the ENERGY lab

PROJECT FACTS

Hydrogen Turbines

High Temperature Unique Low Thermal Conductivity Thermal Barrier Coating (TBC) Architectures—UES

Background

Gas turbine engines used in integrated gasification combined cycle power plants require higher operating temperatures for enhanced efficiency, lower emissions, and increased performance. Currently, the durability of the turbine engine components is achieved by the use of thermal barrier coatings (TBCs) consisting of yttria-stabilized zirconia (YSZ, six to eight weight percent) and/or by internal/external cooling. The current state-of-the-art TBCs (standard [Std.] YSZ) do not adequately protect the metallic components of turbine engines operating at higher TBC surface temperatures (greater than [>] 1200 degrees Celsius [°C]).

In order to enhance efficiency of the turbine engines for power generation, there is a need to develop TBCs for higher temperature applications. TBC materials (pyrochlore oxides, highly doped YSZ) having high temperature (>1300 °C) thermal stability, lower thermal conductivity, and sintering resistance do exist. However, these materials possess very low toughness and thereby exhibit higher erosion rates. UES, Inc. and Pennsylvania State University are involved in the development, characterization, and validation of unique TBC designs involving pyrochlore oxides and doped YSZ for high temperature applications.

This project was competitively selected under the Small Business Technology Transfer (STTR) Program and is 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 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

Two different materials have been selected for the development of higher temperature TBCs: (1) Pyrochlore oxides (specifically, gadolinium zirconate; $Gd_2Zr_2O_7$ [GZO]) and (2) Modified Std. YSZ through chemistry changes (doping). The overall technical approach of this project is focused on the development and evaluation of novel, multilayered/composite TBC design architectures consisting of GZO and doped YSZ for improved relevant characteristics (reduction in thermal conductivity, erosion rate and sintering rate). The Phase I technical approach involved fabrication, characterization, and performance evaluation of the multilayered and monolayered TBC architectures. Electron beam physical vapor deposition (EBPVD) was utilized to fabricate monolayered and multilayered TBCs of the selected materials. Phase II of the project involves

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PROJECT DURATION

Start Date	End Date
07/12/2010	02/14/2014

COST

Total Project Value
$849,938

DOE/Non-DOE Share
$849,938/$0

AWARD NUMBER

SC0004356

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optimization of microstructure and design of the multi-layered TBCs, as well as fabrication and evaluation of composite TBCs fabricated by EBPVD and cost effective atmospheric plasma spray (APS) techniques. Fabricated TBCs are characterized in terms of microstructure, thermal conductivity, erosion resistance, sintering resistance under thermal gradient condition and thermal cycling tests.

