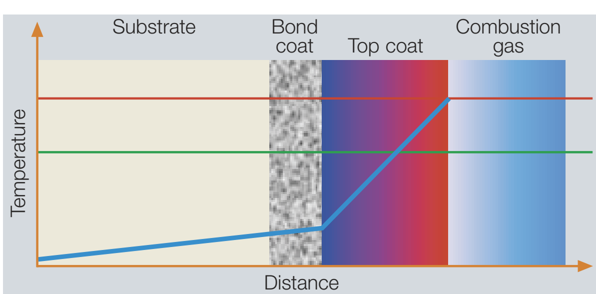
Technical Paper

Advanced Thermal-Barrier Coatings

Since its origins over thirty years ago, the aim of thermal-barrier coatings has been to enhance the longevity of coated parts at higher temperatures. In addition, these ceramic coatings are used for clearance control applications ("abradables") in the high-temperature regime. At Sulzer Hickham, investigations have led to the formulation of one such coating on an advanced frame gas turbine part.

The total world energy consumption is estimated to reach 145 million GWh by 2010. The U.S. demand alone requires up to 15 GW per year of new and replacement capacity. Gas turbines in industrial and utility applications can help meet future power generation requirements. In order to increase the efficiency of gas turbines, the firing temperatures are being continuously increased (up to 1425 °C/2600 °F). Since conventionally cooled superalloys cannot withstand more than 1150 °C/2100 °F, current advanced industrial gas turbines (IGT) and some older turbines rely heavily on the utilization of thermal-barrier coatings (TBC).

The use of TBCs began over three decades ago when the coatings were first applied to combustion parts in a flight gas turbine – which resulted in doubling the part life. Sulzer Hickham has been applying TBC coatings since 1996. It has been estimated that a TBC of about 0.015" (375 μm) can reduce the turbine airfoil temperature by as much as 165 °C (297 °F). This insulating property of a TBC is key to the life enhancement of critical hot-section components in turbines. The thermal conductivity of zirconia used in a TBC is about 1 W/m·K, which is about 3000 times less conductive than copper and about three times more than the wool used to make sweaters.



1 Schematic coating structure and temperature gradient (blue line) of a thermal-barrier coating as a function of distance.

The thermal-barrier coatings applied by Sulzer Hickham, in keeping with the most stringent OEM practices, utilizes a 2-layer coating system (Fig. 1). It consists of a MCrAlYX (M = Ni or Co or both; X = Hf, Zr, Si, or combinations thereof, or other reactive elements) bond coat and an 92%-ZrO_2/ 8%-Y_2O_3 topcoat. The bond coat provides good adhesion between the metal substrate and the ceramic topcoat. It acts as a heat shield, insulating the substrate alloy and therefore allowing higher operating temperatures and/or reductions in cooling requirements.

Protection from High Temperatures

TBC research has focused on more than one front, prime among them being to increase the longevity of the coating. Repeated thermal cycling, between turbine starts and stops, leads to the accumulation of thermo-mechanical strains and, ultimately, failure and coating delamination from the part. Three types of TBC are basically used (Fig. 2):

The air-plasma-sprayed (APS) TBC coating has a structure with built-in porosity that gives it low thermal conductivity and good thermal-shock resistance.

The Electron Beam Physical Vapor Deposition (EB-PVD) method gives a "columnar" type structure more amenable to thermo-mechanical strain. However, it is an expensive process, not particularly suited to large parts typically employed in land-based gas turbines.

Recently, there has been a much activity in creating so-called macro-cracked TBCs using standard plasma spray processes. Unlike a standard APS TBC, these coatings have vertical macro-cracks that simulate an EB-PVD-TBC-type structure and are considered to be superior to a standard plasma spray coating.

Clearance Control

In addition to their thermal-barrier properties, zirconia ceramic materials are also used for clearance control applications in the high-temperature regime. Tighter clearance control leads to improved efficiency of the turbine. Clearance control coatings, so-called abradable coatings, function by permitting a rotating part (such as a blade) to “cut” a path in a seal (abradable coating) with minimum clearance. Many advanced gas turbines utilize a thick ceramic coating to impart both thermal-barrier and abradability properties. Sulzer Hickham has put into production one such coating (Fig. 3) and has also developed a process to apply a smooth TBC. It is believed that such a coating, applied on to the gas path area of rotating parts, enhances the aerodynamic efficiency of the components.

Since its humble origins in stationary parts, modern-day TBCs are being designed into the manufacturing of advanced gas turbines, both flight- and land-based. As the demand for TBCs increases, Sulzer Hickham is well poised to deliver to customers the most exacting and advanced coatings.

3 This first-stage inner shroud of a gas turbine is coated with a Sulzer Hickham TBC that combines the effects of both thermal-barrier resistance and abradability.

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2 Evolution of thermal-barrier coatings (from the left): air plasma spray, EB-PVD, and vertical macro-cracked TBCs.