Gas turbine OEMs constantly seek to improve efficiency and reduce lifecycle costs of their models, while maintaining durability. They introduce novel methods to improve engine performance. But there are challenges. For instance, improved performance could lead to increased mechanical and thermal stresses.

The performance of an industrial gas turbine depends strongly on the operating conditions and the environment in which it functions. Advances in alloys, coatings, and ceramics in the last 20 years are helping designers face these challenges, and support gas turbine requirements.

**Improving combuster liners**

The industrial gas turbine market has demanded improvements that yield higher efficiency, better performance and lower life-cycle costs, while reducing greenhouse gas emissions using a variety of fuel types. Achieving these improvements has provided many challenges, not only in the design and operation of the gas turbine equipment, but also in the materials and processes used in the construction. These challenges often result in designs that involve severe operating conditions, such as higher temperatures and stresses.

Higher temperatures and stresses can cause materials to plastically deform, undergo creep over time, or experience fatigue if the stresses are cyclic. Higher temperatures can also accelerate oxidation.

Sometimes the challenges are unique to a particular application or site and may involve more aggressive environments. When salts or sulfur are present in the air, fuel or cooling water, accelerated attack can occur as a result of hot corrosion or sulfidation.

Costs of materials and processes also pose challenges as they impact lifecycle costs of equipment. Regardless of the challenges, advanced materials are often summoned or developed to provide the enabling technology at an affordable price. The combuster liner and the gas producer blade are the major turbine components that are greatly exposed to these challenges and also benefit most from the advances in materials and processes (Figure 1).

In the combuster, carefully measured amounts of fuel and pressurized air from the compressor section are combined, ignited and burned. The combuster liner is the first component to come into contact with high-temperature flames and therefore deal with the highest gas temperatures. The traditional material of construction of industrial gas turbine combuster liners has been a sheet metal alloy such as Hastelloy X or Haynes 230.

Liners in the past were only occasionally, if at all, coated. Materials must be readily formable into the shapes required and easily joined to construct the liner, which, in service, must face a hostile environment and therefore must have excellent resistance to both high-temperature oxidation and hot corrosion. The material must also have sufficient creep deformation resistance and fatigue capabilities.

Several solutions to these challenges have been formulated. For instance, Solar Turbines Incorporated has progressively employed advanced sheet metal alloys, such as Haynes 230 and Haynes 214, in current and new products. These alloys have increased environmental resistance over Hastelloy X, experiencing lower metal loss in an oxidation environment. In addition to improved oxidation, combuster liner challenges could be overcome by using Thermal Barrier Coatings (TBC) to reduce the metal temperature or ceramic composites to raise temperature capabilities.

An additional benefit from these advances includes improved emissions from lean-premixed gas turbine combustors — obtained by using the “hot wall” concept. In this, air saved from reduced cooling requirements for the combuster wall can be used to lean out the flame in the primary zone, resulting in lower NOx emissions. A second emission benefit is a reduction in CO quenching near the combuster wall.

**Benefits of coatings**

As stated earlier, TBCs can be used to reduce liner wall temperatures. A TBC consists of a metallic-bond coating applied directly onto the component surface followed by the application of a ceramic top coating. The function of the metallic-bond coating is to provide oxidation protection to the metallic substrate, minimize thermal expansion mismatch, and to provide strain compliance between the substrate and the ceramic layer. The ceramic layer with low thermal conductivity creates the thermal gradient needed across the TBC system. Model calculations and instrumented rig tests determined a temperature reduction at the surface of '13°C/0.1 mm to 14°C/0.1 mm (6°F/0.001 inch to 7°F/0.001 inch) of ceramic coating. This level of temperature reduction could be significant to component life (Figure 2).

An alternative material of construction for combuster liners is the application of ceramic matrix composites (Figure 3) in place of the metallic liners. The use of a ceramic combuster allows...
for increased firing temperatures without degrading combustor durability.

