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Protective coatings extend valve life in severe service conditions

Thermal spray coatings, particularly those applied with the high-velocity oxy-fuel (HVOF) process, can extend the service life of a wide variety of industrial machinery and equipment, saving time, money and labor on maintenance and replacement. This equipment includes valves, which are often subjected to extraordinarily harsh operating conditions.

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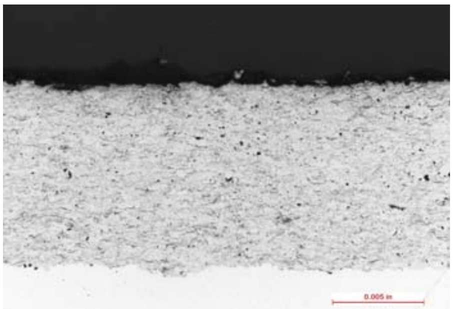
These coatings can be protective, resisting wear, corrosion, oxidation and sulfidation, or they can be functional, altering surface properties such as electrical conductivity, dielectric strength and thermal conductivity. Thermal spray coatings are generally thinner than weld overlays, and are not metallurgical bonded to substrates unless heat treated after deposition. As the price of nickel and other raw materials increases, they are a cost-effective alternative to fabricating entire components from expensive alloys.

Invented over 100 years ago, the thermal spray process has evolved into a family of highly sophisticated, advanced coating materials and methods for applying them. These coatings include basic metallic and ceramic materials, as well as composites and bi-layered materials.

Also available are custom formulations to optimize certain properties such as hardness, toughness and machinability. Materials can be blended to obtain composite properties or layered for graded properties. For example, a base layer of corrosion-resistant nickel alloy can be coated with a harder material for wear resistance.

Post-coating processes can modify the structure and properties of coatings to achieve required performance. Among these is fusing, a type of sintering process done manually or in batch furnaces that densifies coatings and creates a metallurgical bond with the substrate. This maximizes a coating's adhesion strength where sliding or abrasive wear occurs.



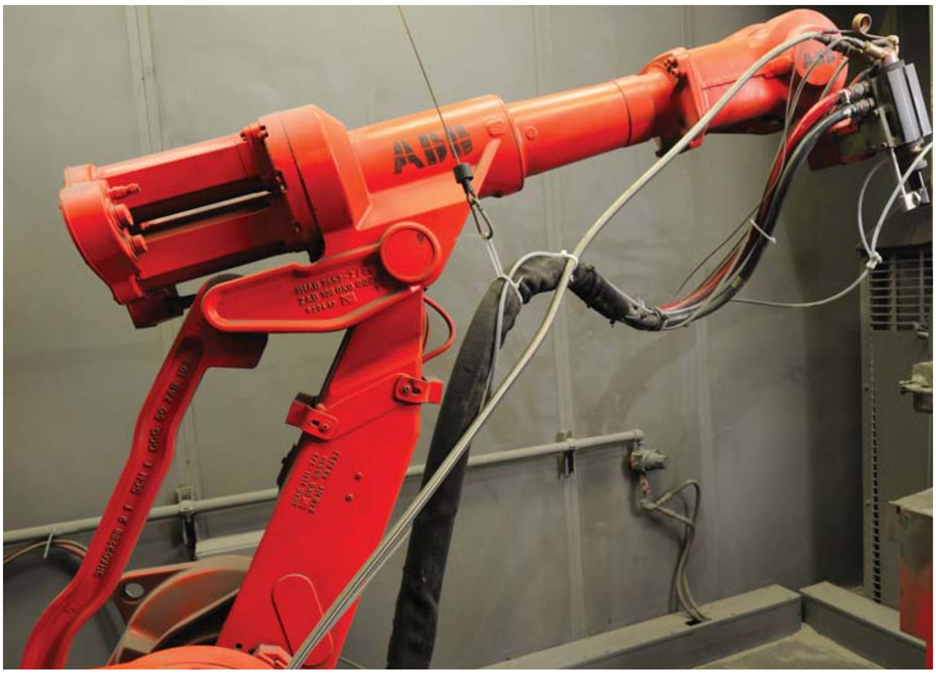
HVOF carbide coating microstructure.

