Metco has left the Sulzer Group and is now part of the Oerlikon Group.

oerlikon metco

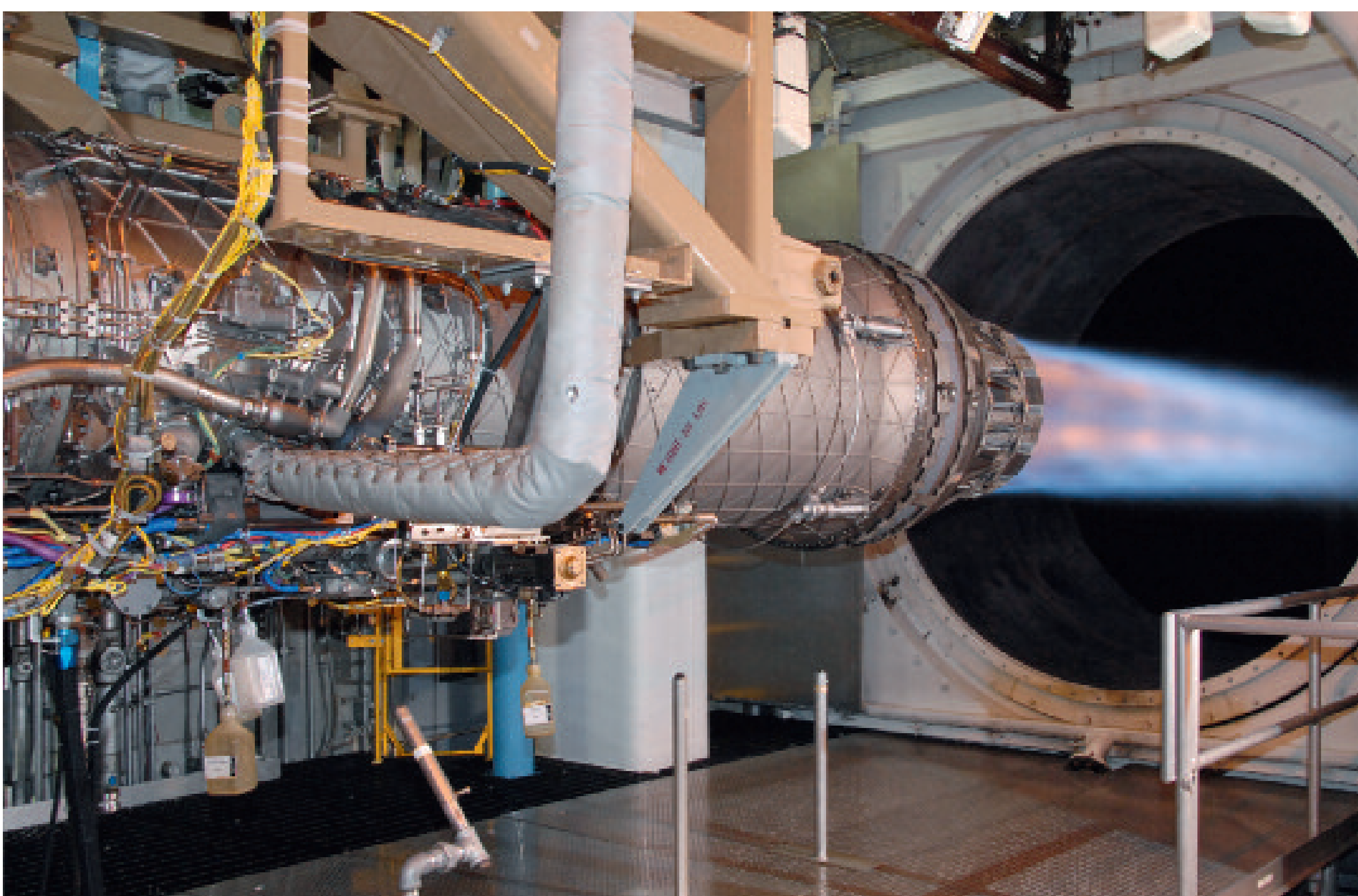
Improving thermal protection through new material solutions

Takeoff with advanced coatings

Sulzer Metco's customers have long benefited from robust and reliable thermal barrier coating (TBC) solutions that protect their turbine engines from the ravages of high temperatures. To increase turbine engine efficiency, better solutions are needed that can withstand hotter temperatures. Using a combination of new material compositions, powder manufacturing processes, and advanced coating application technology, Sulzer Metco is meeting the challenge.

