the ENERGY lab

PROJECT FACTS

Hydrogen Turbines

Advanced Thermal Barrier Coatings for Operation in High Hydrogen Content Fueled Gas Turbines—Stony Brook University

Background

Traditional thermal barrier coatings (TBCs) based on yttria-stabilized zirconia (YSZ) will likely not be suitable in gas turbines used in integrated gasification combined cycle (IGCC) power plants. This is due to higher operating temperatures that will not only affect phase stability and sintering but will accelerate corrosive degradation phenomena. Coatings provide a framework to combat degradation issues and provide performance improvements needed for higher temperature environments.

The Center for Thermal Spray Research (CTSR) at Stony Brook University, in partnership with its industrial Consortium for Thermal Spray Technology, is investigating science and technology related to advanced, thermally sprayed, metallic alloy bond coats and ceramic TBCs for applications in the hot section of IGCC turbine power systems.

This project was competitively selected under the University Turbine Systems Research (UTSR) Program that permits academic research and student fellowships between participating universities and gas turbine manufacturers. Both are managed by the U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL). NETL is researching advanced turbine technology with the goal of producing reliable, affordable, and environmentally friendly electric power in response to the nation's increasing energy challenges. With the Hydrogen Turbine Program, NETL is leading the research, development, and demonstration of these technologies to achieve power production from high hydrogen content (HHC) fuels derived from coal that is clean, efficient, and cost-effective; minimizes carbon dioxide (CO_2) emissions; and will help maintain the nation's leadership in the export of gas turbine equipment.

Project Description

Recent research data indicate that the current bill of coating materials is not directly compatible with the moisture-rich, ash-laden environment present with coal-derived HHC fuels. Thus, Stony Brook University research focuses on a multi-layer, multifunctional strategy that includes discretely engineered coating layers to combat various technical issues through a concerted effort integrating material science, processing science, and performance studies, including recent developments in advanced, in situ thermal spray coating property measurement for full-field enhancement of coating and process reliability. This project will further the science-based understanding of TBCs and elevate the roles that processing and novel materials can play in extending bond coat and top coat lifetimes, and provide a new framework for examining the processing-performance relationship in multilayer thermal barriers as a pathway for reliable IGCC coating development, and provide new insight for the thermal spray industry.

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PARTNERS

None

PROJECT DURATION

Start Date	**End Date**
10/01/2010	12/31/2014

COST

Total Project Value
$517,035

DOE/Non-DOE Share
$401,238/$115,797

AWARD NUMBER

FE0004771

In this project, TBCs will be developed through investigation into how processing affects the oxidation behavior of metallic bond coats in water vapor environments, and by developing ceramic top coat architectures using thermal spray processing of emerging zirconate materials that have shown promise as advanced thermal barriers. Novel, in situ particle and coating state sensors will be used to accelerate process development and understand processing-microstructure relationships and process reliability. A systematic evaluation of multilayer coatings on nickel superalloys will determine properties (including microstructure, compliance, residual stress, thermal conductivity, and sintering behavior) and degradation mechanisms due to high-temperature water vapor and ash exposure as well as erosion.

Goals and Objectives

The overall objective of this UTSR project is to provide enabling science and technology for increased viability of thermal sprayed multilayer coatings (metallic alloys and ceramics) in IGCC turbine systems. To address the requirements for providing effective thermal protection in the hot gas path of moisture-rich, HHC fueled turbines, a multilayer coating architecture based on state-of-the-art materials is envisaged to combat the multiple degradation mechanisms. To accomplish this overall objective, the research will concurrently address individual component-level issues as well as system-level attributes, including:

- Evaluate oxidation characteristics of different types of bond coat materials in water-vapor-containing atmospheres in order to select the most viable material and processing condition.
- Develop processing strategies and maps for plasma spraying of emerging zirconate materials.
- Investigate the role of bond coat chemistry (i.e., rare-earth doping) and bond coat processing such as different types of high velocity oxygen fuel (HVOF) thermal spray and low pressure plasma spray on the processing-microstructure-performance linkages.

