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**CRADA FINAL REPORT**

**ADVANCED ABRASION RESISTANT MATERIALS FOR MINING**

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## **FINAL CRADA REPORT**

### **ADVANCED ABRASION RESISTANT MATERIALS FOR MINING**

#### **ABSTRACT**

The high-density infrared (HDI) transient-liquid coating (TLC) process was successfully developed and demonstrated excellent, enhanced (5 times higher than the current material and process) wear performance for the selected functionally graded material (FGM) coatings under laboratory simulated, in-service conditions. The mating steel component exhibited a wear rate improvement of approximately one and a half (1.5) times. After 8000 cycles of wear testing, the full-scale component testing demonstrated that the coating integrity was still excellent. Little or no spalling was observed to occur.

#### **STATEMENT OF OBJECTIVES**

The main purpose of this Cooperative Research and Development Agreement (CRADA) between UT-Battelle (Contractor) and Caterpillar Inc. (Participant) was to develop the infrared processing technology as a processing method to enhance surface coating performance by improving the interfacial bond strength between selected coatings and substrates, and by producing fused coatings suitable for abrasion resistant, mining applications. The main objective of this project was to develop cost effective processes that permit the implementation of advanced abrasion resistant materials. The benefits sought by increasing wear component life were: 1.) 50% reduction in scheduled downtime; 2.) increased energy efficiency achieved due to a.) the reduced need for processing as many replacement parts, and b.) increased tool efficiency via abrasion resistant material selections; and 3.) reduced operating costs.

#### **SCOPE OF WORK**

To achieve the technical goals of this CRADA and to provide enhanced abrasion wear-resistance coatings for selected mining components, the scope of project work included developing infrared thermal processing parameters, utilizing the HDI/TLC process to provide high-density, metallurgically bonded coatings for selected substrates; and the transfer of this process technology to Caterpillar. Since some mine-related parameters cannot be suitably duplicated in laboratory tests, and since the actual fabrication of some components may present additional challenges, some prototype components were also prepared for field-testing. The following three tasks summarize the efforts undertaken in order to accomplish the overall objective of this project:

- Task 1: Infrared Process Development of Laboratory Scale Specimens;
- Task 2: Infrared Process Development for Prototype Components; and
- Task 3: Final Report.

## **BENEFITS TO THE FUNDING DOE OFFICE'S MISSION**

The key mission of the US DOE, Office of Energy Efficiency and Renewable Energy (EERE), Industrial Technologies Program, Industrial Materials for the Future program is to improve the energy efficiency and energy utilization in energy intensive US industries. The high-density infrared (HDI) transient-liquid coating (TLC) process developed under this CRADA provides a more energy-efficient materials processing technology than other materials processing alternatives. Actual energy benefits estimated to result from this technology development and industrial implementation include the following:

- 1.) a 50% reduction in scheduled downtime due to the extended wear-life performance by over 2X the previous life for wear-intensive components;
- 2.) increased energy efficiency resulting from the industrial implementation and use of the HDI/TLC process technology itself;
- 3.) improved energy efficiency resulting from the need for fewer replacement parts;
- 4.) increased tool efficiency and life through selective abrasion resistant material placement;
- 5.) reduced industrial operating costs.

## **TECHNICAL DISCUSSION OF WORK PERFORMED BY ALL PARTIES**

Caterpillar has, at its private expense, has been involved in developing hard-facing materials and coatings since the early 1970's. As part their on-going efforts to optimize these coatings for use in abrasion resistant, mining applications, a need was identified to develop materials processing technologies that would improve industrial energy efficiency while achieving fully dense coatings that are metallurgically bonded to their substrates. ORNL has developed the infrared processing technology (HDI/TLC) as a processing method that demonstrated enhanced surface coating performance by improving the interfacial bond strength between selected coatings.

For the laboratory-scale trials, Caterpillar Inc. provided thermally sprayed coated specimens of selected material combinations for ORNL to fuse and metallurgically bond these coatings to their substrates. ORNL conducted the IR processing development trials and developed the arc lamp processing parameters and process for fusing the selected coatings. The primary processing parameters investigated were arc lamp power consumption, lamp traverse rate, vibration frequency, and vibration power. Caterpillar conducted laboratory wear testing and subsequent material evaluations to analyze the performance of these coatings.

For the full-scale, coated, cylindrical components, Caterpillar provided a series of FGM coatings deposited onto carburized and hardened steel cylinders, which mimic machine components. All coatings were designed as functionally graded material (FGM) coatings so that the first layers metallurgically bonded to the substrate and would absorb solidification and coefficient of thermal expansion mismatch stresses, and the outer layers were designed to remain hard and wear resistant. ORNL developed a HDI fusing process and specific processing parameters to fuse 15 different FGM coatings onto full-scale cylindrical components. These FGM coatings were HDI fused with little or no cracking observed after IR fusing. Figure 1 illustrates an example of one of these coatings in the (a) as-thermally-sprayed, and (b) as HDI processed/fused conditions. Caterpillar performed material characterization on several of these specimens prior to wear testing to

evaluate and compare the effect of the IR processing on the microstructure and hardness response compared to their current processing. However, Caterpillar conducted wear testing first on the majority of IR fused, full-scale components, and subsequently characterized and analyzed these coatings after wear testing. Laboratory testing of full-scale components demonstrated a volumetric wear rate improvement of approximately five (5) times improvement over the current carburized and hardened surfaces. Figure 2 illustrates an example of the surface of the fused coatings (a) before the three-body-wear testing, and (b) after 7000 wear testing cycles. The mating steel component exhibited a volumetric wear rate improvement of approximately one and a half (1.5) times. After 8000 cycles of wear testing, the full-scale component testing demonstrated that the coating integrity was still excellent. Little or no spalling was observed to occur.

