B. Rapid Surface Modifications of Aluminum Automotive Components for Weight Reduction

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Objectives

- Further develop durability-enhancing coatings on steel for environmental protection and wear resistance.
- Develop a method to dramatically reduce the time required to cure an epoxy used to join automotive body panels.
- Develop a procedure for selective heat-treating of aluminum automotive body construction parts in order to soften selected areas to serve as built-in crumple zones.

Approach

- Fuse abrasion-resistant coatings in air to steel using the high-density infrared (HDI) plasma arc lamp.
- Use a focused tungsten halogen lamp line heater to rapidly cure epoxy used for joining body panels.
- Use the HDI plasma arc lamp to soften selected areas of extruded aluminum tubes used as automotive frame rail structures.

Accomplishments

- Successfully fused onto steel abrasion-resistant coatings that show a reduction in porosity, an increase in hardness, and appropriate bonding characteristics.
- Successfully developed the tungsten halogen lamp line heater for the rapid curing of epoxy resin, a process currently being used on the production line at Ford.
- Developed heat flow models to determine the temperature profile during the pulsing of extruded aluminum tubes with the HDI plasma arc lamp, making it possible to predict the degree of hardness reduction achieved.

Future Direction

- Further develop durability-enhancing coatings for the compression-ignition direct-injection (CIDI) exhaust gas environment to improve the corrosion and wear resistance of relevant components and accommodate the more aggressive environment of exhaust gas recirculation (EGR).
- Resolve accelerated corrosion and wear concerns associated with EGR, especially the use of coatings to prolong the life of critical components such as the intake manifold and EGR valves.
- Use the HDI plasma arc lamp for rapid surface modification of discrete areas to eliminate fatigue-related problems in cast aluminum engine blocks.

Introduction

Three research projects were associated with FY 2002. The first one encompassed the further development of durability-enhancing coatings; this work was performed in conjunction with Caterpillar. Caterpillar was looking for a way to fuse abrasion-resistant coatings to steel with appropriate densities, hardness, and bonding strengths. The HDI plasma arc lamp was used to achieve the required properties. These coatings are potential candidates to enhance the life of exhaust gas components. Because a larger amount of exhaust gas must be combined with the intake mixture to reduce emissions, components such as EGR valves and intake manifolds will see accelerated corrosion and wear. The abrasion-resistant coatings are able to withstand the more severe environment, thus protecting the steel components from premature failure.

The second research project was an effort to reduce the curing time of automotive body filler epoxy. Ford wanted to replace the joining material for body panels with a one-component epoxy, but curing the epoxy took too long for the production line. A focused tungsten halogen lamp line heater was developed at ORNL to help reduce the curing time. Implementing use of the line heater allowed a 2-min reduction in cycle time, eliminated five grinding steps, provided a safer, more environmentally friendly process, reduced energy consumption, and saved $28 per vehicle.

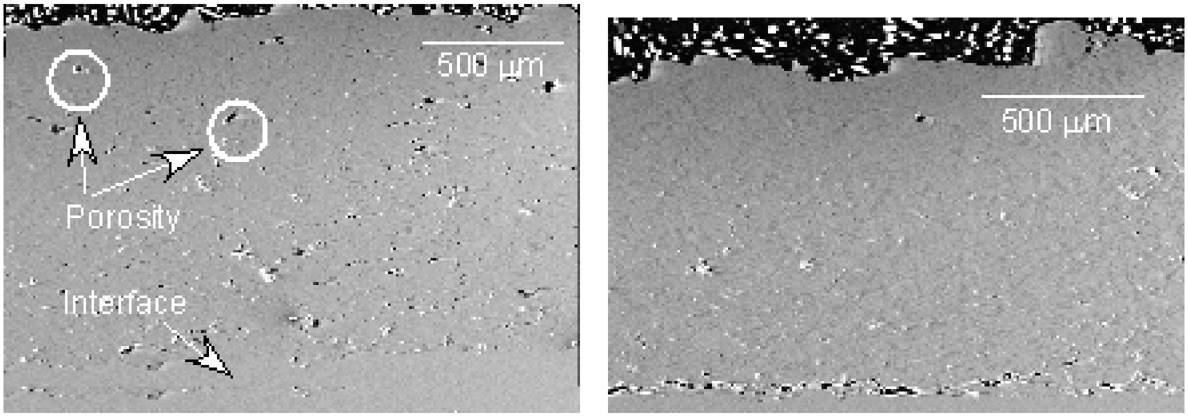
The third project involved working with Ford on preferential heat treating of extruded aluminum tubes intended for use as automotive frame rail structures. The preferential heating was performed to introduce crash triggers so that the structure would collapse on itself in a controlled manner during impact. Using the HDI plasma arc lamp, it was possible to selectively soften the essential areas, eliminating the need to introduce the crash triggers mechanically and thus reducing cost. The introduction of aluminum frame rail structures can lead to a significant reduction in the weight of the vehicle, increasing the fuel efficiency.

