the ENERGY lab
PROJECT FACTS
Hydrogen Turbines

Coating Issues in Coal-Derived Synthesis Gas/Hydrogen-Fired Turbines—Oak Ridge National Laboratory

Background

The Department of Energy (DOE) Oak Ridge National Laboratory (ORNL) is leading research on the reliable operation of gas turbines when fired with synthesis gas (syngas) and hydrogen-enriched fuel gases with respect to firing temperature and fuel impurity levels (water vapor, sulfur, and condensable species). Because syngas is derived from coal, it contains more carbon and more impurities than natural gas. In order to achieve the desired efficiency, syngas-fired systems need to operate at very high temperatures but under combustion conditions necessary to reduce nitrogen oxide (NO_x) emissions. ORNL's current project is focused on understanding the performance of high-temperature, corrosion-resistant coatings that protect superalloys, particularly in light of the high water contents expected for high-hydrogen-fired turbines. ORNL will define and address materials issues to maximize service lifetime of bond coats and thermal barrier coatings (TBCs).

This project is managed by the 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

For this project, ORNL has three tasks. The first task is to study the effect of higher water vapor contents during thermal cycling. Figure 1 shows the average TBC lifetime data for three specimens of each coating type at 1,150 degrees Celsius (°C) in dry oxygen (O_2) and air with 10, 50, and 90 percent by volume water vapor for two different types of diffusion bond coatings. Lifetime is being defined as the time to 20 percent spallation of the low thermal conductivity yttria-stabilized zirconia (YSZ) top coating of the TBC. The addition of water vapor had a dramatic effect on the platinum (Pt)-modified aluminide coating, especially with 10 percent water vapor, but no statistical effect on the average lifetime of Pt-diffusion coatings.

The second ORNL task is to quantify the benefit of adding yttrium (Y) and lanthanum (La) dopants to nickel (Ni)-base superalloys on TBC lifetime. Superalloy coupons were coated with nickel-cobalt-chromium-aluminum-yttrium (NiCoCrAlY) and NiCoCrAlY-hafnium-silicon (NiCoCrAlYHfSi) bond coatings using a thermal spray high velocity oxygen fuel (HVOF) process. Ten percent water vapor had a negative effect on coating lifetime at 1100 °C, but similar lifetimes were observed for the substrates with and without Y and La.

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PARTNERS

None

PROJECT DURATION

Start Date	**End Date**
10/01/2004	09/30/2013

(annual continuations)

COST

Total Project Value
$3,512,000

Base
DOE/Non-DOE Share
$3,512,000 / $0

AWARD NUMBER

FEAA070

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The third task is characterization of the microstructure and microchemistry of these TBC systems to assist in mechanistic understanding of the roles of dopants and water vapor on coating lifetime. The initial results have demonstrated that titanium (Ti) from the superalloy can diffuse through the NiCoCrAlYHfSi coating and become incorporated into the thermally-grown alumina (aluminum oxide) scale.

Goals and Objectives

The primary goal of this project is to evaluate high-performance airfoil coating architectures based on Y- and La-containing superalloys. Another key goal is to quantify and understand the role of elevated water contents on airfoil degradation. Advanced characterization techniques are being used to obtain a better mechanistic understanding of these phenomena.

Accomplishments

- Laboratory evaluations at ORNL are focusing on evaluating TBC specimens in different environments containing water vapor and CO_2 to determine their effect on performance.
- A CO_2-10% water vapor environment was not detrimental to TBC lifetime for diffusion bond coatings tested at 1150 °C. Thus, the lower CO_2 levels found in conventional or syngas-fired turbines are not likely to impact TBC performance.
- The effect of as-sprayed coating surface roughness on thermally-sprayed (metal) MCrAlYHfSi coatings was evaluated at 1100 °C. Rougher coatings (Ra~8) showed similar TBC lifetimes in 1-hour cycles in air with 10% water vapor as coatings with Ra~5. The performance in 100-hour cycles is now being evaluated.
- The TBC test matrix has included lower cost single-crystal superalloy substrates being implemented in current turbines including low-Rhenium (Re) second-generation alloys (N515) and Re-free first-generation alloys (1483). The higher Hf content in N515 resulted in longer TBC lifetimes, while the lower Al content in 1483 may have reduced their performance compared to conventional 3% second-generation alloys X4 and N5.
- Current alloy development is evaluating cast MCrAlYX compositions before fabricating coatings. Recent work has shown that combinations of Y and Hf or La and Hf result in improved oxidation resistance with less internal oxidation and no detrimental effect of Ti additions was identified.

