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MATERIALS/MANUFACTURING SUPPORT ELEMENT FOR THE ADVANCED TURBINE SYSTEMS PROGRAM

CONTRACT INFORMATION

Contract Number	ED 32 01 00 0 Field Work Proposal
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New concepts such as Castcool®, fabricated blades, etc. will be examined as alternate approaches for meeting the requirements for ATS airfoils in large gas turbines. To be viable, any new concept would have to afford advantages in terms of cost and/or cycle performance characteristics.

Ceramics Adaptation

Monolithic ceramics and ceramic composites processing technology will be adapted to ATS hot section hardware such as: shrouds, vanes, hollow (air cooled) stage 1 vane airfoil segments in metal bands, combustors and transition ducts, and seals for closed circuit steam cooling.

Monolithic ceramics and ceramics manufacturing technology will be adapted by process modeling and control and component inspection methodology. Long-Term Thermal and Mechanical Reliability will be studied with regards to oxidation and corrosion and the effect of transient stresses.

Manufacturing Technology for Scale-Up of Current DS and SC Turbine Airfoils

This element focuses on the modifications/ improvements required to produce DS and SC airfoils for land-based gas turbines. Manufacturing technology is included in the three previous sub-elements. Manufacturing issues were consistently cited as one of the high priority technology areas by the gas turbine industries.

Alloy melting practice or treatments to reduce sulfur content in alloys will be studied. This work will be coordinated with the effects of reduced sulfur on oxidation resistance and resistance to spallation in TBCs. The manufacturing technology addressed will include: modifications/improvements in the DS and SC casting parameters, mold materials and design, grain orientation control for large single crystal airfoils, ceramic core materials and design, and mold and core removal and casting clean-up procedures that prevent recrystallization in SC airfoils. Post casting processing e.g. hot isostatic pressing and heat treatments and in-line and post manufacturing quality assurance and associated inspection techniques will also be addressed.

Materials Characterization

Long-term high temperature materials properties are needed for life prediction and reliability and process modeling for ATS. The database on materials selected by industrial and utility gas turbine contractors needs to be expanded. In addition, the generation of 100,000 h creep and fatigue data by standard methods is impractical to meet nearer term ATS needs. Accelerated testing methods and modeling will be investigated to provide reliable forecasted long-term properties. Substantiation of these procedures with microstructural analysis of long-term exposed similar materials from the field will be investigated.

The use of higher temperature airfoil and disk alloys developed for aircraft gas turbine use in ATS gas turbines will require evaluation of longer term microstructural stability.

The characterization of the long-term stability of TBCs subjected to time-dependent thermal and mechanical loads is primary concern since TBC failure may lead to catastrophic failure of the underlying alloy. Current characterization techniques are often based on semi-empirical tests which evaluate coating spallation effects. In order to generate data which can be used to establish life prediction methodologies for TBCs, the thermomechanical characterization tasks will be used to evaluate the failure mechanisms for representative thermomechanical cycles. A major thrust of this task will be to establish standardized test geometries and measurement procedures.

A life prediction analytical model will be developed for life prediction and reliability using the long-term data generated. Modeling will also be applied to large disks as required for ATS.

If protected from externally-induced physical damage, the intrinsic lifetime of TBCs depends on the chemical stability of the bond coat/TBC interface. Of primary concern are the effects of oxidation and salt-induced hot corrosion on the mechanical strength and stress distribution of this interface. Additional concerns relate to the interdiffusion of component elements, such as sulfur, to the interface. Corrosion studies of reference TBC/bond coat systems will be

ABSTRACT

The Technology Base development portion of the Advanced Turbine Systems (ATS) program contains sub-elements which address generic technology issues for the advanced turbine system. One sub-element is the materials/ manufacturing technology program to be directed by Oak Ridge National Laboratory, with work to be performed predominantly by industry. This sub-element includes materials issues, such as the long-term mechanical property testing and materials exposure testing, which are important for all turbine manufacturers but not specific to any one individual manufacturer's project. Projects in this sub-element are aimed toward hastening the incorporation of new materials and components into gas turbines.

