

DOE/OR/22242--T4

**ADVANCED THERMAL BARRIER  
COATING SYSTEM DEVELOPMENT**

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TECHNICAL PROGRESS REPORT

to the

U.S. DEPARTMENT OF ENERGY

Oak Ridge Operations Office

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Submitted By

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## **Advanced Thermal Barrier Coating System Development**

### **Program Objectives**

The objectives of the program are to provide an improved TBC system with increased temperature capability and improved reliability relative to current state of the art TBC systems. The development of such a coating system is essential to the ATS engine meeting its objectives.

The base program consists of three phases:

Phase I: Program Planning - Complete

Phase II: Development

Phase III: Selected Specimen - Bench Test

Work is currently being performed in Phase II of the program. In phase II, process improvements will be married with new bond coat and ceramic materials systems to provide improvements over currently available TBC systems. Coating reliability will be further improved with the development of an improved lifing model and NDE techniques. This will be accomplished by conducting the following program tasks:

- II.1 Process Modeling (deleted)
- II.2 Bond Coat Development
- II.3 Analytical Lifing Model
- II.4 Process Development
- II.5 NDE, Maintenance and Repair
- II.6 New TBC Concepts

Phase III of the program will proof test the best of the newly developed TBC systems on representative sections in a test passage at the Westinghouse Science and Technology Center.

## Technical Progress Report

### Task II.2 Bond Coat Development

#### *Task II.2.1 Bond Coat Deposition Process*

- The evaluation of the bond coat deposition processes continued with furnace testing of superalloy substrates coated using optimized deposition parameters for the high velocity oxy-fuel (HVOF) and shrouded plasma spray (SPS) processes. Air plasma sprayed YSZ top coats were applied over the bond coats. Performance from accelerated test conditions was compared to baseline CoNiCrAlY bond coat performance with air plasma sprayed (APS) and electron beam physical vapor deposition (EB-PVD) top coats.
- The optical pyrometer, necessary for low pressure plasma spray (LPPS) bond coat optimization was received and installed. Preparations are being made to spray the optimization test matrix.

#### *Task II.2.2 Evaluate Bond Coat Chemistry*

- One bond coat chemistry optimized in the previous reporting period and five new bond coat chemistries optimized this period have been deposited on superalloy substrates for furnace testing at accelerated and nominal conditions. All except 2 chemistries have entered furnace testing. The final two chemistries are expected to enter testing in December. The new bond coat chemistries are being evaluated initially with an APS YSZ top coat.
- Metallography was performed on 3 of the new bond coat chemistries cycled to failure at accelerated test conditions.
- An additional bond coat deposition technique was added to the experimental matrix. Preliminary coating deposition runs and a series of coatings for process optimization was deposited. Metallography of optimization runs was initiated.
- Bond coat surface modification/adhesion studies were completed. Testing, consisting of thermal shock tests and tensile bond strength measurements, was used to identify necessary surface finish. Results were used to define final coating parameters for surface modified bond coats.

### Task II.3 Analytical Lifting Model

- The development of the TBC life prediction model continued in this report period. The Bodner-Partom constitutive model, which is an elastic-viscoplastic model that treats plasticity, creep and stress relaxation based on the internal variable approach, was incorporated into the TBC life prediction model for the purpose of treating the inelastic response of the bond coat during thermomechanical fatigue (TMF) load cycling. The same set of equations can also be used for treating the inelastic response in the substrate. As a result the Bodner-Partom model was incorporated into the TBC life prediction model to represent the inelastic behaviors of both the bond coat and the

substrate. The Bodner-Partom model was benchmarked using several simulated TMF cycles. The calculations were intended to test the life prediction schemes of the substrate and the bond coat. Additional data and simulation are required to test the life prediction scheme for the oxide and the TBC.

- Fabrication of the first round of LCF mechanical test specimens is complete and testing is planned the week of December 9th.
- The first round of free standing PVD samples have been thermally aged at Westinghouse.

