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Advanced Turbine Systems, Heat Engines, and Materials/Machining Elements of the Systems, Inc., program

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MATERIALS/MANUFACTURING ELEMENT OF THE ADVANCED TURBINE SYSTEM PROGRAM

ABSTRACT

One of the supporting elements of the Advanced Turbine Systems (ATS) Program is the materials/manufacturing technologies task. The objective of this element is to address critical materials issues for both industrial and utility gas turbines. DOE Oak Ridge Operations Office (ORO) will manage this element of the program, and a team from DOE-ORO and Oak Ridge National Laboratory is coordinating the planning for the materials/manufacturing effort. This paper describes that planning activity which is in the early stages.

INTRODUCTION

A new DOE Program to develop advanced gas turbines for power generation in the utility and industrial section has been initiated. The objective of the program is to develop advanced gas turbines for utility and industrial power generation. The goals of the program are to increase the efficiencies to greater than 60% in utility combined-cycle systems and a 15% improvement in industrial turbines. Additional goals include a 10% reduction in power costs and reduction in acid gas emissions. ATS is a joint program that is managed by both DOE Fossil Energy (FE) and DOE Energy Efficiency and Renewable Energy (EE). The primary focus of the program is on natural gas turbines with program supporting elements on adaptation to coal-derived fuels and biomass fuels. ATS is an eight year program which involves turbine manufacturers, utilities, industrial users, national laboratories, and universities. A work breakdown structure is given in Figure 1. The main element of the program is the system design and system demonstrations conducted by the turbine manufacturers.

BACKGROUND/RELEVANCE OF MATERIALS/ MANUFACTURING ELEMENT

Six screening studies have been completed by the turbine manufacturers and several approaches have been defined to achieve the higher efficiencies. One main approach has been higher turbine inlet temperatures greater than 2600° F. To achieve these temperatures for extended operation periods there is a need for materials development and new blade and nozzle cooling concepts. At the two Clemson ATS planning meetings the gas turbine industry stated a clear need for a materials element in the ATS Program. They also indicated a need for effective interaction between the gas turbine manufacturers, materials suppliers, national laboratories, and others. Therefore, one element of the program is a materials/manufacturing activity, as shown in Figure 1. This element will address critical materials/manufacturing issues for the whole program, including both industrial and utility turbines.

OBJECTIVES OF THE MATERIALS/ MANUFACTURING ELEMENT

The primary objective of the materials/manufacturing element is to provide support to the ATS contractors. Direct support is intended to help supplement the ATS team efforts and provide expertise not available to a single company. Another objective is to develop materials/manufacturing technologies for the various ATS teams and the gas turbine industry at large. The technology development will focus on high risk materials, components, and manufacturing processes with emphasis on generic development. Another objective is to provide a technology transfer mechanism between the various NASA, DoD, and DOE
programs to the ATS Program. Many of these materials efforts will have a direct impact on the ATS Program, and a coordination effort is necessary.

PLANNING STRATEGY

DOE-Oak Ridge Operations Office (ORO) will manage the materials/manufacturing task, and a team of DOE-ORO and Oak Ridge National Laboratory (ORNL) is coordinating the planning for this element of the program. ORNL’s Metals & Ceramics Division is involved in various national DOE materials programs including: (1) Ceramic Technology Programs, (2) Fossil Energy Materials Program, (3) Continuous Fiber Ceramic Composite Program, (4) Advanced Industrial Concepts Materials Program, and (5) Basic Energy Science Welding Program. ORNL also has the High Temperature Materials Laboratory (HTML) which is a modern facility that serves as a focal point for high temperature materials research. It is a major user facility providing members of industry and the university research communities access to an extensive array of special research equipment needed to characterize the micro-structure and micro-chemistry of materials and to investigate the effects of these parameters on the physical and mechanical properties of materials. The gas turbine industry is already using this facility, and it will most likely be heavily utilized in the materials element of the ATS Program.

The planning for the materials/manufacturing element of the ATS Program is in the early stages. A portion of the Clemson planning meetings that were held in 1992 was on materials issues. In addition, ORNL has made some preliminary contacts with the gas turbine manufacturers, materials producers, gas turbine consultants, and contacts with DoD and NASA. In addition, three strategy papers have been developed, and the results of these papers were presented at a workshop in Cincinnati on May 28, 1993.

The intent is to develop a materials/manufacturing plan in FY 1994 and start implementing that plan in FY 1995. This schedule will allow sufficient time to obtain the necessary input from the ATS prime contractors, materials suppliers, DoD, EPRI, NASA, and other gas turbine manufacturers. Using this input, a draft plan will be assembled, and the industry will be allowed time to comment on the draft. The last step is the finalization of the plan using industry feedback. A Small Advanced Materials and Turbine Technology (AM&T) team will be used to develop the plan. The intent is to develop a strong plan using this blend of capabilities. In FY 1995, the AM&T team will be expanded and used to provide recommendations to DOE on the materials/manufacturing element.