A materials/manufacturing plan was developed in several stages with input from gas turbine manufacturers, materials suppliers, universities, and government laboratories. The plan was developed by a small advanced materials and turbine technology team over a six-month period. The technology plan calls for the initiation of several high priority projects in FY 1995.

The technical program for the materials/ manufacturing element focuses on generic materials issues, components, and manufacturing processes. Categories include: Coatings and Process Development, Turbine Airfoil Development, Ceramics Adaptation, Directional Solidification (DS) and Single Crystal (SC) Airfoils Manufacturing Technology, Materials Characterization, Catalytic Combustor Materials, and Technology Information Exchange.

BACKGROUND INFORMATION

In 1993, the Department of Energy (DOE) initiated a program to develop advanced gas turbines for power generation in utility and industrial applications. The Advanced Turbine Systems (ATS) Program is jointly sponsored and managed by DOE Fossil Energy (FE) and DOE Energy Efficiency and Renewable Energy (EE). The program plan (Ref. 1) outlines an eight-year program which will involve turbine manufacturers, utilities, industrial end-users, national laboratories and universities. The objective of the ATS Program is to develop ultra-high efficiency, environmentally-superior, and cost-competitive gas turbine systems for base-load application in utility, independent power producer, and industrial markets. The primary focus of the program is on natural gas-fired turbines, but adaptation to coal and biomass fuels is a design consideration. The program includes two major elements: innovative cycle development and developments to increase the turbine inlet temperature. One of the supporting elements of the ATS Program is a materials/ manufacturing technologies task. The purpose of this element is to address material issues for both utility and industrial gas turbines. This paper describes the ATS materials/manufacturing plan that was completed in April 1994 (Ref. 2).

DOE-Oak Ridge Operations Office (ORO) and the Metals and Ceramics Division of Oak Ridge National Laboratory (ORNL) are coordinating the effort for the materials/manufacturing element. These Oak Ridge organizations are involved in various national DOE materials programs including: (1) Ceramic Technology Program, (2) Fossil Energy Materials Program, (3) Continuous Fiber Ceramic Composite Program, (4) Advanced Industrial Concepts Materials Program, and (5) Basic Energy Science Welding Program. Other Federal laboratories also have extensive materials/ manufacturing expertise that will be used to support this initiative.

OBJECTIVES OF MATERIALS/ MANUFACTURING ELEMENT

Materials and related manufacturing technologies are two key activities required to meet the Advanced Turbine Systems (ATS) Program goals. Several turbine manufacturers have stated a need for turbine inlet temperature as high as 2600°F (300°F higher than current heavy frame machines) to achieve the efficiency goals. To achieve these temperatures for the extended operating periods, there is a need to utilize new materials developments. The turbine manufacturers also indicated a need for effective interaction between themselves, materials suppliers, national laboratories, and others. Thus, the ATS Program Plan incorporates an element to address materials/manufacturing issues for both industrial and utility gas turbines.

The primary objective of the materials/ manufacturing element is to provide manufacturing technologies support to meet the ATS goals. The ATS prime contractors are responsible for the technologies necessary for their demonstration projects. The materials/ manufacturing support is intended to complement the ATS team effort and provide expertise not available to any one single contractor.

TECHNICAL PLAN

The technical program for the materials/ manufacturing element focuses on materials issues, components, and manufacturing processes with emphasis on generic developments. The sub-elements for the program were divided into seven categories as shown in the work breakdown structure in Figure 1.

Coatings and Process Development

This element will develop coatings and application processes to provide thermal barrier coatings (TBCs) for land-based gas turbines. The TBC/bond coat system was noted by all the manufacturers as a particularly high priority issue.

Reliable, higher performance TBCs will be developed to meet ATS temperature requirements. Coatings must be stable for times commensurate with ATS goals. Dependable TBCs would enable increased turbine inlet temperatures while maintaining airfoil substrate temperatures at levels to meet ATS life goals.