## **Task II.4 Manufacturing Process Development**

### *Task II.4.2 Cooling Hole Masking Technology*

- Application of coatings to industrial gas turbine (IGT) component surfaces can cause restriction of cooling holes and alter the heat management of the engine. Altered cooling air flow will lead to increased component temperatures and will shorten the life of the part. Therefore, it is critical to understand the extent of hole restriction caused by the coating process and to 1) account for the restriction in cooling hole design, 2) prevent cooling hole restriction during TBC deposition, or 3) remove the coating material from the holes after deposition.
- Polymer masking trials were performed previously on simulated cooling hole test plates. One polymer and modification of that polymer shows considerable promise. A test matrix has been produced to quantify earlier results. Substrates have been fabricated, and the panels are awaiting overlay and TBC coatings.

### *Task II.4.3 Hole Re-Drilling*

Three techniques have been identified for re-shaping cooling holes after TBC deposition. Flat coupons, simulated cooling hole test plates, and several IGT blades are available for machining trials. Two machining trials have been demonstrated. *(The third technique, sonic milling will be demonstrated during the next reporting period.)*

- Water-jet stripping: Demonstrations of a high pressure water jet technique have shown promising results. The machining parameters were controlled so that only TBC was removed. The method allowed for greater than 90% TBC removal from the holes. Methods for hole location and alignment have been identified as current limitations to the technique. The feasibility of applying several emerging techniques to hole location is being considered.
- Pulsed laser machining trials have been performed. Preliminary evaluation by the vendor have shown some success. However, limiting machining to avoid substrate

damage is an area of concern. Samples are being returned to Westinghouse for evaluation.

## **Task II.5 NDE, Repair and Maintenance**

### *Task II.5.1 Repair and Maintenance*

Localized repair of a coating system offers the potential for considerable cost savings over general stripping and recoating of a component. Two general types of local repairs have been identified and will be considered, namely major repairs and minor repairs. Minor repairs are intended for new or nearly new parts with a chipped TBC, but little if any bond coat degradation. Major repairs constitute a local TBC and bond coat stripping and refurbishment. For both types of repairs, it is assumed that the substrate has not been damaged.

- Repair techniques are being developed on flat 1.5 x 1.5 x .125 inch coupons with MCrAlY bond coats and ceramic top coats. Both single crystal and polycrystalline repair coupons have been machined and coated.
- Process parameters for local stripping of APS TBC's have been identified, and a second set of trials is now underway to determine optimum EB-PVD TBC removal parameters.
- Three variations of minor repairs were conducted on coupons and bond buttons. Repairs were then evaluated by non-destructive inspection, bond strength testing, and cyclic furnace testing. In some cases, repaired samples performed as well as the control. Metallography and analysis of the non-destructive inspection data is still in progress.
- Two bond coat removal techniques are currently under consideration. Initial trials have demonstrated the successful removal of MCrAlY's by both techniques.
- Major repair trials on test panels are underway to determine variables in the major repair process. One series of repair trials was conducted to address variables in the masking configuration. Currently, a second series of major repair trials is considering variables in the bond coat surface preparation process.

### *Task II.5.2 Off-line NDE*

Two types of controlled specimens have been designed to investigate out of frame thermal and Eddy current NDE methods for the evaluation of TBC coatings. The TBC step standard has been completed along with thermal wave imaging. The data demonstrates an excellent correlation between TBC thickness and cooling rate, clearly underlining the potential for simultaneous debond and thickness measurements. The graph of temperature vs. coating thickness is shown in Figure 1.