Today, aero and industrial gas turbine engines employ tighter tolerances, higher pressure ratios, and higher turbine inlet temperatures to improve efficiencies.[1] The ever-increasing need for more efficient turbines with reduced NO_x and CO_2 emissions has led to new fabrication materials, production technologies, and surface modification techniques. While turbine inlet temperatures have increased by 500 °C (932 °F) over the last four decades, the temperature limits of turbine fabrication alloys have only increased by 220 °C (396 °F). Even directionally solidified castings and

1 Thermal barrier coatings protect the engines of military aircraft (like this F100 engine) but are also applied in civil aircraft.



The aircraft industry benefits from coatings through reduced cost of ownership, longer component life, improved engine efficiency, fuel savings, and lower emissions. The picture shows an F15 Eagle.

single-crystal alloys are now operating near their design limits. Because today's turbines are subjected to temperatures of over 1500 °C (2732 °F), designers are resorting to new coating solutions.

Insulating with thermal barrier coating systems

TBC systems consist of a heat-insulating ceramic coating applied over an oxidation-resistant metallic bond coat that results in reduced heat transfer into the base material. The benefits are improved mechanical properties and added life expectancy. Used in both industrial and flight turbine engines, these coatings are applied to transition ducts, combustors, heat shields, augmenters (afterburners), nozzle guide vanes, and blades (buckets). Legacy TBC systems have been plasma-applied Sulzer Metco products such as the Metco 204 family of 7–8 wt.% yttria-stabilized zirconia ceramics deposited over Amdry 995 (CoNiCrAlY) or Amdry 962 (NiCrAlY) bond coats. One example of an application using TBCs is the F100 engine (Fig. 1), which powers F15 and F16 military aircraft. This engine employs a TBC system on the augmenter. Here, already hot exhaust gases are reignited to burn residual fuel, giving the aircraft additional thrust when needed. The TBC system ensures the service life and mission-readiness of the augmenter, both of which would be severely degraded without it.

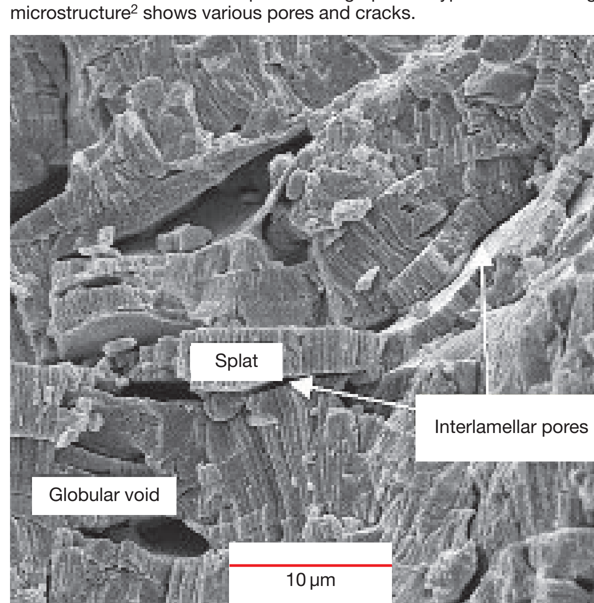
New materials solutions

Research with key universities has shown that alternative coating compositions are critical for future engine designs, but coating microstructure is just as, if not more, important. Typical TBC ceramic microstructures are composed of large globular porosity, fine interparticle porosity, and intraparticle microcracks (Fig. 2). To minimize detrimental coating changes with time and temperature, it is necessary to understand not only the volume of the combined porosity types, but also how their size and distribution affect the coating's thermal conductivity.

> Coating compositions and microstructures are critical for future engine designs.

Changing the apparent density, porosity, and microstructure of a TBC system is not only a function of application parameters but also powder manufacturing methodology and properties. Raw materials are selected for size, purity, chemical homogeneity, and phase stability.

