DOE/OR/22242--T14

**ADVANCED THERMAL BARRIER
COATING SYSTEM DEVELOPMENT**

CONTRACT # DE-AC05-95OR22242

TECHNICAL PROGRESS REPORT

to the

U.S. DEPARTMENT OF ENERGY

Oak Ridge Operations Office

Oak Ridge, Tennessee

December 12, 1997

RECEIVED

FEB 17 1998

OSTI

Submitted By

WESTINGHOUSE ELECTRIC CORPORATION

Power Generation Business Unit

4400 Alafaya Trail

Orlando, Florida 32826-2399

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

**Portions of this document may be illegible
electronic image products. Images are
produced from the best available original
document.**

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

- Bonds coats with improved resistance to substrate- bond coat interdiffusion are being developed. Coating deposition trials were initiated to define required coating chemistry. Topcoat application and furnace evaluation are planned for next quarter.
- Work was initiated to deposit HVOF bond coats with improved density and surface roughness. New HVOF gun hardware, which operates at lower temperatures and significantly higher particle velocities, was used to deposit MCrAlY coatings on furnace test specimens. Metallography indicates that bond coats deposited with the new gun hardware exhibit a high surface roughness and minimal internal porosity. Surprisingly, accelerated furnace testing of the HVOF bond coats showed no improvement over the baseline average life. However, metallography revealed that the as-received TBC's on these samples appeared unusually dense with large cracks in some areas. A second set of samples with HVOF bond coats and APS TBC's was requested from the coating vendor.
- Cyclic furnace testing of LPPS new bond coat chemistries under "nominal" conditions is nearing completion. All testing on CMSX-4 substrates is complete. On CMSX-4, the new chemistries did not offer a significant improvement over the baseline. On MarM-002, three compositions have surpassed the baseline average life by 30%; furnace testing of bond coats on MarM-002 is still in progress.
- Accelerated furnace testing of EB-PVD deposited bond coats is complete. On CMSX-4 and IN-939 substrates, the EB-PVD bond coats did not offer a significant improvement. Marginal life improvement was observed on MarM-002 substrates. In light of the significant cost increase associated with the EB-PVD process, and the fact that the coatings gave only marginal life improvement at best, the EB-PVD bond coats are not recommended for further study.

Task II.3 Analytical Lifing Model

In the last reporting period APS TBC life data from Westinghouse furnaces and burner rig data were sent to SwRI for use in the TBC life prediction code entitled "TBCLPM". Both furnace data and burner rig data were compared against the HOST burner rig data to determine any difference among these sets of test data. The cycle time from the HOST report and the burner rig tests was on the order of 6 and 8 minutes, respectively. In contrast, the furnace cycle was 24 hours. Very different relations for mechanical strain range and the total hot time until failure were observed for the three sets of data. When the same data was entered on a plot of mechanical strain range vs. number of cycles to failure the data sets were found to span the entire plot with each set of data tending to fall

into a particular region. Based on these plots, a strong correlation with time at temperature was not seen.

Hence, the current model has been modified such that thermomechanical fatigue is considered the primary damage mechanism and effects such as TBC sintering and oxide growth have been downplayed. This approach was taken since (1) time dependent effects such as sintering were difficult to characterize and (2) this considerably simplifies the model. The developed model is therefore more accurate under thermal stress/shock conditions than under oxidation emphasis conditions. LCF constants for the model were derived from the data sets and inserted into TBCLPM. The effect of curvature was then incorporated into the model using failure data from samples of varying curvature supplied by Westinghouse. Preliminary plots of the predicted vs. actual number of cycles to failure show a correlation on the order of x3. The model is still in validation / modification iterations and may be changed to make the model more accurate, particularly under oxidative conditions.

Task II.4 Manufacturing Process Development

While no additional masking work was performed on this program during this quarter. Westinghouse Source Assurance has, however, initiated process qualification procedures for use in production.

Task II.5 NDE, Repair and Maintenance

Task II.5.1 Repair and Maintenance

- Cyclic furnace testing of APS minor repairs under "nominal" conditions is continuing. To date, all repaired samples remain in test.

As a result of mechanical damage followed by high temperature thermal exposure, recrystallization of coated single crystal superalloys has been observed. In light of the possible effect of recrystallization on the mechanical integrity of turbine components, a study was initiated to identify if the thermal history associated with the coating process will result in recrystallization. Issues such as coating heat treatments, substrate property degradation, service induced mechanical strain, and surface recrystallization are considered. During this reporting period,

- Mechanical testing of single crystal test specimens, which simulates the strain cycles calculated for the row 1 vane, was completed. The coatings on all samples will be stripped and recoated to simulate the refurbishment process. All samples are currently with the coating vendor, and stripping and recoating of the samples will be completed in December.

