

Taking the mystery out of GT hot-section coatings

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Most of the hot gas path (HGP) components used in gas turbines (GTs) for electric generation are supplied with specialized coatings to protect against high temperatures and harsh environments for the duration of each service interval. In fact, airfoils for the latest generation of high-efficiency GTs rely on coatings and internal cooling systems for their very survival: Gas temperatures now exceed the

melting temperature of the components.

The selection of an effective coating system tailored to the service environment is one of the most critical factors in enabling turbine components to perform successfully for their intended lifetime—nominally 25,000 equivalent operating hours (EOH). If coatings fail during the service interval, the parts quite often are not repairable and expensive new replacements are required.

There are over 50 different coating systems commercially available for HGP blades and vanes. Each has its strengths and weaknesses, depending on the type of service and service environment. Initially the GT manufacturer decides on the coating system that it feels is best suited to the engine firing temperatures and the widest range of service environments. In a few cases, the OEM (original equipment manufacturer) may offer an alternative coating for certain environments, but typically there is one standard coating offered for each component.

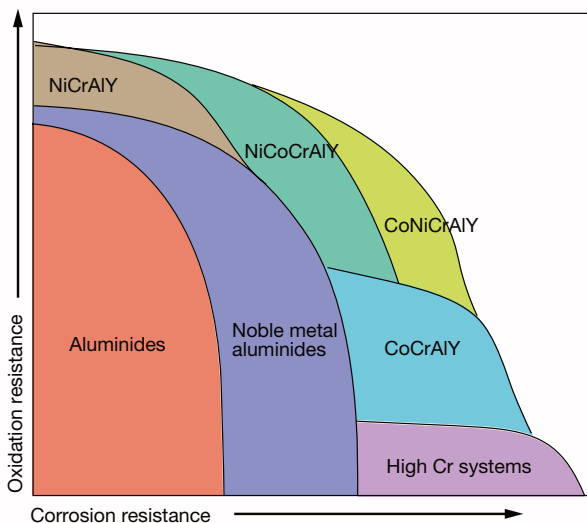
Because coatings are applied to the surface of the components, they are one of the design details that can most readily be changed from the new-part standard and tailored to the plant's specific operating environment. The effectiveness and suitability of the original new-part coating is best determined by performing a detailed metallurgical analysis after the first service interval. Therefore, it is very important for plant managers to understand the various coating systems available, how they perform under different conditions, and how they may be upgraded at the time of repair to better match the service environment and extend component life.

HGP coatings are referred to as coating "systems" for good reason. The inter-relationship of several

elements influences the function and effectiveness of the coating. The coating interacts with the airfoil alloy, and also is influenced by the design of the airfoil cooling circuit

high gas temperatures (in excess of 1650F) typically associated with the first- and second-stage airfoils. Note that the higher the firing temperature, the greater the need for oxidation protection. Hot corrosion can occur at lower temperatures (as low as 1200F) when contaminants are present in the air and/or fuel. The most troublesome combination typically encountered is relatively small quantities of sodium or potassium salts and sulfur.

HGP coatings can be separated into three main families: diffusion aluminide, overlay MCrAlY, and thermal barrier. Each has been used extensively by the industry for many years, and each has distinct strengths and limitations, and different methods of application as outlined below.



1. Oxidation and corrosion resistance of the various types of coatings are illustrated here in relative terms

(both internal cooling passages and external film cooling). Operating environment is another important factor since it dictates the type of protection required—for example, oxidation protection against high gas temperatures, corrosion protection against harmful constituents in fuel and combustion air, and resistance to coating strain cracking and spalling caused by the severity and frequency of starts and stops.

Oxidation is a function of the

Diffusion aluminides

Diffusion aluminide coatings are aluminium-rich layers formed on the component surface by processing at high temperature to create an interaction with the base metal. In the case of a nickel-alloy turbine blade, the result is a nickel aluminide coating. The aluminium diffuses into the nickel alloy and nickel from the component diffuses outward into the aluminium surface layer to form an inter-metallic coating with an aluminium content of 25% to 35%.

The coating material can be applied by various methods: as a slurry (Sermaloy J, for example), powder pack (Codep, PWA273, RT21, and others), or gas (PWA275, RT67, etc). The slurry coating has the advantage of ease of application since the high-temperature processing is carried out as a second step after the slurry has been applied and dried. With the powder pack and gas coatings, the aluminium material and high temperature processing are carried out in the same chamber.