#### **SUBJECT INVENTIONS (As defined in the CRADA)**

The decision has been made to file a patent on accomplishments resulting from this CRADA. The preliminary title of this patent is "Fusing of Coatings by Infrared Light."

#### **COMMERCIALIZATION POSSIBILITIES**

Although this work is still considered by Caterpillar to be in the research and development stage, it is considered worthy of future time and monetary investments. An infrared arc lamp is being purchased for further research and development at the Caterpillar Technical Center. The installation of the arc lamp will provide the ability to optimize processing parameters to maximize product yield while minimizing overall process costs, requirements for industrial viability.

#### **PLANS FOR FUTURE COLLABORATION**

Similar fusing work will be performed at ORNL through a CRADA under the recently awarded DOE program entitled "Structurally Integrated Coatings for Wear and Corrosion." Efforts will be made to fuse coatings selected for wear and/or corrosion resistance to both ferrous and non-ferrous substrates in this program.

#### **CONCLUSIONS**

In summary, the high-density infrared (HDI) transient-liquid coating (TLC) process was successfully developed and demonstrated excellent, enhanced (5 times higher than the current material and process) wear performance for the selected functionally graded material (FGM) coatings under laboratory simulated, in-service conditions.

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UT-Battelle PI(s) are Gail Mackiewicz-Ludtka and Craig A. Blue.  
Participant(s) PI(s): D. Trent Weaver and M. Brad Beardsley

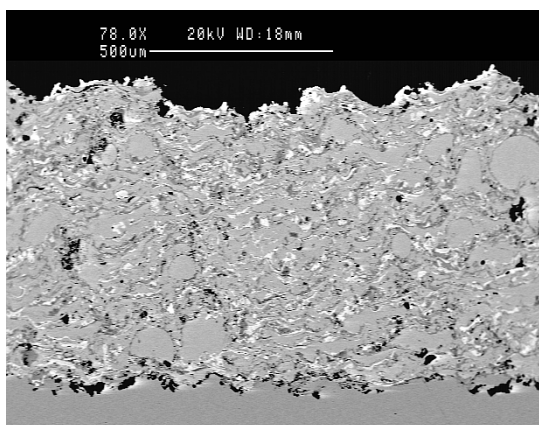
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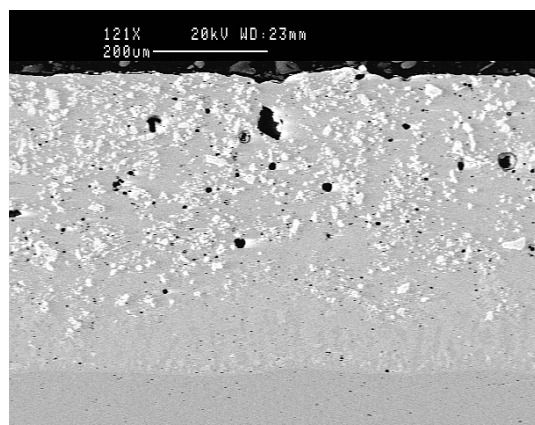
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(a)

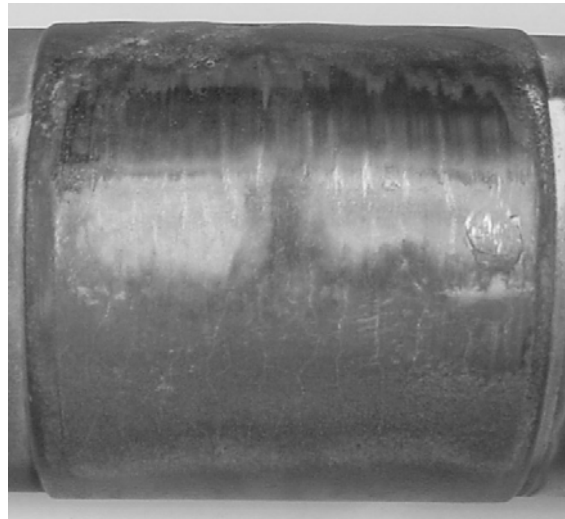


(b)

Figure 1. SEM images of coating cross-sections in the (a) as-thermal sprayed and (b) fused states.



(a)



(b)

Figure 2. Digital images of fused coatings on cylindrical substrates (a) before high-stress, three-body wear testing and (b) after 7,000 wear testing cycles. The coating shown in (b) provided approximately a 5X improvement in wear life over carburized and hardened steel.