Current bond coats serve a dual purpose of providing oxidation and corrosion resistance to the metal substrate (and in some instances, the internal air-cooling passages of the airfoil) and bonding of the TBC. Corrosion requirements for land-based gas turbines require this work to be coordinated with work described under Materials Characterization and efforts on reducing the effects of sulfur described under Manufacturing Technology for Scale-up of Current DS and SC Turbine Airfoil Processes. Bond coats will be developed that have demonstrated reliability to allow increases in turbine inlet temperature dependent on the TBC system while maintaining airfoil substrate temperatures at levels to meet ATS life goals.

Analytical models will be developed to enhance the reliability of dependence on the TBC systems to provide turbine inlet temperature increases with long life required to meet ATS goals. Testing will be used to validate the model's capability of predicting long-term behavior. The model would also provide a basis for developing diagnostic techniques for detecting impending coating failures.

Current manufacturing processes will be modified as required to process the reliable, higher performance TBC systems. Such processes will ensure that the benefits of TBCs and advanced air cooling airfoil designs are additive and cost effective.

Inspection and repair techniques will be developed in parallel with efforts described above that are applicable to the maintenance of ATS gas turbines in the field. Again, the dependence of TBCs systems to provide turbine inlet temperature increases with long life required to meet ATS goals will require development of procedures/devices to ensure preliminary indication of impending TBC failure. Life prediction methodology and sensor techniques will be developed, validated, and demonstrated.

Innovative coating concepts will be studied where a significant payoff can be forecast in terms of reliability, cost, or physical properties.

Development of Turbine Airfoils for ATS

Modification of current alloys will be investigated to meet specific requirements of ATS e.g., corrosion and long-term creep and fatigue properties. Special consideration will be given to alloy needs for closed circuit steam cooling.

Alloys will require modification /improvements in: casting process parameters, mold materials and design, core materials, implementation of computer modeling and rapid prototyping being developed elsewhere.

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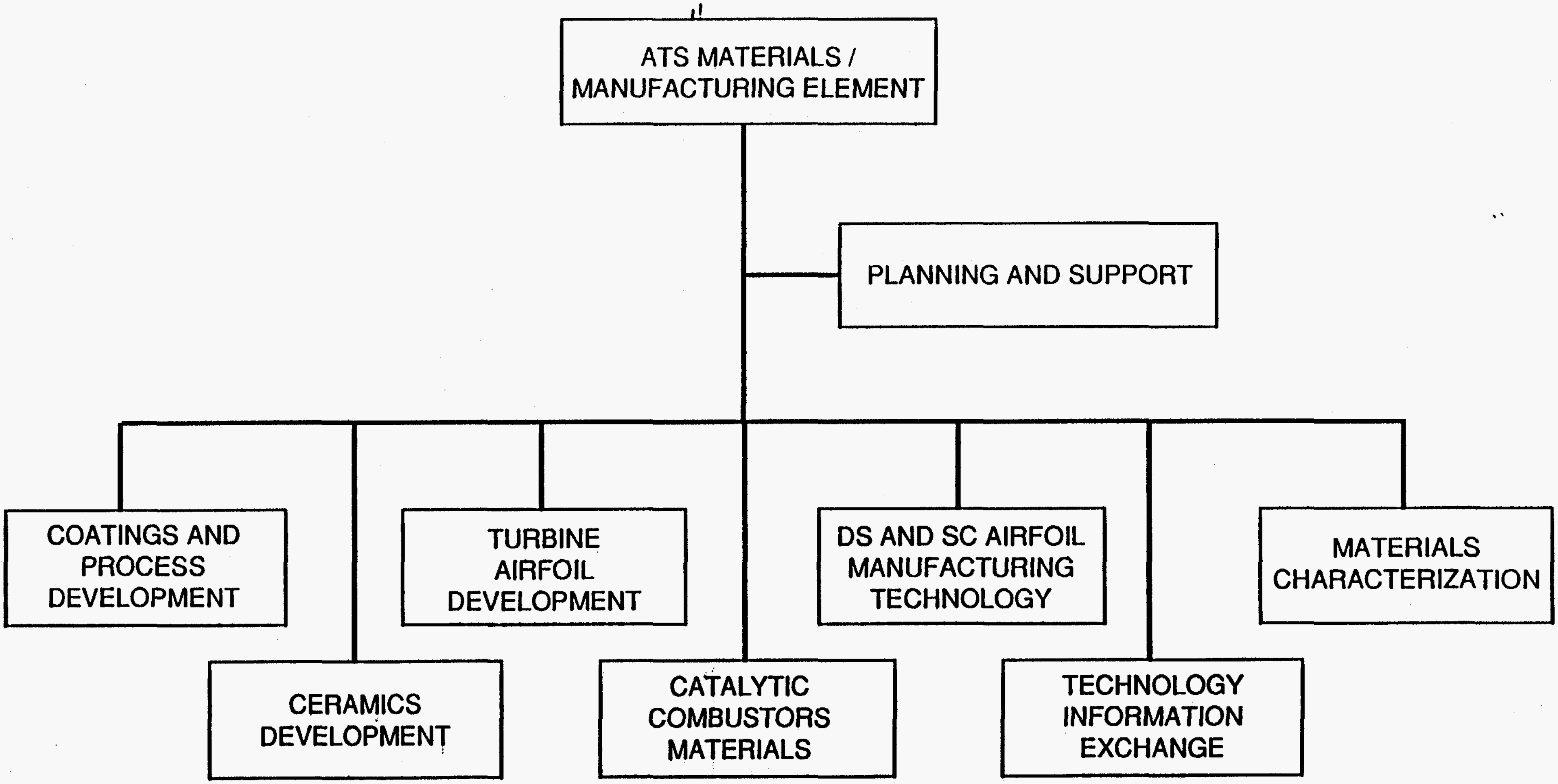