2 The cross-sectional SEM photomicrograph of a typical TBC coating microstructure[2] shows various pores and cracks.

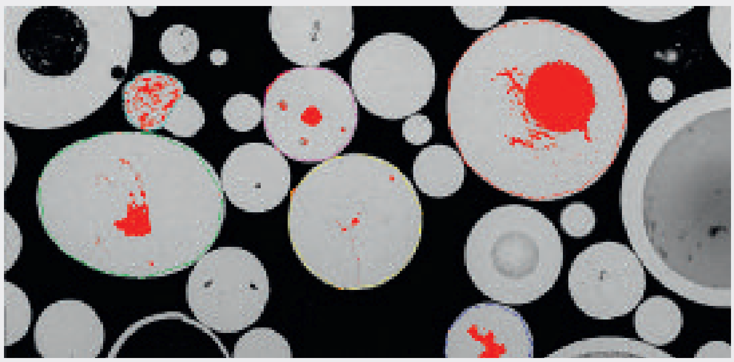


Sulzer's TBC powders

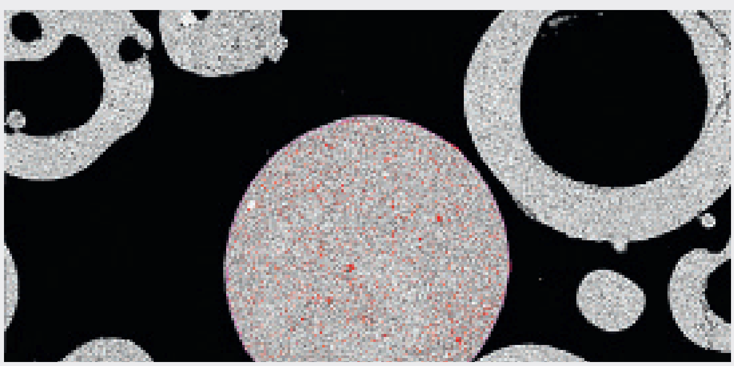
TBC powders are made of the ceramic material zirconia and stabilized with yttria (YSZ). Sulzer applies two types of manufacturing procedures for blending and fusing the components of the TBC powder:

- Agglomeration and plasma densification—these powders are best for standard porosity, high-deposit-efficiency applications
- Agglomeration and sintering—these powders are best for high-porosity, thick TBC coatings

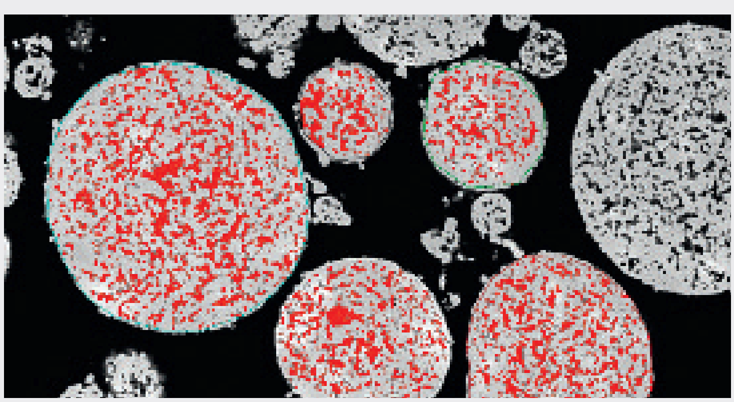
The figures show cross sections of exemplary TBC powders developed by Sulzer. The red color highlights porosity (b and c), the black circles are spherical holes (a and b).



a) The Metco 204 product family includes plasma-densified hollow-oven spherical powders (HOSP™)/7–8 wt.% YSZ.



b) High-purity zirconia-based powders have been developed in response to new customer specification requirements and show improved high-temperature sintering resistance due to low concentrations of alumina and silica. Metco 222A is an agglomerated and sintered, high-purity 7–8 wt.% YSZ powder.



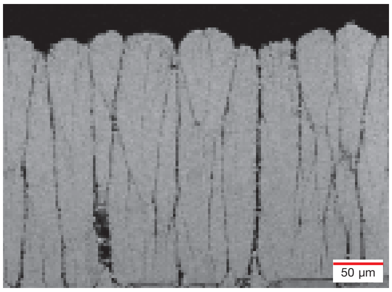
c) Low-k materials are better insulators than legacy 7–8 wt.% YSZ ceramics. Low-k materials have been developed for greater phase stability and service temperatures of more than 1200 °C (2192 °F). Metco 206A is an agglomerated and sintered low-k powder.