Deposition processes

Thermal spray deposition is done by propelling heated particles of the coating material toward a substrate. Coating properties depend largely on the type of thermal spray process used and the processing parameters. Two of the most common processes are air plasma spray (APS) and HVOF.

APS uses plasma to heat the particles and a torch to accelerate them toward the substrate. The plasma can be controlled for high- or low-melting-point materials. The ability of this process to deposit a wide range of materials makes it suitable for many applications. It should be noted, however, that the relatively slower velocity at which APS deposits the particles will affect coating properties.

HVOF uses flame to heat the particles and an accelerating nozzle to provide supersonic gas flows to propel them. The high kinetic energy imparted to the particles by this process produces different coating properties than those applied by APS. Carbide coatings applied by HVOF, for example, will have better wear resistance and damage tolerance. These improved properties are the result of reduced oxidation of the particles in flight and residual compressive or peening stresses in the coating.



HVOF process with robotic control.

For highest consistency and repeatability, thermal spray coatings are applied by industrial robots, but large infrastructure applications and process components can be sprayed manually in the field.

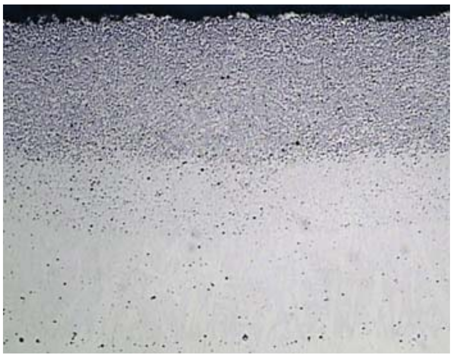
Coating materials

Metallic coatings are used for dimensional restoration and resistance to sliding wear and chemical attack. They include metals and alloys of aluminum, copper, nickel, iron, molybdenum, tantalum and cobalt. Spray-and-fuse or self-fluxing coatings are cobalt- or nickel-based alloys containing boron and/or silicon as fluxing agents, plus iron and carbon. They are usually deposited by low-velocity, combustion flame processes, but HVOF produces denser coatings with less shrinkage during fusing, increased hardness and greater resistance to abrasive wear.

The boron and silicon allow the formation of eutectic phases and lower the melting point of the alloy. During fusing a portion of the coating will melt, making it nearly 100% dense and forming a metallurgical bond with the substrate, precipitating hard phases such as borides and carbides, increasing hardness and reducing abrasive wear.

If the substrate cannot be heat treated or a metallurgical bond is not required, these coatings can be used as sprayed, but fusing provides a more uniform chemistry and microstructure with no through-porosity and low oxide content. These properties make them ideal for high-temperature applications subject to wear corrosion.

Metallic coatings provide a high degree of corrosion resistance, particularly cobalt-based Stellite™ and nickel-based Hastelloy™. Stellite™ offers low friction and high wear resistance. Hastelloy™ is also extremely corrosion-resistant, making it suitable for sliding applications in chlorine and other acidic environments.


Fused coating microstructure.

Ceramic coatings include aluminum oxide, titanium oxide, chromium oxide and zirconium oxide. Because they have high melting points, they are typically applied using APS for greater heating of the particles. These coatings provide high hardness, can be used at extremely high temperatures and withstand corrosive environments.

Carbide coatings are ceramic-metal composites, or cermets, in which the metallic phase retains the carbide particles during deposition. The WC-Co and Cr3C2-NiCr families of materials are commonly used to provide wear resistance, and can be applied using either the APS or HVOF process. However, the heat of the APS plasma can decarburize the carbide particles during deposition, causing oxidation of the carbide phase into more brittle forms. While this may not reduce the hardness of the coating, it will adversely affect its cohesive strength and toughness. The HVOF process causes significantly less decarburization and results in denser coatings with better wear resistance.

