EXTREME COATINGS

THERMAL BARRIER COATINGS AND SURFACE TECHNOLOGIES LEAD THE PUSH TOWARD GREATER EFFICIENCY AND LOWER LIFECYCLE COSTS

Figure 1: Chromalloy's Electron Beam Physical Vapor Deposition coating center in Orangeburg, NY

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At Mitsubishi Hitachi Power Systems (MHPS) facility in Florida, a robotic arm made use of an ultra high-temperature flame to spray a thermal barrier coating (TBC) onto a blade. The technical sophistication as well as the major investment in surface technology equipment made it clear that this was an area more than worthy of investigation.

It is possible that innovation in TBCs and other surface coatings outstrips development efforts in most other areas of turbomachinery. As well as being in heavy representation among the presentations at this year's ASME International Gas Turbine Institute conference in Dusseldorf, Germany, almost all turbine OEMS are actively working to improve TBC effectiveness.

"Solar Turbines is in steady pursuit of material and coating improvements to enable industrial gas turbine operation at higher firing temperatures and in more aggressive environments, while meeting cost and emissions targets," said Rainer Kurz, Manager of Systems Analysis at Solar.

In addition to Solar, OEMs such as GE, Siemens, Alstom and Mitsubishi Hitachi are strong proponents of coating quality. They are supported by companies such as Chromalloy, Praxair Surface Technologies, Saint-Gobain, Sulzer, Sensor Coating Systems and Flame Spray which are working on new additions to the TBC landscape. And the reason is simple. It is all about finding ways to operate at ever higher temperatures.

"A TBC is an insulator that makes the part cooler which increases its life," said Dr. Henry Bernstein, President of Gas Turbine Material Associates (GTMA). "A TBC is also the best way to increase engine performance currently available."

Aerospace lead

The first thermal barrier coatings (TBCs) were introduced on aircraft engines in the 1960s. From there they filtered into the industrial gas turbine sector. They consist of a layer of material deposited on hot section metal components to improve resistance to high temperatures. The underlying metal is typically composed of Ni- base and Co-base superalloys which combine strength at high temperatures with resistance to degradation in oxidizing and corrosive environments. On top of the substrate metal a bond coating is applied. The bond coating typically consists of the elements Al, Cr and Y for superior oxidation resistance, combined with Co and/or Ni for good adhesion.

"You need a bond coat to attach the ceramic insulator to the metal substrate," said Bernstein. "Between the two, a very thin thermally grown oxide layer forms, which assists this attachment."

The top coat usually consists of ceramic powders with low-thermal conductivity such as zirconium oxide partially stabilized with yttrium oxide (YSZ). As the ceramic top coat has very low thermal conductivity, it permits a gas turbine to run at higher temperatures without increasing the temperature of the metal. These improvements in alloy and TBC capability generally come from the aerospace industry.

"Whereas in the 1980s the maximum inlet temperature that a gas turbine could support was 900°C, this limit had been pushed up in excess of 1,500°C," said Willibald Fischer, Head of Gas Turbine Product Management at Siemens.

He pointed out that at 1,500°C, steel glows bright red. This heat is reduced by blowing cold air through a labyrinth of tiny channels running through the interior of the cast blades. To further cope with such extreme environments, blades are normally Ni-based superalloys, which are well known for their high-temperature strength, superior creep and fatigue resistance. But even the best alloys and most advanced laser-drilled cooling networks need further help. That is where TBCs come in.

"For additional protection, these high-tech blades are enveloped in a microscopically thin ceramic coating," said Fischer. "This material is so finely distributed over the structure of the blades that it does not compromise the extreme heat resistance of the metal, its original advantage. This coating material has been specially designed to avoid the traditional drawback of ceramics, namely their brittleness."

Latest coatings

A large number of suppliers offer TBCs or provide advanced coatings as part of the repair process. Praxair Surface Technologies, for example, is well known in this field.

"Advancements continue to be made in two areas that are critical to the protection of turbomachinery components while helping to improve fuel efficiency: thermal barrier coatings and tip seal systems," said Paul Brooks, Global Market Network Lead for Power Generation at Praxair Surface Technologies.

Used as a protective layer in the turbine hot section, Praxair's Zircoat HP yttria-stabilized zirconia TBC makes use of what is known as controlled vertical segmentation, i.e., instead of a general top coat layer, the material is adhered in vertical segments with cracks between the segments. Due to this segmentation, it is resistant to solid-particle erosion, contains stable properties within the turbine environment, and is durable under thermal cycling.

