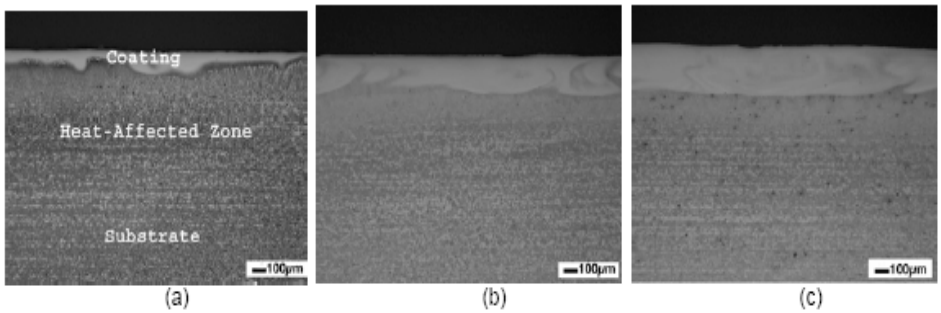
Industrial Technologies Program

High-Energy Density Coating of High-Temperature Advanced Materials for Energy-Efficient Performance

Improvement over Conventional Surface Modification Techniques in Wear, Oxidation, and Corrosion Resistance

Surface engineering consists of technologies and processes designed to modify surface properties of metallic and non-metallic components. Surface modification techniques are critical for many industrial components such as hydro turbines, continuous steel casting rolls, and auto engines because they improve corrosion and wear resistance, extending the life of useful components. Longer availability of equipments, in turn, enhances the industrial processing efficiency. Also, surface modification techniques result in cost savings because they involve modifying metal substrates instead of developing bulk alloys. The development of bulk material is time consuming and expensive. Conventional surface modification coating techniques include physical vapor deposition, chemical vapor deposition, thermal spray, and weld overlay techniques. However, conventional coating techniques produce coatings with physical and chemical properties that restrict their use to a limited number of applications (e.g., coatings are seldom able to withstand high service temperatures >500°C). Furthermore, they are costly and time consuming. There is a critical need to develop more suitable, reliable, and cost-effective coating techniques.

This project developed the technique and material systems for coatings on ferrous (steel) and nonferrous (aluminum) structural alloys for high-temperature wear and corrosion applications. A high-energy-density Laser- and Plasma-Infrared-Assisted Surface Modification (LPIASM) technique was developed to deposit ceramic-based titanium carbide (TiC) and titanium boride (TiB_2), and iron-aluminide (Fe-Al) intermetallic coatings on metal substrates. This project demonstrated technical feasibility and advantage of using LPIASM to coat metal substrates to improve their wear, oxidation, and corrosion resistance properties.



(a) (b) (c)

Cross-sectional optical micrographs of samples with Fe-Al alloy coatings prepared using 75 mole % Al precursor coating and a laser power of (a) 1250 watts, (b) 1500 watts and (c) 1750 watts. Samples were etched with 2 vol. % Nital solution.

Benefits for Our Industry and Our Nation

- Extend industrial component life
- Enhance industrial processing efficiency
- Potential energy savings of up to 250 trillion Btu/year
- Cost savings

Applications in Our Nation's Industry

The project will benefit the following industries and their components:

- Hydropower (water turbines)
- Chemicals (multiple components)
- Pulp & Paper (multiple components)
- Steel (continuous caster rolls)
- Glass (transfer rolls)
- Mining (equipment)
- Aluminum (die casting dies)
- Automotive (cylinder liners)

Project Description

The goal of the project was to improve energy efficiency by extending the life of industrial components through a surface modification technique based on high-energy laser and infrared (IR) plasma lamp.

Barriers

Industrial components and their materials often experience extreme mechanical, thermal, and chemical loading conditions and are expected to perform effectively for extended periods. The performance of these materials can be extended via surface modification technology. Conventional coating techniques commercially available produce limited technical and commercial success. There is a critical need to develop surface modification techniques that are suitable for large components and varied field applications.

Pathways

The objectives were accomplished by performing the following tasks:

Task 1: Surface Enhancement

- Developed laser coating and IR coating technologies for advanced materials
- Created technologies to use advanced materials for enhancing surfaces of industrial components

Task 2: Microstructural and Compositional Characterization

- Characterized the physical appearance of the coating, coating depth, and porosity
- Performed microstructural characterization of the coating region, interface and heat-affected zone
- Analyzed the distribution of solute elements in and adjacent to the interface region
- Performed detailed phase analysis of the coated sample
- Conducted computational modeling for evolution of phases during coating

Task 3: Wear, Oxidation, and Corrosion Behavior Evaluation

- Performed mechanical tests such as hardness and wear tests
- Performed corrosion and oxidation tests including high-temperature oxidation tests

Task 4: Assessment and Report Preparation

- Reviewed project data and recommendations for future direction

Results

This project achieved the following results:

- Developed reliable, efficient, and economic surface modification technique, LPIASM
- Demonstrated feasibilities for intermetallic coatings on structural steel (AISI 4340), and ceramic coatings on ferrous and nonferrous metals
- Obtained coatings free of porosity and cracks
- Demonstrated that coated materials improved wear resistance by 2-4 times, oxidation resistance by 2 times, and surface hardness by 1.5-3 times over the bulk material ultra-high strength 4340 steel and 6061 aluminum alloy
- Demonstrated improvement in corrosion resistance of coated sample compared to the substrate
- Studied coating microstructures to understand their improved response to the chemical (corrosion and oxidation) and physical (hardness and wear) stress as function of processing parameters
- Configured LPIASM coating technique to process the components of various surface geometries
- Achieved various thermal conditions ranging from equilibrium to near- or non-equilibrium to tailor the microstructure, and both chemical and physical properties of the coatings

Commercialization

Companies operating in the global economy are striving to extend the lives of old plants and systems by engineering better forms of surface treatment of inexpensive materials to provide accurate, repeatable, and uniform properties. The concept of extending component life through service and repair is rapidly growing and becoming accepted practice. The high-energy-density processing tools such as laser and IR plasmas stand in the midst of these developments and offer tremendous potential for this purpose. Although there are commercially available surface modification/coating techniques in the market, LPIASM holds a niche for producing more suitable, reliable, and cost-effective coatings. Currently, there is no patent on LPIASM technology therefore it is available for usage in agreement with Oak Ridge National Laboratory (ORNL) and University of Tennessee. There are several efforts underway to commercialize various components of the technology.

Project Reports

This project was completed in December 2004. The final report can be found on the Industrial Technologies Program Web site: http://www.eere.energy.gov/industry/imf/completed_rd.html.

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Weyerhaeuser Company
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A Strong Energy Portfolio for a Strong America

Energy efficiency and clean, renewable energy will mean a stronger economy, a cleaner environment, and greater energy independence for America. Working with a wide array of state, community, industry, and university partners, the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy invests in a diverse portfolio of energy technologies.

U.S. Department of Energy
Energy Efficiency and Renewable Energy

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