DOE/OR/22426--T1

ADVANCED TURBINE SYSTEMS--RESEARCH AND DEVELOPMENT OF THERMAL BARRIER COATINGS TECHNOLOGY

DOE CONTRACT NO. DE-AC05-95OR22426

1st Bimonthly Report
December 1995

INTRODUCTION

The objective of the Advanced Turbine Systems (ATS) Program is the development of ultra-high efficient, environmentally superior, and cost-competitive gas turbine systems. The operating profiles of these industrial gas turbines are long, less cyclic, with fewer transients compared with those for aircraft gas turbine engines.

The durability and performance demands of ATS can be achieved by appropriate reduction of metal temperatures to retain the structural properties of the substrate alloy. This is accomplished by applying thermal barrier coatings (TBCs) onto the substrate. Currently, TBCs are primarily processed by two methods: plasma spray (PS) and electron beam-physical vapor deposition (EB-PVD). Achieving ATS specific goals requires the TBC to be self-reliant and stable in the thermal and corrosive environment of the industrial engine for durations to 25000 hours. The TBC requirements to meet ATS objectives, detailed in the Statement of Work, are divided into four phases. Phase I (Program Plan) includes the development of the technical plan, schedules, milestones, material selection, test selection, test parameters, and criteria for completion of each task and phase. Phase II consists of six tasks. Task 1 focuses on ceramic candidates; Task 2 on bond coat development; Task 3 on analytical modeling; Task 4 upon TBC manufacturing process development; Task 5 upon maintenance, repair and inspection; and Task 6 upon new TBC concepts. Based upon Phase II screening test results, TBC systems will be selected for application on blades for hot section specimen bench test performed in Phase III. Actual engine testing, Phase IV (optional), will be conducted in a customer engine.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

PHASE I: Program Plan

PROGRESS

MASTER

The program plan which included the development of the technical plan, the schedules, milestones, material selection, test selection, test parameters, and the criteria for the completion of each task and phase has been finalized, reviewed with DOE and accepted. The technical plan, schedules and milestones are shown in the Appendix. In the interim, the 887-lb. master heat of PWA1483 alloy ordered from Howmet has been received. The

DISCLAIMER

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

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, make 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.

characterization of the alloy for chemical composition and mechanical properties is in progress at P&W's Materials Control Laboratory. The authorization to produce the hollow burner bars for Tasks 1, 2, 3 and 6 from the master heat and the casting schedule has been executed. The nominal dimensions of the bars are 0.490 in. OD, 4.3 in. length, and 0.08 in. wall thickness. In addition, up to 6 slabs with the nominal dimensions 4.5 in. by 4 in. by 1 in. are being cast as part of the requirements for Task 3. The slabs are expected to be cast at the end of December 1995.

PHASE II: Development

Phase II describes the development work required to advance TBC technology for gas turbine hardware to meet the high performance requirements of the ATS program. A schematic overview of Phase II is presented in Figure 1, followed by the approach taken for each of the six tasks.

The objective of Tasks 1 and 6 is the development of higher performance TBCs to meet ATS goals. The approach rationale is as follows. Based upon extensive laboratory tests and the results of millions of hours of flight experience it is concluded that stress plays the major role with respect to TBC longevity. The principal sources of stress are physical, mechanical, thermal and oxidative. The candidate ceramics, deposited on LPPS NiCoCrAlY bond coat will be evaluated in a high-temperature, high thermal gradient hot corrosion burner-rig test. The thermal gradient, commensurate with the engine environment, is established with a high heat flux in the presence of corroding sulfate salts and oxide fluxes. In order to ensure that conventional hot corrosion processes are not overlooked, the coatings that pass these tests will be screened through the conventional 1700°F (926°C) corrosion burner-rig tests. The ceramics that pass will then be combined into complete TBC systems with the bond coats that are screened through further tests. The ceramic candidates selected based upon these tests, combined with the bond coat

candidates selected in Task 2, will be further screened through tests designed to address the formation, and the growth rate of the protective oxide scales, as well as to establish the rates of formation and growth of sulfides within the candidate bond coats. In these tests, the candidate materials are exposed in an environment in which the partial pressures of oxygen and sulfur are controlled, favoring the formation of (1) only oxides, (2) oxides and nickel sulfide, and (3) sulfides and only aluminum oxide.

The objective of Task 2 is to select the best bond coat for the advanced TBCs. The approach is to conduct hot corrosion burner rig tests, as well as controlled oxidation/sulfation tests to determine equilibrium phase stability and verify corrosion kinetics.

The objectives of Task 3 are to establish the TBC material property database and develop analytical TBC life prediction model. The approach includes the construction of the material database on industrial gas turbine relevant TBC spalling mechanisms. In this reporting period preliminary specimen designs were completed. Design dimensions were established based on existing experience.

The burner rig specimen design (Figure 2) is unique in that the internal surface is lined with small ribs (i.e., tripstrips) to provide adequate internal surface heat transfer coefficient. The tripstrip geometry shown in Figure 2 should provide from 2.5X to 3.0X the heat transfer coefficient in a fully turbulent flow smooth walled tube. An augmentation of at least 2.0X is required to meet the gradient burner rig heat flux goals of this program.

Figure 2 Hollow Burner Rig Specimen Geometry

The erosion specimen design (Figure 3) can be coated on both sides with Electron Beam-Physical Vapor Deposited (EB-PVD) ceramic to save fabrication costs.