Manufacturing details such as heat-treatment profile, particle sizing, and shape are critical for the stability and reliability of the final coating. Sulzer Metco understands these critical factors and synergistically combines them to meet their customers' needs. As there is no single coating material that meets the design requirements for all turbine engines, Sulzer Metco offers a range of materials in standard, high-purity, and advanced low-k compositions, i.e., with better thermal insulation properties (see infobox).

Working with customers and academia, Sulzer Metco is developing new material compositions, including:

- Pyrochlore oxides (Metco 6041)
- Zirconia structures co-doped with rare earth oxides to create oxide defect clusters (Metco 206A)
- Perovskite structures for advanced, low-k alternatives

To be successful, many of these new compositions will require intermediate ceramic coating layers and improved bond coats. The Amdry 386 family of bond coats (NiCoCrAlSiHfY) is another family



3 Sulzer developed PS-PVD processes to create improved TBC microstructures. The picture shows the cross section of a TBC sprayed with Metco 6700.

of Sulzer Metco products that has shown excellent performance as a TBC bond coat. Materials can be applied by atmospheric plasma spray, controlled-atmosphere plasma spray, or high-velocity oxy-fuel spray (HVOF).

Advances in application technology

Cascading-arc technology for plasma spray guns is now a proven method for reducing the application costs of TBC systems. The Sulzer Metco Triplex*Pro*™-210 spray gun applies coatings as much as 300% more efficiently than traditional plasma spray guns, saving both time and cost. Furthermore, the inherent process stability of the Triplex*Pro*-210 reduces both run-to-run variation and coating variability on individually coated components. This translates to more reliable TBC coatings and more predictable service life. Other plasma systems using this cascading-arc concept are those that use the Sinplex*Pro*™ spray gun technology.

Augmenters are large parts of approximately 2 m. (6.5 ft.) by 1.0 m. (3.5 ft.) in diameter that require roughly 4.5 hours for TBC coating application using a conventional plasma gun. For this application, the gun must be maintained after 15 hours of spray time, which causes work stoppages after every three parts. The same coating can be applied using the Triplex*Pro*-210 in only 1.5 hours, and work stoppage for gun maintenance need only occur after around 150 to 200 spray hours. Moreover, Triplex*Pro*-210 coatings are more consistent.

Sulzer Metco has also been developing TBC application using plasma spray in near-vacuum conditions (approximately 1 mbar) to create new coating microstructures with improved compliance. This special plasma spray PVD process (called LPPS-Hybrid PS-PVD) creates microstructures that resemble the thick columnar structure of traditional electron-beam PVD coatings, but at much faster deposition rates and with superior characteristics (Fig. 3). And, for the first time, this technology allows the application of thermal spray coatings to shadowed (non–line-of-sight) areas, making processing of compound vane and airfoil segments more practical (Fig. 4). Metco 6700 is a high-purity, 7–8 wt.% YSZ material specially designed for the PS-PVD process. The powder has been used to spray HP nozzle guide vanes. The PS-PVD process also allows for multilayer microstructures that may be beneficial for high-temperature erosion and CMAS (calcium-magnesia-alumina-silicate) infiltration. CMAS is a foreign material typically from sand and volcanic ash that deposits and infiltrates the pores of traditional TBC systems above 1250 °C (2280 °F) causing destabilization and failure.

Sulzer's cascading-arc technology reduces the application costs of TBC systems.

Promising coating results and economics

New powder and equipment technologies support changes in coating microstructures that result in lower thermal conductivity and are more robust. TBC coatings with typical porosity levels of 5 vol.% are less thermally insulating and more prone to sintering and spallation than new high-purity systems with porosity levels of 10–15 vol.% (Fig. 5). Testing has shown that these high-purity systems show improved sintering characteristics, are less prone to structural changes, and have better thermal-cyclic life.

Looking at coating economics, the following costs have to be considered:

- Coating materials
- Coating system (spray gun)
- Maintenance
- Labor
- Consumables (gases, electrical, etc.)

While new TBC materials with alternative rare earth oxides may be significantly more expensive than legacy materials, much of this cost will be offset by

4 The commercialization and scale-up of the LPPS-Hybrid PS-PVD process is demonstrated here with multiple dummy vanes mounted within the spray chamber.