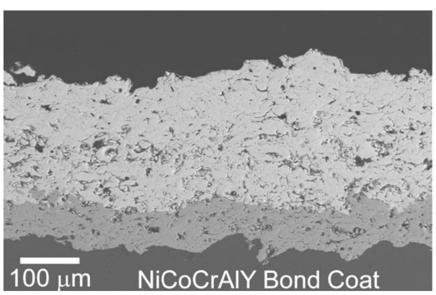

Figure 1. Cross-sectional scanning electron microscope image of the tri-layer TBC on NiCoCrAlY bond coated substrate.

- Consider single and multilayer top coats, in addition to the baseline YSZ system, incorporating an advanced zirconate composition as well as emerging co-doped compositions.
- Subject both individual components (bond coat and top coat) as well as assembled multilayers to isothermal and gradient exposures in water-vapor-laden high-temperature environments to assess the role of chemistry, micro-structure, and process induced states. Simulated erosion and chemical deposition studies will also be conducted to enable identification of both individual material performance (in its processed form) and performance of a multilayer assemblage.

Accomplishments

- Completed the process map for plasma spraying of gadolinium zirconate ($Gd_2Zr_2O_7$ [GZO]) with controlled mechanical properties (achieving process-enabled elastic moduli ranging from 13 to 34 gigapascals) thus facilitating the design of a compliant TBC.
- Optimized HVOF spray parameters for nickel-cobalt-chromium-aluminum-yttrium (NiCoCrAlY) and nickel-cobalt-chromium-aluminum-yttrium-hafnium-silicon (NiCoCrAlYHfSi) bond coats to minimize porosity and achieve a compressive residual stress state.
- Determined the Larson-Miller parameter for plasma-sprayed GZO as a function of spray condition in order to understand sintering kinetics and demonstrate that the material sinters more slowly than YSZ.
- Produced a multilayer TBC-YSZ/compliant GZO/dense GZO for initial industrial rig testing and ash exposure.
- Characterized the erosion resistance of GZO and compared it to that of state-of-the-art YSZ.
- Investigated the role of HVOF bond coat roughness on TBC life and developed processing strategies to address the same.
- Determined the fracture toughness of both TBC materials YSZ and GZO and also studied the thermal aging effects on the toughness of both.
- Identified durability strategy for bi layered YSZ coatings based on the parameters of fracture toughness and elastic modulus.

Benefits

This UTSR project supports DOE's Hydrogen Turbine Program that is striving to show that gas turbines can operate on coal-based hydrogen fuels, increase combined cycle efficiency by three to five percentage points over baseline, and reduce emissions. TBCs developed in this project will enable increased temperatures in IGCC turbines contributing to the efficiency goals of the program. Coatings are also an economic means to extend the life of expensive structure-critical superalloys used in IGCC turbines.

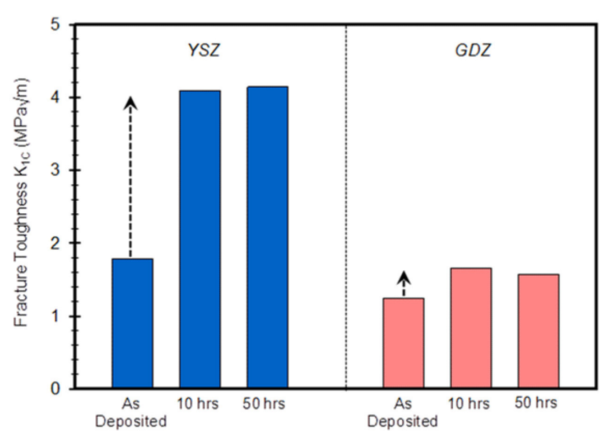

Figure 2. Measured Fracture Toughness of YSZ and GZO (Gadolinium Zirconate) coatings using Double Torsion Technique. It can be observed that with thermal aging, the measured toughness of YSZ coatings increased significantly, while that of GDZ did not increase as much. This could be attributed to the slower sintering rate of GDZ compared to YSZ. The fracture surfaces show the sintered interfaces after 50 hours of thermal exposure. This observation becomes critical while designing a TBC system comprising of the two different materials.