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ADVANCED MANUFACTURING PROCESSES FOR GAS TURBINES - CHALLENGES FACING THE INDUSTRY

G. S. Reddy

Mechanical Engineering Department,
Sreenidhi Institute of Science and Technology, Yamnampet, Hyderabad, 501301, INDIA.

Abstract— *Manufacturing processes are continuously changing from the current traditional to those processes which: (i) are sustainable, (ii) produce recyclable products, (iii) has lower carbon foot-print, (iv) easy to artificial intelligence and robotics-ready, (v) socially responsible, (vi) energy efficient, (vii) offers safer operation, (viii) improves return on investment, (ix) effective risk management and (x) environment friendly.*
Advanced technology associated with the manufacturing of gas turbine blades and vanes is presented. Advantages of single crystal blades over the equiaxed and DS blades is explained. Recent advances which took place in vacuum investment casting manufacturing process are described. Manufacturing is an ever-changing industry, where manufacturers face new issues and concerns every year. Since this decade is no exception, here are a few of the top concerns that manufacturers are dealing with. Simulation is an indispensable problem-solving methodology for the solution of many real-world problems. Simulation is widely used to describe and analyze the behavior of a system, ask what-if questions about the real system, and aid in the design of real systems. Both existing and conceptual systems can be modeled for effective simulation.

I. INTRODUCTION

Significant research and development efforts are underway to reduce thrust specific fuel consumption (TSFC) for commercial and military aircraft propulsion. Approaches for reducing TSFC include increasing overall pressure ratio (OPR), turbine inlet temperature, and bypass ratio. Engines with high OPR and turbine inlet temperature require significant increases in temperature capability of engine materials. While significant advances in single crystal nickel-base super alloys along with thermal barrier coatings and cooling technologies have been responsible for increases in turbine operating temperatures over the last several years, the blade alloy temperatures are reaching close to their melting points. Advanced thermal barrier coatings (TBCs) with lower thermal conductivity and improved bond-coats, will be required for increasing temperature capability of turbine engines using metallic blades and vanes.

Revolutionary increases in OPR and turbine inlet temperature can be achieved by the use of ceramic matrix composites (CMCs) in hot section of gas turbine engines. It is envisioned that CMCs will be introduced in static structures, such as shrouds, combustor liners, vanes, and then in rotating components, first with low pressure turbine (LPT) blade and then with high pressure turbine (HPT) blade. Besides offering the capability for higher operating temperatures, CMCs have densities 1/3rd of nickel-base super alloys, thus offering significant weight benefits as well. Silicon carbide fiber reinforced silicon carbide (SiC/SiC) CMCs is the material of choice for gas turbine engines. SiC/SiC CMCs are targeted to have temperature capability equal to or greater than 1315^0C, offering greater than 100^0C increase in temperature capability over single crystal nickel-base super alloys.

Because of high stresses in turbo machinery disk, it is unlikely that CMCs will be used for disks. High OPR engines will require compressor disk alloys with temperature capability greater than that for the current state-of-the-art alloys. With recent introduction of third generation of powder metallurgy nickel-base disk alloys, the disk temperature in advanced commercial engines today is on the order of 704^0C. With further increases in the OPR beyond the current state-of-the-art, the disk temperature for last stage of compressor is expected to be greater than 760^0C. It is envisioned that for OPR of 60, disks with 815^0C temperature capability will be required.

In addition to the mechanical and thermal loads, the environmental factors and the combined effect of environment plus mechanical/thermal loading are expected to have a greater degree of influence on durability of advanced materials with further increase in hot section temperatures for gas turbine engines. With increase in turbine operating temperatures, new environmental effects, such as deposition of sulfate melts and glassy silicate melts along with erosion by small particles, are becoming major factors affecting durability of new high temperature materials.

II. RESULTS AND DISCUSSION

A. Challenges in advanced super alloy manufacturing and materials modelling:

Advanced alloy development is an active area of research with pervasive impact on the world manufacturing industry, indeed airframe, jet engine, power generation, medical device, defense, and automotive companies all stand to benefit from such research. The time-consuming traditional methods of development be avoided and access state-of-the-art micromechanical modeling techniques that accelerate the development of these alloys and sustain our country's global competitiveness. Unfortunately, a disconnect currently exists between alloy developers and the manufacturing base of industries that want to machine components utilizing new alloys.

Time-to-market advantages are being lost while our manufacturing base struggles with machinability issues that accompany new, unfamiliar alloys. Additionally, new alloys are inhibited from broad-based dissemination due to prohibitive manufacturing costs.

B. Challenges in supply chain management— To achieve supply chain integration, multiple enterprises need to work cooperatively to deliver end products. Some examples of the functional elements of a supply chain include component part and raw material suppliers, transportation networks, distributors, warehouses, final assembly plants, and retailers. Typically, some elements of a supply chain will cross enterprise boundaries. Simulation analysts building supply chain models may need to interact with peer analysts in other enterprises that use different simulators for their enterprises.