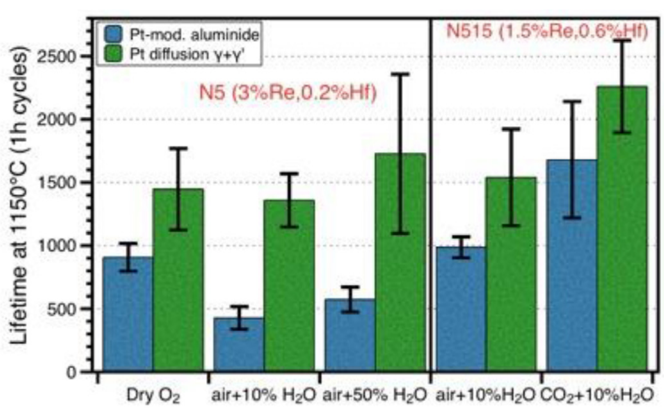

Figure 1. Average lifetimes (number of 1-hour cycles to failure) for EB-PVD (electron-beam, physical vapor deposition) yttria-stabilized zirconia (YSZ)-coated superalloy specimens with two different platinum-containing diffusion bond coatings exposed in 1-hour cycles at 1150 °C in several environments. Two different superalloy substrates were evaluated. The bars note the standard deviation for 3 specimens of each type.

- High-resolution analytical electron microscopy has been used to study the segregation behavior of Y, La, Hf and Ti as well as study the minor effects of water vapor on the thermally-grown alumina on the surface of coatings and model alloys.
- A characterization methodology was developed where the same 500 by 670 µm area was characterized as a function of exposure time to determine changes in the surface roughness and residual stress in the thermally-grown alumina scale. The technique was also used to track the location of transient metastable alumina phases on aluminide bond coatings and these phases did not appear to contribute to increased oxide thickness or higher stress levels.

Benefits

This project supports DOE's Hydrogen Turbine Program, which 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. ORNL's research is advancing mechanistic understanding of factors that contribute to airfoil degradation and extends cycle efficiency with an increased temperature capability of the hot gas path components by maximizing the service lifetime of bond coats and TBCs.

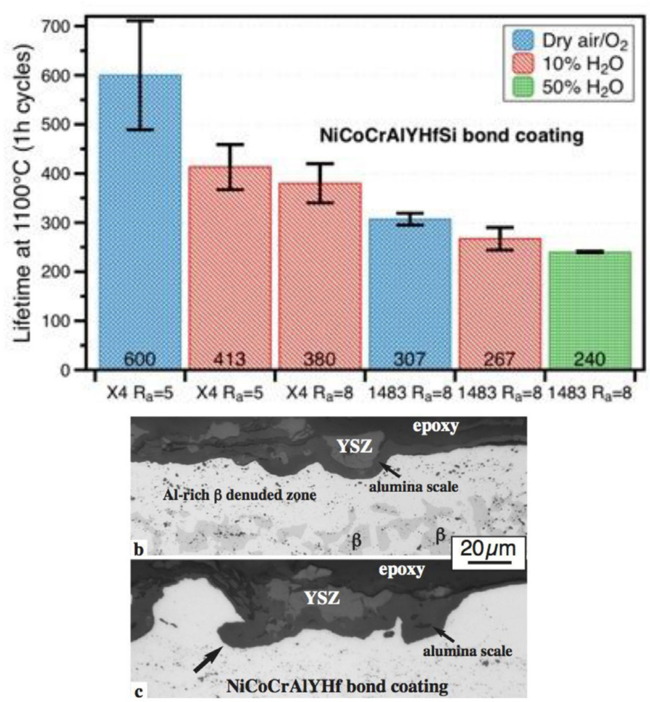

Figure 2. (a) Average coating (number of 1-hour cycles to failure) lifetimes for APS (air plasma sprayed) YSZ coated alloys X4 and 1483 16mm diameter superalloy coupons with HVOF NiCoCrAlYHfSi type bond coatings with two different average roughness (Ra) values exposed in 1-hour cycles at 1100 °C in dry and wet environments. Bars note one standard deviation for three specimens of each type. Light microscopy of polished cross-sections of failed X4-coated specimens exposed in 10% water vapor (b) R_a=5 after 440 cycles and (c) R_a=8 after 380 cycles. The arrow in (c) shows where thermally grown aluminum oxide is beginning to undercut an asperity in the higher roughness coating.