"Vertical segmentation allows Zircoat HP to accommodate the expansion and contraction of underlying metal substrates, which minimizes stresses during thermal cycling," said Brooks.

He added that the application of the Zircoat vertical segmentation coating along with Praxair's Tribomet abrasive coating to blade tips and labyrinth seals creates an outer air seal to minimize operating clearances. This is done to prevent the abrasive coatings damaging a machined, gas-path seal and avoid the generation of thermally induced rotor cracking as a result of friction heating.

Recent advancements in coating technology for turbomachinery include chrome-free coatings that are a safeguard against corrosion and heat degradation, said Brooks. Praxair's SermeTel CF chrome-free slurry coatings offer performance equal to slurry coatings that contain carcinogenic hexavalent chromium as a means to impede corrosion.

Chromalloy has been involved in coatings for oxidation, corrosion and thermal protection of gas turbine engines used in the aerospace and energy industries. This includes subjecting turbine section blades, vanes and ducts to diffusion aluminide or platinum aluminide coatings as well as overlay MCrAlY (M=Co or Ni, Cr=Chromium, Al= Aluminum and Y= Yttrium) coatings for oxidation and corrosion protection, and ceramic TBCs applied by air plasma spraying or electron beam physical vapor deposition (EBPVB) (Figure 1).

"In turbines, we use standard yttria-stabilized zirconia TBCs, and yttria-stabilized zirconia TBCs doped with neodmymium for low-thermal conductivity," said Ravi Shankar, Chromalloy's Director of Coating and Process Technologies. "Each of these coatings provides an insulating protective barrier to reduce part temperature, i.e., greater oxidation resistance which allows parts to operate longer."

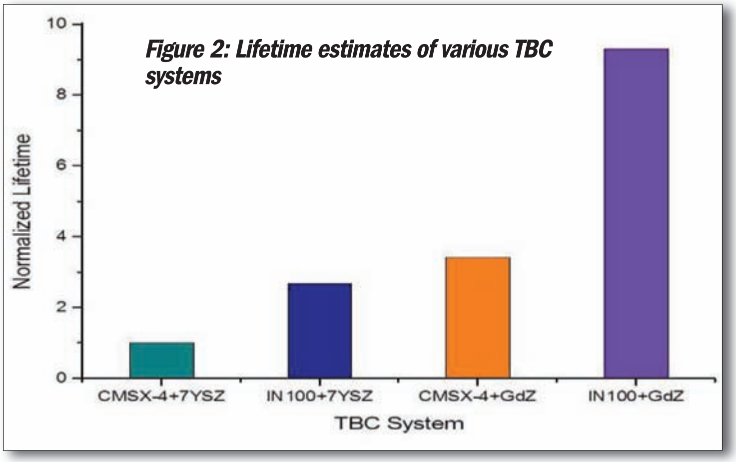

Figure 2: Lifetime estimates of various TBC systems

In the compressor section of the engine, coatings are a little different, however. Chromalloy applies airfoil tungsten carbide-cobalt hard coatings using high-velocity oxy-fuel spraying as a means of achieve erosion protection within the compressor.

Kurz cautions users about the presence of corrosion in centrifugal compressors in wet or sour gas service. "Coating, plating or cladding of compressor casings is inferior to casings made from stainless steel in oil and gas applications where the gas contains significant amounts of CO_2 and H_2S with water," he said.

OEM coatings

Solar Turbines is one of many OEMs looking into material and coating improvements. "It is well known that increases in the high-temperature strength of turbine hot-section materials are often accompanied by decreases in high-temperature corrosion resistance," said Kurz. "With this trade-off in mind, Solar continues to implement material and coating systems for turbine hot-section components that deliver the optimum balance of corrosion resistance and mechanical properties for end-user applications."

GE has several of its own proprietary coatings — a combination of a metallic-bond coat and TBC. The bond coats are plasma-sprayed MCrAlYs that GE calls GT33 and GT21. The ceramic TBC used is 8% yttria-stabilized zirconia with a thermal-spray process that produces vertical cracks in the microstructure of the ceramic, providing strain compliance as well as ablation resistance, said Jon Schaeffer, Senior Manager of materials for power generation products at GE Power & Water.

