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**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

WESTINGHOUSE ELECTRIC CORPORATION

Power Generation Business Unit

4400 Alafaya Trail

Orlando, Florida 32826-2399

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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

- Additional MCrAlY deposition trials were performed using axial feed plasma spray equipment. After several iterations, metallographic examination of the coatings indicated a high degree of undesirable internal oxides and porosity was still present in the bond coat. Further study of this techniques was, therefore, discontinued.
- In the evaluation of HVOF bond coats, it was observed that there is a balance between obtaining high density coatings for good oxidation resistance and obtaining a rough coating surface suitable for APS TBC adhesion. In order to provide both high density and adequate surface roughness, a number of powder blends were evaluated. Bond coats were deposited using the blended powders. Metallographic examination is in process.

Task II.2.2 Evaluate Bond Coat Chemistry

- Bond coat furnace evaluation of new chemistries continued at both nominal and accelerated test conditions. Bond coats were deposited by LPPS and evaluated with an APS ceramic top coat. Several coating systems showed a significant improvement over the baseline LPPS bond coat with an APS top coat.
- Bond coat performance was found to be strongly dependent on substrate alloy.
- Surface modified bond coat studies indicated that additional work was needed to understand the effect of roughness on coating adhesion. This work was performed and coating adhesion evaluated using a bend test. Based on these tests, final deposition parameters were selected and test pieces prepared for furnace evaluation. Furnace testing is continuing.

Task II.2.3 Interface Modification

- Controlled atmosphere heat treatment was used as a means of modifying the surface of a bond coat to improve the TBC adhesion for both APS and PVD TBC's. Interface modification and TBC coatings were applied to test pieces. The effect of modification is being evaluated by means of cyclic furnace exposure. There have been no failures of the modified coatings to date.

Task II.3 Analytical Lifting Model

- The development of the TBC life prediction model continued in this report period. A review of the current life prediction model was held at Westinghouse on December 19th, 1996. In this review a number of suggestions were made by SwRI, and accepted by Westinghouse, to simplify the calculation of system strain and system creep.

These changes result in significantly fewer model variables and allow rapid computation of TBC life for a multi-nodal geometry.

- The effect of bond coat creep was modeled assuming a multi-layer TBC cylinder. The stresses with each layer were computed as a function of time for the assumed turbine duty cycle. This exercise revealed that a simple modification could be made to the central fatigue equation to account for bond coat creep.
- A trial run was performed on the lifing model using load and temperature data for turbine blades supplied by Westinghouse. The purpose of the calculation was simply to provide a trial run for interfacing the output of the Westinghouse FEM structural design codes with the TBC life code. The trial run was successful with no unexpected difficulties. For this run, simply the oxidation terms in the model were left active. Terms considering sintering, bond coat creep, etc. were de-activated, but will be activated for future runs when all the material constants are available.
- Compression tests on free standing TBC specimens have been performed. LCF testing on TBC coated specimens is underway.

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 are underway using full scale gas turbine hardware. Film cooled 501DA vane segments have been grit blasted and cleaned in preparation for subsequent coating application. Preliminary inspection of cooling holes is complete. The vanes will be masked using a modified heat resistant polymer. Both overlay coatings and bond coat/ TBC systems will be deposited. Final inspection will include visual inspection and cross-sectional metallography.

Task II.4.3 Hole Re-Drilling

- Three techniques for cooling hole re-drilling were selected for evaluation using flat coupons with simulated cooling holes. Laser drilling was found to be extremely sensitive to minor variations in working distance. Considering the part to part variation, particularly at refurbishment after engine exposure, it is believed that this sensitivity would cause significant processing difficulties. Therefore, the process was eliminated from further consideration. A second technique that was demonstrated showed promising results. TBC was stripped with minimal effect on the underlying alloy. The process was shown to be fairly insensitive to variations in operating

parameters. Evaluation of a third technique is underway and should be completed by mid March.

- The major challenge for removing excess TBC from cooling holes is relocating holes after the part has been heat treated or service exposed. Thermal aging tends to change the positions of cooling holes relative to their original as machined location. Therefore, a technique for locating holes prior to machining is needed. Several methods for hole location are being considered, and recommendations on how to proceed will be made during the next quarter.

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 the local removal of APS and EB-PVD TBC's have been identified. In both cases, the ceramic top coats are stripped down to the bond coat and visually inspected to ensure complete removal.
- Four 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. One minor repair variation is still being evaluated.
- Three bond coat removal techniques have been investigated for major repairs. Initial trials demonstrated the successful removal of MCrAlY's by two techniques. The third technique failed to strip bond coats in a timely manner and was dropped from consideration. In order to prevent any removal of the underlying base metal, the MCrAlY stripping processes depend heavily on NDE for bond coat characterization prior to and during stripping.
- A series of major repair spray trials was conducted to determine variables in the major repair process. Surface preparation and spray parameters have been identified, but masking still remains an issue. During bond coat and top coat deposition for a major repair, the remainder of the component must be masked off. Ideally, the masking configuration must be versatile such that any local area of a component can receive a major repair.

Task II.5.3 In-Frame NDE

- Raman spectra is being investigated as a means of on-line TBC monitoring. Spectra from as-deposited and aged samples have been examined. Initial indications have led to the selection of an appropriate excitation wavelength. Definite changes in the spectra are seen as a result of aging.
- In order to explain the changes that are seen in the spectra, a molecular mechanics study has been initiated.
- Additional spectra from aged samples are in progress. Examination of engine hardware is planned to examine the effects of typical and gross contamination.

Task II.6 New TBC Concepts

Task II.6.1 New TBC Chemistry

- Ceramic chemistries were identified for EB-PVD TBC development. Three new ceramic chemistries are being evaluated in the current task. Chemistries were reviewed with the coating vendor and initial contact was made with the ingot manufacturer.
- Thermal spray powders for four new ceramic compositions have been manufactured and sent to the coating vendors. Initial coating trials were conducted on all four compositions. Based on metallographic examination, additional optimization is needed to tailor coating microstructure for three of these chemistries.
- Detailed optimization spray trials were conducted for two new ceramic chemistries. Coated test pieces were placed into accelerated cyclic furnace evaluation.
- Furnace testing of one new TBC chemistry resulted in early coating failure. The cause of failure is being investigated.

Task II.6.3 Process Optimization

- Earlier results from accelerated furnace testing suggested that improved processing control could substantially extend the life of APS TBC's for industrial gas turbine applications. Coatings were deposited to confirm these early results and to demonstrate reproducibility. While the current accelerated thermal cycling tests are not as favorable as the earlier report, significant improvements over the baseline are seen. There have been no coating failures under nominal conditions. Accelerated and nominal condition thermal cycling tests are continuing.