The material of choice for ceramic liners is a Continuous Fiber-reinforced Ceramic Composite (CFCC) material based on a silicon carbide-based fiber (Nicalon) as reinforcement, with a silicon carbide (SiC) matrix incorporated by chemical vapor infiltration. CFCCs were selected over the more conventional monolithic ceramic materials due to their superior fracture toughness, which gives them a distinct advantage over monolithics for large structures such as combustor liners.

Rapid oxidation (in few thousand hours) due to environmental degradation is a challenge for the SiC material. An Environmental Barrier Coating (EBC) system was developed under the NASA High Speed Civil Transport, Enabling Propulsion Materials Program in the mid-1990s to successfully overcome this.

The EBC system was scaled up and optimized for combustor liners. It has proven itself in a single engine test for operation of over 15,000 hours. Barium strontium aluminum silicate provides the oxidation barrier for the EBCs.

**There is a tradeoff in oxidation and hot-corrosion protection as strength is increased**

An alternative system based on aluminia ceramics has been developed and tested. The oxide composite by itself does not have the temperature capabilities of silicon carbide composite. The addition of a Functionally Graded Insulator that acts as a thermal barrier creates a higher temperature system than the silicon carbide material with EBC. The system has now logged over 20,000 hours in a field test for an outer combustor liner. Field experience has been demonstrated on a number of units in various industrial applications.

**Gas producer blades**

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For this reason, today’s gas producer blade material must, first of all, be castable. Along with castability, the material must feature excellent creep strength and fatigue resistance. In addition, the material must be capable of retaining these characteristics after long periods of service, which requires excellent microstructural stability.

The blades must also be equipped with sufficient oxidation- and hot-corrosion-resistance. Coatability and coating performance per design requirements are also important. Improvements in creep life have been achieved by the introduction of new alloys and processes (Figure 4). CMSX-4 offers an increase of 3x in creep life compared to CMSX-3 and a 10x increase over equiaxial alloys at 982°C (1,800°F).

Today, we are seeing the advent of more capable nickel-base superalloys and the use of polycrystalline directional solidification and single crystal casting techniques originally developed for aero applications. New generations of single crystal alloys are increasing creep strength by increasing the amount of rhenium and ruthenium in composition.

However, there is a tradeoff in oxidation and hot-corrosion protection as strength is increased. Chromium percentage, which is a measure of environmental resistance, decreases with increasing strength. Therefore the need for coatings becomes more important as the mechanical properties of alloys are improved.

New alloy systems require protection against oxidation and hot-corrosion. These alloys carry with them new challenges related to their coatability and coating stability in service. Environmental resistant coatings have been implemented to address alloy oxidation and hot corrosion degradation.

Coatings, such as simple aluminides and platinum-modified aluminides, have
result of the diffusion coating process is the formation of an aluminum-rich outer layer on the component. The protective nature of the coating stems from this aluminum reservoir.

TBCs applied by an Electron Beam Physical Vapor Deposition process (EB-PVD) can lower blade surface temperature. The process involves vaporizing a ceramic ingot using an electron beam, thus forming a vapor cloud of ceramic material, typically Yttria Stabilized Zirconia (YSZ). The YSZ ceramic coating is applied on the turbine blade surface either directly or over a metallic bond coating such as platinum aluminide (Figure 6).

The use of monolithic ceramic materials for gas turbine rotating components remain a major challenge in this industry. Advances in ceramic material properties, both mechanical and environmental, as well as in processing technologies and design methodologies are necessary before successful implementation in these challenging applications.

Achieving success

The challenges facing the modern industrial gas turbine are numerous. The environmental and mechanical conditions demand materials and processes that can survive thousands of hours of service without serious degradation. Advances in material technologies have often provided the capability to achieve success.

New alloys, coatings and processes have provided technological advancements for many components. Combustor liners and turbine blades are a few of the components that have benefited from these advancements. Better performance, higher efficiencies, and lower lifecycle costs are often attained with material technologies. Development and implementation of new material technologies are necessary to meet the challenges of tomorrow.

Author

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