"Surface protection is vital because the H-class firing temperature enables the 60+% combined cycle efficient gas turbines where the temperatures routinely exceed the melting points of the Ni-base superalloy substrates," said Schaeffer.

Future HA (H-class Air-cooled) turbines will have what Schaeffer called a more phase-stable TBC with lower inherent thermal conductivity and the same vertically segmented structure. The bond coat has been adjusted to match the alloy and ceramic.

"Initial HA units will have our existing TBC systems," said Schaeffer. "Follow-on HA units will have a next-generation TBC system that has evolved over the last five years and will give us at least 100°F of additional temperature capability."

TBC innovation

Various vendors and academics are also advancing coating technology. Sensor Coating Systems (SCS) of the UK developed a sensor coating technology to measure turbine temperatures online. SCS successfully conducted a test on a Rolls-Royce Viper 201 engine using this technology.

Classical temperature detection methods, such as the use of thermocouples or pyrometers, struggle in the extreme heat of modern turbomachinery. This can lead to lower operating temperatures being used to maintain a safety margin. SCS provides an on-line monitoring tool which enables more accurate remote detection of temperature on and in the TBC which could lead to a further boost in GT efficiency.

In essence, this technology combines high temperature protective coatings with the luminescent properties of ceramics. When you illuminate the coating with light, it creates phosphorescence which can be used both to read temperature and detect evidence of ageing in the coating.

SCS has also developed a temperature memory coating called Thermal History Coating. "Off-line temperature detection can be accomplished as our thermal history coating has a temperature memory," said Jörg Feist, Managing Director, Sensor Coating Systems.

This memory coating can be either applied as paint for ease of application or as a more robust atmospheric air plasma coating. The latter approach has run successfully at a power plant in the UK (Didcot Power Station) for 4,500 hours. Feist said the company has demonstration projects for Thermal History Paint either ongoing or about to commence in a marine-drive diesel engine in Japan, an automotive turbo charger application in Germany and three gas turbine engine tests (nozzle guide vanes and turbine blades) in Germany, the U.S. and Czech Republic.

Flame Spray of Italy, another TBC and coating vendor, has introduced a High Enthalpy Cascade Plasma Spray gun which takes a high voltage and low current approach to application of coatings. "This provides greater spray accuracy and the same gun can be used for the bond coat and TBC," said Andrea Chierichetti, Flame Spray's European Sales Manager.

The application method has greater forgiveness in terms of spray distance and angle variation, added Chierichetti. This is particularly important for blades and vanes as their complex shape can make it difficult to obtain a TBC of uniform thickness. Yittria is used for the top coat while MCrAlY forms the bond coat which is applied in such a way as to obtain a high degree of roughness. This strengthens TBC adhesion. These coatings have undergone successful testing and are now in production.

Saint-Gobain has developed the Rokide Spray System, which melts ceramic oxide rods and then projects the fully molten particles onto the substrate. These particles, which have high kinetic energy and thermal mass, cannot leave the spray until fully molten. Rokide ceramic coatings, which protect metal up to 4,500°F (2,480°C) are used for coating tubes in fluidized-bed boilers, and for coating rotary valves, and pump sleeves, shafts and impellers.

Meanwhile, researchers at the University of Rome-Tre studied two different superalloy substrates (IN100 and CMSX-4) used in conjunction with an NiCoCrAlY bond coat as well as ceramic top coat materials 7YSZ and GdZ. The study concluded that on both substrate alloys, GdZ possessed a nearly fourfold longer lifespan compared to 7YSZ (Figure 2).

Rare earth elements

Chromalloy and Praxair Surface Technologies have more developments in the pipeline. "Advances in protective coatings include material changes such as the addition of rare earth elements to lower thermal conductivity in TBCs," said Shankar. "We are also working on the modification of ceramic coatings for better corrosion resistance in newer higher-temperature engines."

Praxair is considering suspension plasma spray (SPS) as a lower-cost alternative to electron beam physical vapor deposition for niche turbomachinery applications, said Brooks. "Currently, SPS coatings are delivering comparable performance in aviation applications, so there may be a future for these coatings in turbomachinery."

Further work on advanced TBCs is taking place at Mitsubishi Hitachi Power Systems' Japanese National Project, which aims to achieve temperatures of 1,700°C, well above current limits.

"In the future, we can look forward to TBCs that provide even greater insulation and higher reliability," said GTMA's Bernstein. TI