combination of time and temperature. This curve can be used directly for selection of practical heat treating schedules.”

Problem Solving Activities. The Materials Group at the Energy Research Center also works with power plant personnel on short-term problem solving activities through the Energy Liaison Program (ELP). These interactions include literature reviews, short range test programs, third party reviews, materials section, and failure analysis.

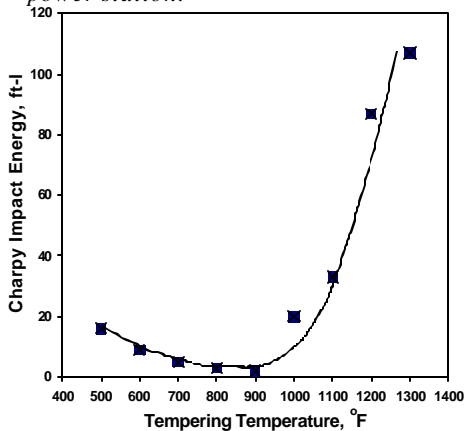
John Sale, Director of the Energy Liaison Program explains, “The major benefit of working through the Energy Liaison Program on a materials problem is to take advantage of the group’s knowledge base and research equipment to obtain quick answers to practical problems in the plant. For example, the Materials Group worked with personnel from a nuclear power station to determine the cause of failure of shaft couplings from a vertical circulator water river pump. These couplings were constructed from quenched and tempered martensitic stainless steel and were considered safety-related in the nuclear industry.”

DuPont continues, “Examination of the fracture surface using scanning electron microscopy indicated that the coupling failed in a brittle, intergranular manner. Charpy impact testing showed that the coupling material exhibited an impact toughness of only 10 ft-lbs, which is significantly less than the value of 90 ft-lbs normally expected from this material. A series of heat treatments and metallographic examinations were conducted to demonstrate that the material experienced a significant reduction in toughness due to temper embrittlement that was caused by use of an improper heat treating temperature. The test data showed the impact toughness of the coupling material is reduced significantly due to temper embrittlement when the steel is tempered in the range of 600 to 1,000°F. The brittle, intergranular fracture mode of the impact test samples matched the fracture surface observed on the shaft coupling, thus confirming that failure of the coupling occurred due to temper embrittlement. The results we obtained also provide useful practical information for selecting heat treating temperatures needed to avoid this problem, since tempering above approximately 1200°F reverses the embrittlement and restores impact toughness.”

DuPont adds, “Problems associated with materials can be isolated incidents specific to a particular plant, or they can be industry-wide problems. We have had much success in finding solutions to both kinds of problems for the network of utility sponsors we work with. We feel our group is rather unique in its ability to find practical solutions for industry. We are able to do this because of the knowledge we have generated from our research, our understanding of power plant operations and the wide range of materials characterization equipment in our laboratories.” #



Photograph of a failed shaft coupling from a vertical circulator water river pump that operated at a nuclear power station.



Charpy impact energy as a function of tempering temperature for martensitic stainless steel used to fabricate shaft couplings. Impact toughness is reduced significantly due to temper embrittlement when the steel is tempered in the range of 600 to 1000°F.

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RESEARCHERS' PROFILES

- **Dr. Carlos Romero** is an Associate Director of the Energy Research Center with a Ph.D. in Mechanical Engineering. He is a specialist in combustion kinetics and emissions control.
- **Dr. John DuPont** has a Ph.D. in Materials Science and Engineering and is an Associate Professor of Materials Science and Engineering at Lehigh. His research interests include welding metallurgy and process modeling, corrosion, and mechanical properties.
- **Dr. Arnold Marder** is Associate Director of the Energy Research Center and a Professor of Materials Science and Engineering. His research interests include processing-structure-property relationships in various coating systems.