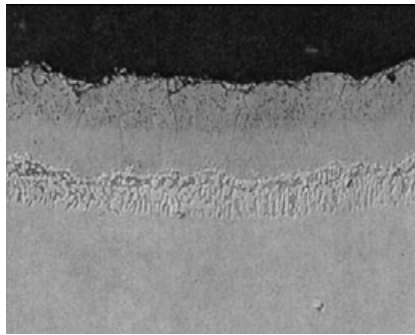
The basic diffusion aluminide coatings provide relatively good high-temperature oxidation resistance, but have limited corrosion resistance as shown in Fig 1. Diffusion aluminide coatings also can be modified or enhanced by adding other elements. Silicon, chromium, and noble metals—such as platinum—are most common. Silicon aluminides improve oxidation and corrosion protection, chromium aluminides enhance corrosion resistance, and platinum aluminides offer significantly greater oxidation resistance and improved corrosion resistance at high temperatures.

Diffusion aluminides are relatively thin coatings, typically 0.002 in. in total thickness (Fig 2), with about half of the thickness being additive to the surface and the other half being created by diffusion penetration into the surface of the component. These coatings are most common for aero and aeroderivative blades and vanes because they add minimum thickness and weight to the part. For industrial frame components they find greatest use in the second and third stages of the turbine where temperatures are lower and the increased oxidation resistance of the MCrAlY coatings is not required.

Diffusion aluminides may also be used to coat the internal cooling passages of the latest GTs—machines with the highest firing temperatures. Simple aluminides, rather than enhanced aluminides, typically are used for internal coatings and their thickness usually is limited to 0.001 to 0.002 in.

Overlay MCrAlY coatings

Overlay coatings derive their name from the fact that they are typically applied using a thermal spray process to the component surface and have very limited inter-diffusion into the component alloy. Overlay coatings are also known as MCrAlY

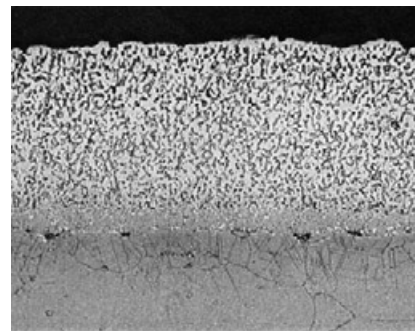


2. Diffusion aluminides are relatively thin coatings, typically 0.002 in. in total thickness. Cross section provides a basis for comparison

coatings, an acronym for the main elements in the coating powder that is sprayed onto the component surface: M for metal (some combination of nickel and/or cobalt), Cr for chromium, Al for aluminium, and Y for yttrium. All MCrAlY coatings (GT33, PWA211, ATD61, etc) contain these elements. The coating can also contain traces of various other elements such as hafnium, rhodium, etc.

The advantage of MCrAlY coatings is that they require minimal interaction with the alloy being coated, and can therefore contain a wide variety of elements. Also, because they are applied in a powder form, overlay coatings can be easily formulated into an extensive range of compositions. Fig 1 shows that MCrAlY compositions range from the nickel-rich NiCrAlY for maximum oxidation resistance to the cobalt- and chromium-rich CoCrAlY coatings. Most of the MCrAlY coatings used by the OEM for new parts fall in the mid range of Fig 1 and provide some degree of both oxidation and corrosion resistance.

MCrAlY coatings are relatively thick, typically in the 0.007-0.010-in. range, all of which is additive to the surface (Fig 3). MCrAlYs are preferred because of their superior oxida-



3. MCrAlY coatings are relatively thick, typically in the 0.007-0.010-in. range, all of which is additive to the surface

tion/corrosion protection for heavy-duty industrial frame blades and for other components, as well, where the coating thickness and weight are not detrimental. Some industrial frame engines may be operated in a corrosion environment where it is impractical to provide clean fuel and air. In these situations, an upgraded coating with a composition specially tailored for corrosion can be used to replace the standard coating.

Thermal barrier coatings

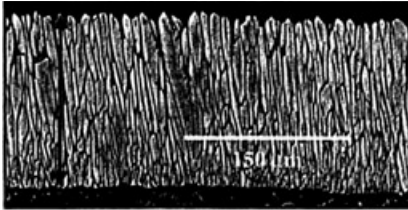
Thermal barrier coatings (TBC) are ceramic materials based on yttria-stabilized zirconia, and are quite different from the oxidation- and corrosion-resistant coatings described previously. TBCs provide an insulating layer on the external surface of an airfoil, thereby separating the hot gases from the component surface. This insulating effect assists the internal cooling system in reducing metal temperature. TBCs are only applied to internally cooled components; were they applied to a solid airfoil, the entire component would quickly heat-soak to the point where the metal temperature is uniform throughout and the insulating effect wasted. For maximum effectiveness, TBCs are applied as a relatively thick (0.010-0.020 in.) layer.