C. Challenges for Increasing Temperature Capability of EBCs— The state-of-the-art EBCs have upper temperature limit of 1315^0C. Use of CMCs in hot section components of high OPR gas turbine engines will require EBCs with temperature capability greater than 1482^0C. Based on the recession data so far, it appears that coatings will consist of complex silicates as one constituent of the coating. While complex silicates show initial promise in terms of chemical stability in moisture environment, long-term durability needs to be demonstrated. Chemical reaction of coatings with moisture at high gas velocities encountered in turbine section of the gas turbine engine is of concern as reaction rates increase with gas velocity. Experiments in high pressure burner rig has shown eight fold increase in recession rate for SiC/SiC with increase in velocity from 30 m/s to 200 m/s. Maintaining long-term phase stability of complex oxides at temperatures on the order of 1482 – 1648^0C is a challenge as one component of the oxide preferentially reacts with moisture to form a volatile product. A suitable non-Si containing bond coat will be required for such high temperatures as Si melts at 1410^0C. The thermo chemical stability challenges will even be greater for thin coatings that will be required for rotating components, such as turbine blades.

D. Degradation of Hot Section Components Due to Foreign Object Impact and Erosion
Gas turbine engine components are subject to foreign object damage (FOD), which is induced by impact of foreign objects, which could be due to ingestion of sand, debris, rivet mandrels, and other substances. First stage high pressure CMC turbine blades would be prone to impact damage. The sizes of the hard foreign objects could be in the micron to millimeter range, which can damage the CMC turbine blades. Impact studies (ref. 30) at NASA with 1.59 mm diameter steel-ball projectiles at velocities ranging from 115 to 400 m/s have shown the extent of damage for uncoated 2-D woven SiC/SiC CMC increasing with increase in projectile velocity. At 115 m/s projectile velocity, the composite showed no noticeable surface or internal damage and retained its as-fabricated mechanical properties. Beyond 115 m/s projectile velocity, the extent of material degradation increased with increase in projectile velocity, with degradation of mechanical properties. At velocities > 300 m/s, the projectile penetrated the composite;

E. Regulatory compliance and traceability
Nearly every type of manufacturer faces increasing regulations aimed at everything from ensuring product safety to managing disposal and reclamation procedures. While many regulations may be beneficial to consumers, each regulation adds an additional burden to the companies that must comply with the requirements, which often differ from country to country. Manufacturers must ensure they have complete visibility into global supply chains so they can prove not only their own compliance, but also that of their suppliers. Regulations often require the ability to track where specific items have been used or to trace materials from an end-item at a customer site back to specific materials used in its manufacture.

F. Environmental concerns
Many local and regional regulations affect various aspects of the manufacturing process, from the ability to use certain materials, to worker exposure, to disposal of waste and byproducts. Manufacturing is inherently a harsh environment, so ensuring the safety and health of workers with proper care and equipment is of crucial importance. Disposing of waste products and recycling programs for scrap and returned materials add costs and complexity to manufacturing, but also result in a healthier environment and protection for customers and workers alike.

G. Healthcare costs
Rising costs of healthcare for workers put a strain on already fragile manufacturing cost structures. Manufacturers in the U.S. in particular face the burden of providing healthcare while their competitors in other countries do not. There is no strong alternative to the current solution on the horizon, so manufacturers need to be cognizant of this large and growing item that can increase the cost of products to the point where they are not competitive.

H. Keeping products relevant

Product innovations come at a dizzying pace, and manufacturers struggle to keep up. As companies vie to be first to market with a new concept, the temptation to skip steps or skimp on quality materials can be overwhelming. Companies need to plan to have adequate engineering time to ensure that the specifications for critical materials such as wires and cables are in line with operating conditions. The last thing a new product needs is to develop a reputation for poor quality right out of the gate.

Fast times to market mean that companies may need to become more systematic about managing innovation rather than leaving new product ideas to chance. Product preferences change so quickly that delays in introducing new ideas may be the death knell for once popular products. Implementing procedures that keep a steady stream of new product ideas and innovations in the pipeline is essential to manufacturing success.

III. CONCLUSION

Alloy development to meet the today's requirement of higher temperature capability for hypersonic plane be addressed more aggressively before it is too late. Ceramic fiber reinforced Ceramic matrix composites will offer the solution. Thermo-mechanical processing and fabrication of advanced composites need immediate attention. Aggressive introduction of artificial intelligence and robotics is more likely to take the driver's seat and cannot be neglected in order to accomplish global competitiveness. Innovation in materials research to cope up the demand for very high temperature capabilities for hypersonic engines need to be addressed in realistic framework.

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