The projects in the materials/manufacturing element will be performed at national laboratories, private industry sites, and universities. A major segment of the effort will be conducted by materials suppliers. DOE-ORO and ORNL will utilize solicitations and a variety of contractual mechanisms. Work under this sub-element will be performed mainly in existing facilities. Only when absolutely necessary will new facilities be constructed. There are a number of existing facilities available for materials research and these will be utilized prior to any consideration of developing new facilities. However, it is likely that modification of existing facilities will be necessary.

Several possible project areas were identified in the strategy papers that were reviewed at the workshop in Cincinnati on May 28, 1993. The developmental needs generally fall into two categories: evolutionary and revolutionary. Evolutionary materials carry forward the design capability of existing
turbine materials. Revolutionary materials would leap-frog current materials limitations, but their feasibility still must be proven. One of the critical evolutionary technologies is improved thermal barrier coatings (TBCs). TBCs build on current technology to achieve the turbine inlet temperature and life requirements set for the ATS Program and are therefore a key to near-term ATS deployment. They can provide a 100°-200°F benefit which is equivalent to 2-3 generations of super alloy development. However, significant advances in thermal barrier coating technology will be required to meet the ATS development goals.

Additional evolutionary materials needs include: (1) turbine/disk alloy development, (2) large air-foil directional solidification casting, (3) metallic coating technology, (4) seal technology/closed circuit steam cooling, (5) modeling of large casting for disks, and (6) manufacturing processes. The key objective to the revolutionary materials development is to reduce or eliminate the need for air-cooling of hot section components. The potential use of steam for blade cooling introduces questions concerning hydrogen embrittlement, oxidation, and fouling. Revolutionary materials needs include: (1) ceramics, (2) intermetallics, (3) refractory metals, and (4) composite materials. One strategy being proposed for revolutionary materials development is to tie in with on-going programs within NASA, DoD, and other DOE programs.

CURRENT MATERIALS SUPPORT PROJECT

The Ceramics for Stationary Gas Turbines Project is one of the main elements of the ATS Program. This project is being conducted by Solar Turbines, Inc. and was started in September 1992. The goal of this project is to improve the performance of stationary gas turbines in industrial applications through the selective replacement of metallic hot section parts with uncooled ceramic components. The materials/manufacturing element is providing support to Solar Turbines, and this project is a good example of possible future tasks under the materials/manufacturing element.

The primary goal of the Ceramics for Stationary Gas Turbines project is to determine the long-term survivability of ceramic materials for industrial gas turbine applications. Because existing data for many candidate structural ceramics are limited to testing times less than 2,000 h, this project will focus on extending these data times on the order of 10,000 h, which represents the lower limit of operating time anticipated for ceramic blades and vanes. This long-term test effort will be done in coordination with Solar Turbines and University of Dayton Research Institute (UDRI) as shown in Figure 2.

The specific of the research project includes evaluating the static tensile creep and stress rupture (SR) behavior of three commercially available structural ceramics that have been identified by Solar Turbines as leading candidates for use in industrial gas turbines. Tensile creep data will be generated in air by measuring creep strain as a function of time, applied stress, and temperature. The SR resistance will be evaluated by continuing each creep test until the specimen fails. For each material investigated, a minimum of three temperatures and four stresses will be used to establish the stress and temperature sensitivities of the creep and SR behavior. The test matrix utilized in this program is intended to extend the test conditions investigated by the engine component manufacturers. These conditions focus primarily upon the evaluation of the creep and SR behavior of two candidate materials at one temperature only. Consequently, the temperatures chosen for the ORNL/UDRI
effort will bracket that used by the engine component manufacturers.

For each material investigated, the associated creep and SR data will be used to generate a mechanical reliability diagram describing the time-to-failure and failure mode (creep damage versus slow crack growth) as functions of stress and temperature. The applicability of various creep and SR models (Monkman-Grant, Sherby-Dorn, Larson-Miller, etc.) to the description of the experimental data will also be investigated. The final material selection will be based upon the comparison of these diagrams.

SUMMARY

The materials/manufacturing element of the ATS Program is needed to attain the goals of the overall program. One of the main approaches to achieving the higher efficiency goals is to obtain higher turbine inlet temperatures of greater than 2600° F for extended operation periods. To achieve these temperatures, there is a need for materials development.

The specific objectives of the materials/manufacturing element include:
(1) providing support on materials/manufacturing activities to the ATS prime contractors, (2) develop materials/manufacturing technologies for the various ATS teams and gas turbine industry at-large, and (3) provide a technology transfer service between the various programs at NASA, DoD, DOE, and the ATS Program. The schedule calls for the development of several projects in FY 1995. The plan will be developed in several stages with input from the gas turbine manufacturers, materials suppliers, and various other organizations. An Advanced Materials and Turbine Technology team will be used to develop the plan. In future years this team will also be used to guide this element. The detailed
Figure 1. Advanced Turbine System Program
Figure 2. Current Project with Solar Turbines
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