II.5.2 Off-Line NDE

- Methods of creating *controlled* debonds for NDE standards has been identified. Samples have been fabricated (as part of another Westinghouse program). Thermal wave imaging of the defects will be performed in December. NDE methods are expected to differentiate between debonds within various layers of the coating system.

II.5.3 On-Line NDE

- SwRI responded to Westinghouse comments on the draft final report. This response is being reviewed and will be incorporated in the Westinghouse final report and recommendations.

Task II.6 New TBC Concepts

Zirconia (ZrO_2) stabilized with 8 wt. % yttrium oxide (8YSZ) is widely used as a thermal barrier coating due to its superior thermal cycling performance and low thermal conductivity. With an increase in the rotor inlet temperatures, the surface of the ceramic coating is subjected to temperatures above which 8YSZ is stable. These high temperatures can lead to sintering of the ceramic coating thus decreasing its strain tolerance and consequently the life of the coating. In addition, leaching of the stabilizing phase, Y_2O_3 , by fuel contaminants, leads to destabilization of the ZrO_2 phase, further reducing the coating life in corrosive environments. Therefore, new ceramic materials need to be evaluated for utilization as thermal barrier coatings in ATS conditions.

- Additional APS deposition trials were conducted to replicate earlier favorable results - samples were prepared for furnace testing (to be initiated in December)
- PVD ingots were fabricated and received for 3 new TBC chemistries. Deposition plan was reviewed with coating vendor - substrates are receiving bond coats and surface preparation for the TBC deposition during the next reporting period.
- Developed a methodology for the selection of new ceramics for TBC's based on their melting points, thermal expansion, thermal conductivity values and also their potential corrosion resistance to fuel contaminants.
- Ceramic compounds were ranked according to the best combination of melting points, thermal expansion coefficients and thermal conductivity values.
- An approach was developed to identify the relative corrosion resistance of the compounds, to aid in the selection of materials for applications in corrosive environments.

- Ten new compounds have been selected for immediate evaluation by preliminary screening tests to determine their long term high temperature phase stability. Additional compounds are being identified in the course of the next 2-3 months.
- Experimental details were planned for preliminary laboratory screening tests of addition TBC chemistries. Results are expected in the next reporting period. Materials with the best combination of all the properties will be later subjected to thermal cycling tests.
- Long term exposure of new ceramic chemistries at ATS relevant temperatures continued during the last quarter. Samples were aged up to 42 days and then examined for evidence of phase instability. One composition showed significant phase changes and was therefore eliminated from further consideration.
- An earlier process optimization study, which focused on one new TBC chemistry, produced coating life comparable to the baseline YSZ. However, two attempts to reproduce test results from that optimization study have proven unsuccessful. In both cases, the TBC microstructure appeared dense when compared to the original optimized coating. The coating vendor has since resprayed the TBC coating, using the optimized parameters and using a section of the original optimized coating as a microstructural reference. Furnace testing of the resprayed coatings will begin in December.
- Thermal conductivity measurements of new TBC chemistries requires that the sample be evaluated at ATS relevant surface temperatures. Due to this elevated temperature requirement, the thermal conductivity samples must be entirely ceramic. For the new APS chemistries, the requirement was met by fabricating freestanding APS ceramic disks. The PVD ceramics, however, lack strength between their columns such that they require a substrate which can also tolerate ATS relevant surface temperatures. In preparation for the deposition of new PVD chemistries, ceramic substrates for thermal conductivity samples were obtained. Coated substrates will later be machined to size; a machining vendor and process has been identified for this effort.

Phase III Bench Test

- Three Air Plasma Sprayed samples have been tested to failure under ATS thermal conditions. Using two different heating cycles to evaluate the initial effect of cycle length on performance. Supporting analysis, including metallography is currently being conducted.
- Test pieces have been coated with the baseline APS and EB-PVD TBC systems on MarM-002 and IN-939 substrates.

- The test rig was designed to run on a 24 hour/day schedule. However, several facilities requirements must be implemented to meet safety requirements before 24 hour operation can be achieved. These are expected to be in place in the first quarter of 1998. In the mean time, the facility will continue to operate in an attended mode.
- Testing is continuing.

III.6 Blade and Vane TBC Monitor - Feasibility Study

The adherence of the TBC to the row 1 blade and vanes is absolutely critical to the ATS engine. With the life of the component dependent on the coating, early detection of failure is necessary to ensure safe operation and enable component refurbishment.

- Requirements for a vane TBC monitor and environment were defined.
- Calculations were performed based on the initial concept and several back-up detection scenarios. The initial detection scenario was found to be infeasible due to a lack of temperature sensitivity. Several of the back-up materials have been identified as favorable. Detailed calculations are continuing.
- IR imaging as a means for blade TBC monitoring is being evaluated. IR camera requirements and resolution have been calculated based on the Westinghouse engine design.
- IR camera options have been evaluated relative to the above requirements and preliminary recommendations made.
- Blade imaging timing schemes have been worked out for data acquisition but require precise synchronization to the shaft rotation.