Project No. 03-01-SR107 – Superior Thermal Barrier Coatings for Industrial Gas-Turbine Engines

FACT SHEET

I. PROJECT PARTICIPANTS

A. Prime Participants:
Profs. Eric H. Jordan and Maurice Gell: University of Connecticut

B. Sub-Award Participants:
Prof. Nitin P. Padture; The Ohio State University
Dr. Xinqin Ma: Inframat Corp.

II. PROJECT DESCRIPTION

A. Objective(s) –

The primary project objective is to optimize the solution precursor plasma spray (SPPS) process for making thick TBCs that are suitable for use in industrial turbine engines, and that have the potential to impart dramatic advantages in terms of durability and cycle efficiency to be realized. This primary objective will be accomplished by achieving the following supporting objectives:

1. To elucidate the operative failure mechanism in the cyclic heat-treatment and microstructural thermal stability in isothermal heat-treatments of thick SPPS TBCs. This specifically includes hot-corrosion effects related to the use of alternate fuels such as syngas.
2. To identify the processing parameters that yield the optimum thick SPPS TBCs in terms of cyclic durability, hot-corrosion resistance, and thermal conductivity using systematic SPPS spray trails and insights from (1) above.
3. To identify microstructural characteristics for optimum SPPS TBCs that can be used for process control.
4. To transfer the developed SPPS technology to appropriate industrial participants to bring the exciting advantages of the new coatings to the application stage.

B. Background/Relevancy –

To meet the ever increasing demands for durability and performance, industrial engines require thermal barrier coatings (TBCs) with improved spallation resistance, thermal insulation, thermal stability, and hot-corrosion resistance. A novel process, called solution precursor plasma spray (SPPS), has the potential to satisfy all of these requirements. The SPPS process is being developed jointly by the University of Connecticut and Inframat Corp. for military fighter engine applications under Office of Naval Research contracts. The highly promising results from the ONR-funded work is being used as the foundation to evaluate the special long-term durability and hot-corrosion environments of High Efficiency Engines and Turbines (HEET) program engines requiring 30,000 hours of operation with fuel flexibility, which may include the use of alternate fuel such as coal-derived syngas.

C. Period of Performance –

July 1, 2003 to December 31, 2006

D. Project Summary –

In the SPPS process, an atomized spray of liquid precursor is injected into the plasma jet, instead of the powder that is used in the conventional air plasma spray (APS) process. The SPPS process produces a unique TBC microstructure with:

1. an uniform distribution of micrometer and nanometer size porosity, whose volume fraction can be varied over wide ranges for optimized thermal conductivity and strain tolerance,
2. closely spaced through-coating-thickness vertical cracks for enhanced strain tolerance, and
3. a toughened ceramic microstructure, resulting from the absence of "splat" boundaries that are responsible for crack initiation and spallation in conventional APS coatings.

Initial thermal-cycling tests of yttria-stabilized zirconia (YSZ) SPPS coatings show these TBCs to have superior spallation resistance as compared to conventional APS TBCs. This improvement in life results from the enhanced strain tolerance associated with the vertical cracks, and the improved ceramic toughness associated with the absence of the "splat" boundaries. In addition, after 500 hour exposure at 1121^{o}C, the SPPS structures shows very little densification, suggesting that SPS TBCs will retain their favorable initial low thermal conductivity and high strain tolerance for much longer times than conventional APS TBCs.

Conventional APS coatings are limited to less than 1 mm thickness to prevent spontaneous premature spallation. Somewhat thicker APS coatings can be produced, either by incorporating segmented vertical cracks in denser TBCs or by introducing a graded metal/ceramic interface. Using the SPPS process, we have recently demonstrated the ability to produce TBCs that are over 2 mm thick, with excellent bond strength, a uniform, porous microstructure containing through-thickness vertical cracks, and no "splat" boundaries. This does not require a graded interfaces or additional steps to introduce the vertical cracks. Thick SPS coatings provide the opportunity to dramatically reduce metal temperatures, thereby greatly enhancing TBC durability. Such thick SPS TBCs are applicable to static parts such as vanes, combustors, and as abradable turbine blade outer air seals. Thus, the goal for TBCs made using the SPPS process is at least a two-fold improvement in spallation life at a given coating thickness, and with constant cost, compared to conventional APS coatings. For thick SPPS TBCs, the goal of the program is at least a four-fold improvement in spallation life.