Since TBCs alone offer no oxidation resistance, the surface of the part must first be coated with a thin layer of MCrAlY both for protection in service and to provide a somewhat rough surface for better bonding of thermal sprayed TBC. When used this way, MCrAlYs are sometimes referred to as a bond coats.

TBC coatings are ceramics and therefore relatively brittle. They do not expand and contract as readily as the metallic components they protect. TBCs are applied using different methods, all aimed at producing a coating structure able to respond to expansion and contraction without spalling off of the part. The most basic application method is air plasma spray (APS), which employs a thermal spray in ambient conditions to produce a porous, lamellar structure. It achieves reasonable strain tolerance through the porosity and network of subcritical cracks embedded in the structure.

When TBC coatings need superior adhesion and strain tolerance, an electron-beam physical vapor deposition (EB-PVD) process is used. It requires a large high-vacuum chamber and is relatively expensive

GT COATINGS

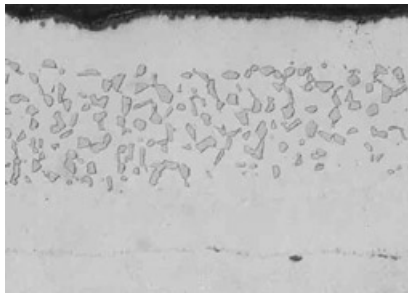


EB-PVD YSZ



APS YSZ

4. Thermal barrier coatings insulate the external surface of an airfoil. Result of application by electron-beam physical vapor deposition is at the top, application by air plasma spray at the bottom



5. Depleted MCrAlY coating is at the end of its useful life. Compare it to the as-new coating in Fig 3 for perspective

compared to the other methods. The EB-PVD process produces a columnar structure (Fig 4) which is able to spread and contract to achieve excellent strain tolerance.

A more recent TBC process development is the dense vertically cracked (DVC) coating. It is able to expand/contract through the introduction of micro cracks oriented similar to the EB-PVD without the expense of a vacuum chamber for its application.

Coating selection, effectiveness

When a part is removed from service the visual appearance and various discolorations on the surface may be indicative of where the local hot spots occur on the component. However, they are no indication of the remaining coating life, or how well suited the coating is to the type of service. The effectiveness of hot-section coatings can only be evaluated

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by laboratory analysis of a cross-section taken from various locations on the component.

Using specialized techniques, the remaining beta-phase aluminium content and other elements of the coating can be quantified and expressed as a percentage remaining life for the coating. Fig 5 shows a depleted MCrAlY coating at the end of its life. Compare it to the as-new coating in Fig 3. The remaining thickness of the coating is not a meaningful indicator, since most coatings begin to lose thickness only in the very final portion of their life, after most of the aluminium content has been exhausted.

Laboratory analysis also can determine the degree of oxidation versus corrosion protection required of the coating for the specific service environment. The analysis of a component removed from service is the best indicator of how the part is behaving in service. At this point more information is known than was available to the original designer. Decisions can then be made to tailor the coating system for the type of oxidation/corrosion environment prevailing at your plant.

Strain tolerance, the coating's resistance to cracking in service, is also best determined from the parts themselves after the first service

interval. Coating cracks can be a serious problem. They can lead to cracks forming in the component which may lead to declaring the part scrap. All hot-section coatings are relatively brittle at room temperature, and are therefore susceptible to damage from strains on startup and shut down when the underlying component expands and contracts under sudden temperature changes. For this reason, coatings on engines operating in peaking duty are more prone to cracks forming in service.

Depending on their composition and thickness, certain MCrAlY coatings can be more prone to forming strain cracks in service than others. In recent years, at least one OEM has changed the composition of its standard coating to one that is more strain-tolerant as well as more oxidation-resistant and in so doing provided a coating that is more appropriate for the majority of its customers' GTs. This same evaluation and selection of coatings can be applied to any engine type once the components have operating experience in a given environment. In addition to variations in coating composition, there are also post-coating heat treatments which can be used to condition some coatings for improved strain tolerance. CCJ

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