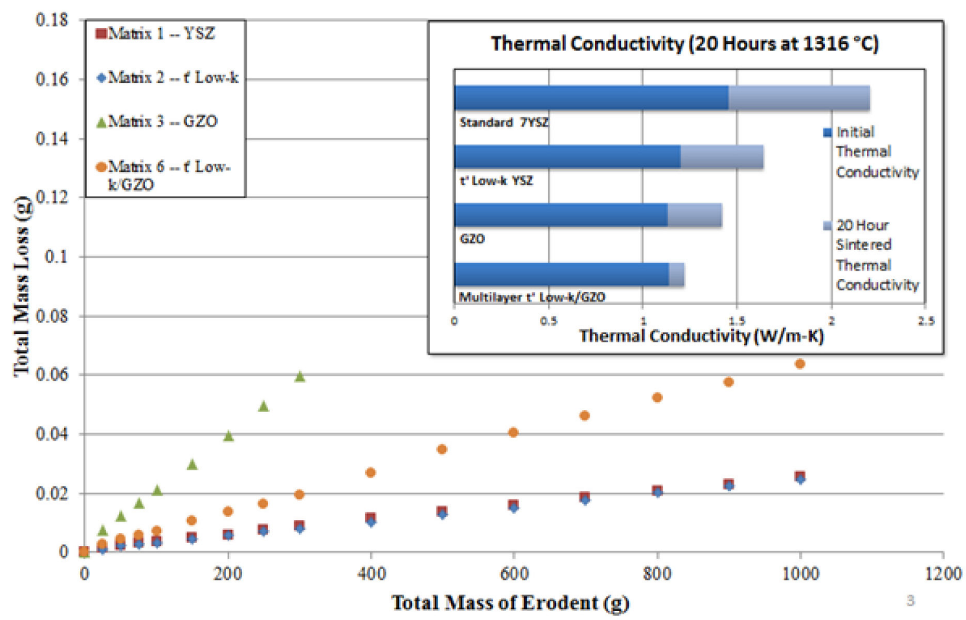
Goals and Objectives

The overall goal of this project is to develop novel TBC architectures that provide high thermal insulation (low thermal conductivity) and high erosion resistance without sacrificing strain tolerance.

Accomplishments

Phase I

- Successfully fabricated monolayered and multilayered EBPVD TBCs of selected materials namely GZO and doped YSZ. Monolayered Std. YSZ coating was also fabricated for comparison purposes.
- Demonstrated crystalline nature with columnar structure and faceted surface morphology of the as-fabricated mono-layered and multilayered TBCs.
- Demonstrated lower thermal conductivity of the as-fabricated monolayered GZO and doped YSZ TBCs compared to Std. YSZ TBC. It was also demonstrated that the thermal conductivity of GZO can be further lowered by multilayered design. Increase in thermal conductivity after 20 hours of test of the TBCs fabricated from the selected materials was found to be lower compared to the Std. YSZ.
- Demonstrated that the intrinsically higher erosion rate (lower erosion resistance) of GZO can be lowered considerably by the multilayered coating architecture.



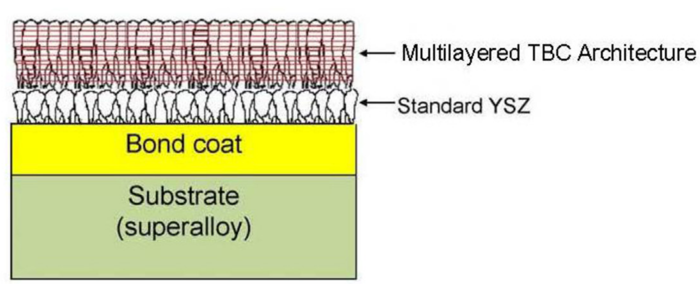
Multilayered (t' low k-GZO) TBCs, as compared to Std. YSZ, can provide lower thermal conductivity with very small increase after 20 hours of test under thermal gradient test at 1316 °C. Multilayered (t' low k-GZO) TBCs can also provide lower erosion rate compared to monolayered GZO.

Phase II

- Microstructural analysis of thermal conductivity samples revealed better high temperature sintering characteristics of selected TBC materials and multilayered coating architectures compared to Std. YSZ.
- Trend in the erosion rate of the high temperature annealed TBCs was found to be similar to as-deposited TBCs. Even for annealed samples, multilayered TBC architecture was able to considerably reduce the erosion rate of GZO.
- Further reduction in thermal conductivity of multilayered EBPVD TBC was achieved by microstructural manipulation.
- Modified multilayered coating design exhibited considerable sintering resistance up to 500 hours at higher temperature (>1300 °C).
- Composite and monolayered TBCs of selected doped materials were fabricated by cost effective APS technique.
- Erosion rates of composite APS TBCs scaled with the composition. Composite TBCs exhibited lower erosion rate than the monolayered coating of highly doped APS TBC.
- Composite TBCs of selected materials were also fabricated by EBPVD technique and are currently being evaluated.

Benefits

This SBIR 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. This project demonstrates that the multilayered TBC architectures of the pyrochlore oxide GZO and doped YSZ can enable the operation of gas turbine engines at higher temperature for higher efficiency and reduced emission.



One of the TBC architectures developed in Phase I.