Figure 1.1. Work Breakdown Structure of the Research Tasks in the ATS Materials/Manufacturing Element

conducted under prototypic ATS temperature and environmental conditions to identify degradation mechanisms operative at the bond interface and to model their kinetics to enable predictions of long-term (100,000 h) effects. Test variables will include effects of reactive metal additions to the bond coat and pretreatments to remove sulfur from the substrate alloy.

Catalytic Combustors Materials

The applicability of a simple catalytic combustor that could operate at the higher projected temperatures required for ATS is limited by the current state-of-the-art materials. New materials will be explored that could meet these stringent demands.

Technology Information Exchange

This element will provide a mechanism to transfer information on materials issues developed at NASA, DoD, and other DOE materials programs to the ATS Program. Many of these materials efforts will have a significant impact on the ATS Program.

SUMMARY AND CONCLUSIONS

The technical program for the materials/ manufacturing element is focused on mid-to-long range R&D as identified by the gas turbine industry. For this element to be successful, it is necessary that industry have a lead role in executing the technical agenda. The majority of the projects will be directly with the gas turbine industry and many others will be lead by gas turbine suppliers. Federal laboratories will also have projects in the materials/manufacturing element, and these projects will also be required to be coordinated with the gas turbine industry. Projects will be selected based on competitive solicitations and other contractual mechanisms. Requests for proposals will be issued for the industrial materials/manufacturing projects, and informal competitions will be held for the federal laboratory projects. All of the projects will require teaming with a gas turbine company operating division. The involvement of universities will also be encouraged for both the industrial projects and the federal laboratory projects.

Two major solicitations were issued in FY 1994. One solicitation was for the development of thermal barrier coating systems and the second was for manufacturing of single crystal turbine blades for both utility and industrial size gas turbines. Proposals have been received and are currently under evaluation. Work will be initiated in both of these project areas in early FY 1995. It is anticipated that additional solicitation in other high-priority project areas will be initiated in FY 1995–96.

REFERENCES

1. "ATS Program Plan", Office of Industrial Technologies and Office of Fossil Energy, Department of Energy, July 1993, DOE/FE-0279

2. "Materials/Manufacturing Plan for Advanced Turbine Systems Program", Office of Industrial Technologies, April 1994, DOE/OR-2007