In the this project, process optimization trials, are being conducted to define the best conditions for low cost, durable SPPS coatings with: (a) thickness variations from 0.3 to 3.0 mm, (b) porosity from 15 to 50 vol%, and (c) graded porosities, with reduced or zero porosity at the surface.

Thermal-cycling tests are being performed to demonstrate the project objective of improved durability of SPPS TBCs compared to conventional APS TBCs. Spallation mechanisms and thermal stability studies will be conducted and compared with conventional APS TBCs. Special emphasis is being placed on determining the mechanism(s) associated with the retarded densification for SPPS TBCs. The understanding gleaned from these studies will be used to guide the design and the processing of improved SPPS TBCs.

To assess the improved thermal insulation of the SPS coatings, thermal conductivity measurements will be conducted as a function of specimen thickness, porosity content, and thermal exposure.

It is expected that near the end of this program, we will have demonstrated that the SPPS process is a low cost process for making highly durable TBCs with improved thermal insulation and long-term stability. The results of this program will then be transferred to the HEET industrial partners and their coating suppliers for scale-up, leading to production.

III. PROJECT COSTS

A. DOE Costs $ 546,468
B. Prime Cost Sharing $ None
C. Partner Cost Sharing $ None

IV. MAJOR ACCOMPLISHMENTS SINCE THE BEGINNING OF THE PROJECT

- Using the SPPS process, we have demonstrated the ability to produce TBCs that are over 3 mm thick, with excellent topcoat-bond coat interface, a uniform, porous microstructure containing through-thickness vertical cracks, and no "splat" boundaries. (August 2003)

- We have demonstrated that the SPPS TBCs are about 5 times tougher than the APS TBCs in the critical orientations. (November 2004)

- We have shown that the average thermal-cycling life of the 4-mm thick SPPS TBCs is 820 cycles. While most of the conventional air plasma sprayed (APS) coatings of the same composition and thickness deposited on identical bond-coated superalloy substrates were found to be detached partially from the substrates in the as-sprayed condition, the APS TBC that was intact failed after 40 thermal cycles. The dramatic improvement in the thermal cycling life in the SPPS TBCs can be attributed to: (i) the significantly higher in-plane indentation-fracture toughness (over fivefold) in the SPPS TBCs over APS TBCs and (ii) the presence of the vertical cracks in SPPS TBCs resulting in a high degree of strain tolerance. (December 2004)

- We have shown that the SPPS process is capable of producing novel microstructures consisting of inter-pass boundaries in the SPPS thick TBCs that provide a 40% reduction in the thermal conductivity. (March 2005)

- We have modeled microstructural effects on the thermal conductivity of SPPS thick TBCs in a effort to provide guidelines for the microstructural design of SPPS thick TBCs. (June 2005)

- We have elucidated the failure mechanisms of SPPS thick TBCs using a combination of electron microscopy studies and object-oriented finite element modeling.

V. MAJOR ACTIVITIES PLANNED DURING THE NEXT 6 MONTHS.

- In next phase of the project, further microstructural and modling studies of failure mechanisms, as function of thermal cycles and severity of environmental conditions, will be carried out on both, uniform porosity and multilayer type of thick TBCs.

VI. MAJOR ACTIVITIES PLANNED IN OUTYEARS (6 - 18 MONTHS)

None.

VII. ISSUES

A 6-momt no-cost extension was granted, with a new end date of December 31, 2006. This will completion of PhD of one of the students, Amol Jadhav, supported by this grant.

VIII. ATTACHMENTS

None.