Future direction of Sulzer Metco's TBC development

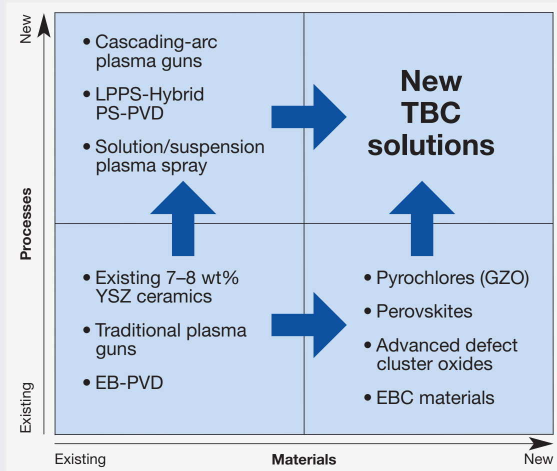
New ceramic materials include:

- High-purity zirconia-based materials for improved high-temperature sintering resistance
- Low-k compositions utilizing pyrochlores, perovskites, or advanced oxide defect cluster ceramic compositions for improved high-temperature heat insulation, high-temperature phase stability, and/or CMAS resistance
- EBC compositions for optimal protection of CMC structures

New methods of manufacture such as agglomerated and sintered powders are required for high-porosity and high-coating-thickness TBCs. New application techniques include:

- Cascaded gun technology for reduced spray time, more consistent quality, and vertically segmented cracked structures
- Modified PVD-type processes for extremely strain-tolerant coatings

The design of unique multilayer TBC coating microstructures will optimize performance.



improvements in application technologies. Of course, these overall coating economics must be weighed against the expected gain in turbine engine efficiency and component service life, as well as the reduction in exhaust gas emissions. In general, these gains will be much larger than the anticipated increases in coating costs.

Future developments

For Sulzer Metco, the development of new TBC systems and application technologies will continue into the foreseeable future (see infobox). Two important topics are:

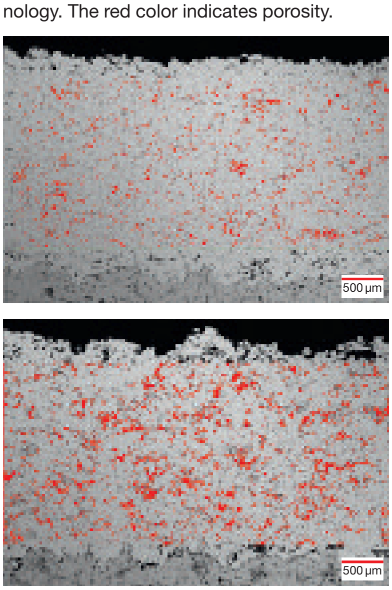
a) Segmented TBC coatings applied with atmospheric plasma spray (APS):
Besides PS-PVD and Triplex*Pro*-210 technology; Sulzer Metco is looking at supporting the customer base through the development of unique strain-tolerant, segmented coating microstructures with existing products like Metco 204F, Metco 204NS-G, Metco 233B, and new TBC chemistries.

b) Environmental barrier coatings (EBCs) for ceramic matrix composites (CMCs):
A new class of high-temperature protective coatings called environmental barrier coatings (EBCs) is emerging. These systems will be used to protect lightweight, silicon-based ceramic matrix composites (CMCs). CMCs are expected to replace superalloy substrates, but they have to be protected from water vapor attack. Sulzer Metco's ability to customize EBC compositions using different powder-manufacturing approaches is critical to the success of this application, so as to give engine manufacturers the coating properties they require.

Further advances in the performance of thermal barrier coatings will be made possible by new ceramic material compositions, new powder-manufacturing methods, new multilayer, functional designs in coating microstructure, and new application processes. To meet the challenges, Sulzer Metco has invested in a strong global supply chain management and alternative powder-manufacturing technologies as well as experienced scientists, engineers, and technicians to support the commercialization of advanced materials and future application technologies.

> Sulzer applies different powder-manufacturing approaches to customize EBC compositions.

5 High-purity, 7–8 wt.% YSZ ceramics (e.g., Metco 222A or Metco 204C-XCL, bottom) show higher porosity than legacy materials (top) when applied using Triplex*Pro*-210 technology. The red color indicates porosity.



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