Results

Abrasion-Resistant Coatings

Caterpillar was interested in evaluating the capability of the HDI plasma arc lamp to fuse abrasion-resistant coatings to steel components. The essential purpose of these coatings is to increase the wear resistance and corrosion resistance of components exposed to exhaust gases, such as EGR valves and intake manifolds. One of the coatings the company was interested in was an Fe-Cr-B-Mn-Si wire arc-sprayed coating. Caterpillar's main concerns were associated with the porosity and the hardness of the coating and the bonding characteristics of the coating to the substrate. Experiments were conducted by varying the arc lamp's reflector geometry, amperage (i.e., power density), and pulse or exposure time. The lamp processing parameters were optimized to obtain the desired coating properties.

It was shown that there was a significant reduction in porosity, increased coating hardness, and adequate metallurgical bonding. The micrographs in Figure 1 reveals a cross-sectional view of a coating, pre- and post-processing. It was also shown that altering the processing parameters could vary the degree of mixing between the substrate and coating. This research demonstrates the plasma arc lamp's capability to rapidly fuse coatings in an air environment. This capability leads to a very robust fusing technique that makes it



(*a*) (*b*)

Figure 1. Scanning electron microscope micrographs of a cross section of an abrasion-resistant coating on a steel substrate: (*a*) pre-processed by the HDI plasma arc lamp (note the porosity) and (*b*) post-processed by the plasma arc lamp, revealing the densification of the coating.

suitable for high production volumes, ideal for automotive components in the EGR system and combustion chamber.

Rapid Curing of Automotive Body Filler Epoxy

Ford was interested in replacing a welding process for joining body panels with a one-component epoxy. The specific joint to be considered was a welded seam in the C-pillar of the Lincoln LS vehicle. Ford wished to eliminate steps associated with the production of the body to reduce cost. The process being used was operator-dependent and thus susceptible to quality concerns and throughput issues. The major challenge was to develop a process that used a one-component epoxy and a procedure for curing the epoxy in a timely manner.

Ford pursued a collaboration with ORNL to develop a method to rapidly cure the epoxy seam on the C-pillar, since it was not cost-effective to heat the entire component to elevated temperatures to cure the epoxy. After several methods to heat the seam were investigated, the focused tungsten halogen lamp line heater showed the most promise as a robust heating system. It was able to cure the epoxy in approximately 20 s. The line heater is capable of going to full power in less than 1 s and is 90% efficient in converting electrical power to radiant power. Its inherent properties make it ideal for industrial applications. Ford was able to realize a $28-per-vehicle savings by using the epoxy filler with the line heater curing method, as well as a 2-min reduction in cycle time. Figure 2 shows the line heater lamp on the production line and the joint after the curing process.

Preferential Heat-Treating of Aluminum Tubes

In an effort to reduce the overall weight of an automobile, Ford has been investigating the use of aluminum for the frame rail structure. One of the main purposes of this assembly, located in the front portion of the body, is to absorb energy during an impact. To do so, its structure must collapse in a certain sequence. This process is accomplished by built-in crash triggers, which are points along the structure that allow the structure to collapse and deform in a controlled manner.

Currently, front frame rail structures are manufactured from steel. Replacing steel with 6063 aluminum alloy would result in considerable weight savings. Extruded square aluminum tubes are more cost-effective than stamped aluminum because of their lower tooling costs. However, it is easy to build crash triggers into stamped aluminum during the manufacturing process; that is not the case for extruded aluminum tubes. Therefore, the HDI plasma arc lamp was used to soften (i.e., reduce the hardness of) selected areas along the aluminum tube to eliminate the need to introduce crash triggers mechanically.