Figure 3 Particulate Erosion Specimen Geometry

Bond coat and ceramic oxidation/corrosion specimens (Figure 4) are burner rig specimens cut into approximately 4 equal length sections. The exposed ceramic edges at the top and bottom will be tapered to minimize ceramic spalling.

Figure 4 Ceramic Sintering, Diffusion, and Phase Stability Specimen Geometry

The dogbone specimen designs (Figure 5a) selected for cyclic and one-way tension mechanical tests are based on previous mechanical test experience with ceramic coatings. Stress-strain behavior of the EB-PVD ceramic behavior can be deduced by subtracting out the substrate/bond coat response. This technique was used successfully in the NASA HOST program.

Figure 5a Ceramic Cyclic and One Way Tensile Specimen Geometry

The bending specimen design (Figure 5b) is configured to provide good relative properties between as-deposited ceramic and thermally aged (i.e., sintered & corroded) ceramic materials. Only one side is coated because 1) compressive failure is the dominant mechanism and 2) the asymmetrical tensile-compressive strength of ceramic coatings would unnecessarily complicate deducing the thermally aged behavior. Should tensile behavior be needed, the specimen can be tested up-side down.

Figure 5b Bending Specimen Geometry

The objective of Task 4 is to ascertain manufacturability of successful TBC systems. An approach and a detailed schedule has been developed to accomplish the objective of Task 4. The approach consists of several elements as summarized below:

- Assess current TBC manufacturing process
- Compile generic process steps
- Identify important process variables

Introduce modifications to process steps to adapt to:

- New TBC system
- Specific sample geometry
- Increased TBC thickness

Identify Process Steps involving

- Labor
- Materials movement
- Capital investment
- Sensor/automation adaptability

Incorporate lower Cost and environment-friendly process elements

Substitute HVOF for LPPS

Adapt PS method for TBC developed by EB-PVD (fabrication and testing to be done in Task 6)

10 mils PS for vane application

20 - 40 mils PS for combustor application

Incorporate supplier's non-proprietary process steps into the manufacturing process

Define final manufacturing process

As part of the assessment of current TBC manufacturing process, several elements of the generic process steps have been mapped out. This is shown below. The generic process chart depicts elementary steps typical of many coatings. The initial step starts with the receipt of castings from supplier and a TBC design from analytical tasks such as Task 3.

In Task 5 inspection and repair techniques will be developed which would include procedures/devices to ensure preliminary indication of impending TBC failure. In addition, sensor technique will be developed, validated and demonstrated in Task 3.

The approach consists of several elements. These elements with details of nondestructive evaluation as well as screening of repaired samples are:

Evaluate full repair technique

- Complete stripping of selected failed baseline samples of Tasks 1 and 2

 - Remove ceramic coat

 - Alkali digestion (6 samples)

 - Water jet removal (6 samples)

 - Remove metallic bond coat (12 samples)

- Reapply bond coat (12 samples)

- Reapply ceramic (12 samples)

- Conduct C1 and C2 tests under Tasks 1 and 2

- Compare durability with pre-repair lives

- Multiple strip and recoat selected samples (8 samples) to determine life dependency on number of strip cycles

 - 2 samples to be stripped and recoated once and put on test

 - 2 samples to be stripped and recoated twice and put on test

 - 2 samples to be stripped and recoated three times and put on test

 - 2 samples to be stripped and recoated four times and put on test

Demonstrate feasibility of inspection methods

- Laser holography

 - Screen by laser holography selected samples partially exposed for varying times in tests A1 and C1 (2 samples for 3 partial test exposures)

- Acoustic emission

 - Under Task 3, correlate acoustic activity to damage initiation and progression during mechanical testing

The objective of Phase III is to substantiate TBC system performance on turbine airfoils. In this phase, FT-8 single crystal blades will be modified for thermocouples and made adaptable to the thermal gradient burner rig. Thermal gradients will be verified prior to application of any coatings. With respect to the metallic coating, a number of blades will be supplied to the coating supplier with process approval for deposition of the metallic bond coat down-selected from Phase II. With respect to the ceramic coating, the bond-coated blades will be provided to the supplier of the ceramic coating for deposition of the ceramic system down-selected from combined Tasks 1 and 6 using the appropriate process.

APPENDIX

TECHNICAL PLAN, SCHEDULE AND MILESTONES

Contract # DE AC05 950R 2246

		1996	1997	1998	1999	2000	2001	2002
1	Phase 1 cost 57.8K							
2	Phase 2 cost 1,289.2K							
3	Task 1a,6a (Total cost259+124)							
4	procurement							
5	A1 tests							
6	A2 Tests							
7	DOWN SELECT							
8	Task 2 Bond Coats Cost 310.7K							
9	MCrAlYs							
10	Low Sulfur NIAIs							
11	-procurement							
12	-characterize,produce							
13	Pt Modified Alloys							
14	ODS alloys							
15	High Cr modified MCrAlYs							
16	HVOF							
17	B-1 Tests							
18	B-2 Tests							
19	DOWN SELECT							
20								
21	Task 1b,6b, Ceramic							
22	produce blade,vne,duct TBC config							
23	C 1 Tests							
24	C2 Tests							
25	PS2/PO2 Tests							
26	DOWN SELECT FOR PHASE 3							
27	Task3 Model Cost 492.1K							
28	Design, Calibrate Rig Specimens							
29	Fabricate TBC Specimens Task 3							
30	Ceramic erosion Tests							

[illegible]

[illegible]