## Temperature-Time Curve of Westinghouse Sample IN738

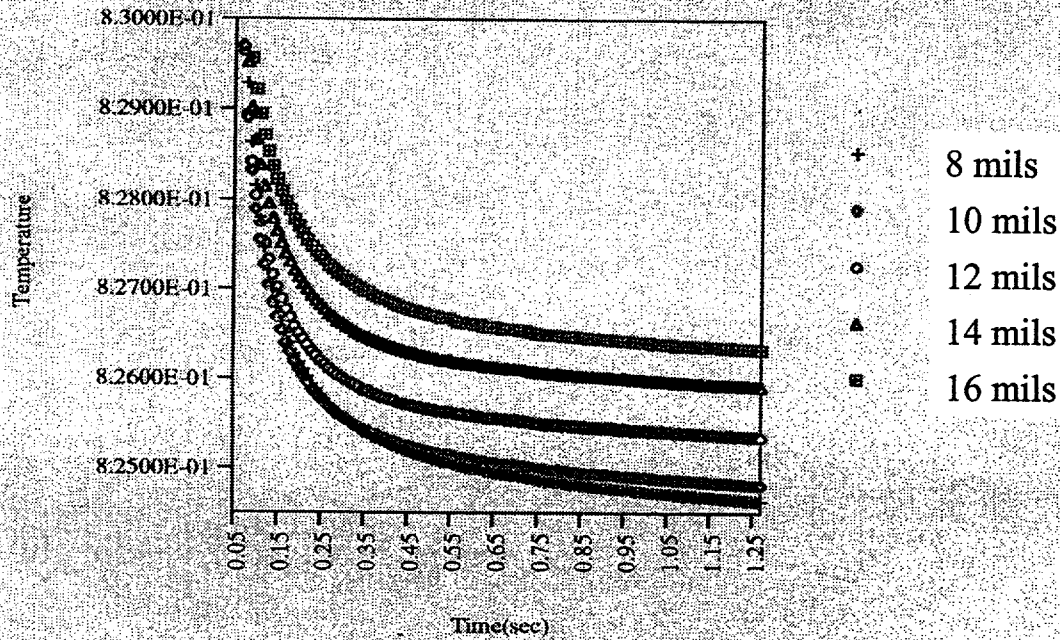


Figure 1 - Graph of temperature as a function of time

The standard for a simple debond is currently being manufactured by ORNL. New attempts are being pursued to complete these standards. Once completed, both ORNL and Wayne State University will conduct different thermal measurements. Thermal images or repair coupons have also been completed and have assisted the TBC development effort in further refinement of the local repair process.

### Task II.5.3 In- Frame NDE

For the new effort regarding in-frame NDE, Southwest Research Institute has completed the transition to the new program and has begun work. A literature search of the past five years was completed regarding the topics of Raman, Rayleigh, and Brillouin scattering methods, thermal phosphorescence, and fluorescence. Also two of three training sets for initial scattering measurements have been supplied to Southwest. Work will continue at Southwest to begin the scattering experiments as well as complete the feasibility study for the application of these advanced technologies to the gas turbine industry.

## **Task II.6 New TBC Concepts**

### *Task II.6.1 New TBC Chemistry*

- APS deposition of the second new TBC composition was initiated and optimization continued on the first new TBC composition. Optimization is continuing to tailor the TBC ceramic microstructure. Test pins have been coated with TBC composition 1 and are being readied for furnace evaluation. In addition, modification of the TBC powder particle size distribution is being investigated to make the system easier to deposit by plasma spray.
- X-ray diffraction was performed on TBC composition 1 revealing plasma deposition does result in the desired coating phase. Additional TBC coupons have been deposited for phase stability examination. Coupons have also been coated with TBC composition 2 for x-ray diffraction phase identification.
- Free standing films of the two new TBC ceramics have been deposited for thermal conductivity measurements. A series of coupons exposed to various aging cycles will be evaluated during the next reporting period.

### *Task II.6.2 Microstructure: Microcracked / Segmented / Columnar*

- Cyclic furnace testing of eight columnar, plasma sprayed TBC ceramic coatings was completed during the current reporting period. Results of accelerated furnace tests indicate that improvements over the current commercial process are possible. Metallographic examination of the test pins was performed to evaluate differences in coating performance. Analysis of the results is ongoing.

### *Task II.6.3 Process Optimization*

- Optimization of four YSZ TBC powders has been performed using a parallel, systematic design of experiment. Metallography and cyclic furnace testing were used for evaluation. Several modifications appear to provide improved performance over previous baseline APS coatings. Analyses of the results are being finalized to define coating systems for more in-depth evaluation.