(*a*) (*b*)

Figure 2. The line heater lamp on the production line curing an epoxy seam (*a*) and the seam after the curing process (*b*).

Experiments were performed at ORNL to determine the necessary plasma arc lamp parameters to achieve the required reduction in hardness. It was shown that the required 50% hardness reduction could be reached. From these experiments, a heat flow model was developed to optimize the process, and a microhardness map was developed to determine the required hardness reduction along the profile of the tube. Tubes are currently being pulsed according to the optimized process and will be sent to Ford for crumple test evaluation. Figure 3 shows the crumple test setup.

Microstructural evaluation of the 6063 T-6 aluminum specimens revealed that Mg_2Si precipitates had gone back into solution in regions that had been heat-treated. The microstructure farther away from the heat-treated zone resembled that of the overaged condition, a dense Mg_2Si precipitate matrix with precipitate-free zones at the grain boundaries. The micrographs in Figure 4 show these two regions.

Summary

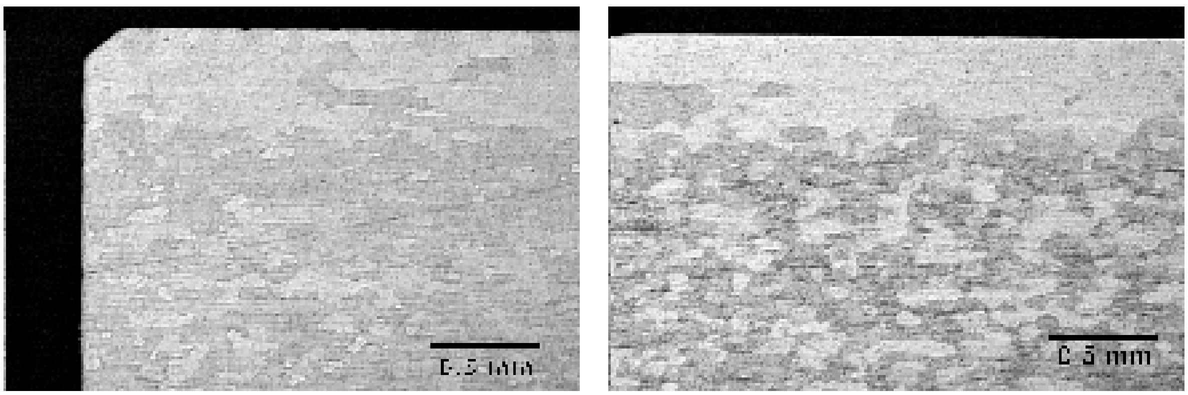
Work is ongoing in the area of abrasion-resistant coatings for steel and aluminum components. The plasma arc lamp has shown great promise for processing these coatings for numerous applications. Work also continues on the preferential softening of the aluminum frame rail structure tubes. Aluminum tubes that have been heat-treated by the plasma arc lamp will be crush-tested at Ford to evaluate the optimal heat-treating process. Ford officials believe that this is a viable technology and has a real chance to be implemented into production.

The HDI plasma arc lamp has shown promise in depositing wear- and corrosion-resistant coatings on steel substrates intended for the gaseous oxidant environment of the exhaust gases. The coatings produced by this method have shown promising properties in regard to adherence to the substrate, reduction in porosity, and mechanical strength. They can be deposited quickly in an environment suitable for high production volumes, such as the automotive industry. This process has been shown to be an ideal technology for producing protective coatings to reduce emissions.

Presentations

R. D. Ott, C. A. Blue, A. S. Sabau, T. Y. Pan, and A. M. Joaquin, "Preferential Softening of 6063-T6 Aluminum Alloy Utilizing a High Density Infrared (HDI) Plasma Arc Lamp," The Minerals, Metals & Materials Society Fall Meeting, 2002.

Figure 3. An aluminum tube undergoing a crumple test.



(*a*) (*b*)

Figure 4. Micrographs of the (*a*) heat-treated region and (*b*) non-heat-treated region of 6063 T-6 aluminum. Notice the lack of grain definition in the heat-treated region compared with the non-heat-treated region. This is due to the dense Mg_2Si precipitate matrix resembling that of the overaged condition.