During deposition, the metal must be heated sufficiently to form a dense coating, but the heating must be controlled to minimize decarburization. The size and distribution of the carbide particles within the powder affect the coating structure and properties, as well as deposition efficiency. Hardness and wear resistance are a function of carbide content and how well the particles bond to the metal matrix.

These properties generally increase as carbide content increases and particle size decreases. However, increasing hardness by manipulating these parameters can reduce fracture toughness. Under high contact loads, this can change the wear mechanism to one dominated by cohesive failure between the coating layers, resulting in a higher wear rate.

Cermets are the materials of choice for wear resistance. Less porous and more crack-resistant than ceramics, they can be customized for hardness and toughness by the type of carbide and binders used, and by modifying the mix of ceramics and metal. Tungsten-carbide and chromium-carbide can be added to the self-fluxing metal coatings to create a material that is heat-treatable for metallurgical bonding.

Wear mechanisms

Hardness is not the sole criterion for selecting a protective coating, since there are usually multiple mechanisms acting to degrade a surface. Understanding these mechanisms, including erosion, sliding, abrasive and adhesive wear, and corrosion, is key to selecting the proper coating for a given application.

Erosive wear occurs when solid particles impinge on a surface, causing minute plastic deformation or crack formation, and eventually removing material from the surface. Affecting the rate of erosion and the selection of a protective coating are the angle of impingement, type and size of the particles and the temperature and chemistry of the operating environment.

Sliding wear occurs when two surfaces in contact move over one another at different speeds. Factors affecting wear rate and type of coating required to mitigate it include applied mechanical load, chemistry of the environment, temperature, lubrication, surface speed, and composition of the mating surfaces. Hard chrome plating, or electrolytic hard chrome (EHC), was used extensively in the past, but has been replaced in many applications by HVOF cermet coatings.

There are instances where carbide coatings may not be optimal, for example in applications where surfaces have complex topographies and grinding the coating would be prohibitive. All thermal spray coatings have a texture in the as-sprayed condition; HVOF coatings are typically >150µin RA, and due to their hardness require diamond grinding to finish.

Abrasive wear, a particular concern in valve bodies and seats, occurs when particles are introduced between two moving surfaces. The particles can be trapped between or attached to the surfaces. As with sliding wear, abrasive wear is affected by the type and size of particles, mechanical load, surface speed, temperature and corrosive elements. Hardness generally improves abrasion resistance, however toughness also must be taken into account.

For applications with high mechanical loading or impact, HVOF cermets or a fused coating should be considered to create a metallurgical bond with the substrate.

For less severe applications, plasma and HVOF carbide coatings can be used. WC coatings are used for applications up to 482°C; Cr_3C_2 coatings are used for applications up to 870°C. Typically, WC-CoCr coatings have more than five times the abrasive wear resistance of hard chrome plating.

Adhesive wear or galling occurs under some conditions where there is metal-to-metal contact under extreme temperatures or sliding speeds. The points on the surfaces at which contact occurs appear to be welded together, then crack or tear as they slide apart. Wear particles are generated and the roughness of the sliding surface increases significantly.

Like wear, corrosion has multiple mechanisms and coating solutions to protect against them. Thermal spray coatings provide greater resistance to wear, abrasion, erosion, and oxidation or sulfidation in hot gases. Many nickel-based coatings can withstand temperatures approaching 1,000°C. Carbide coatings can handle up to 870°C, and generally have porosity levels below 3%. For salt water and corrosive aqueous environments, heat treatments or sealants further reduce porosity to less than 1% for maximum barrier protection of the substrate.

Preventing corrosive media from reaching the substrate is key to preventing galvanic and general corrosion.

For corrosion protection, coatings perform one of two functions. Acting as a sacrificial anode, Al or Zn coatings on steel in atmospheric or marine environments corrode preferentially to protect the cathodic substrate. Because Al, Zn, or ZnAl coatings act as sacrificial anodes in preference to the steel, any porosity that allows moisture to permeate them to the substrate is not detrimental. However, even in the case of protective anodic coatings, sealants are commonly used to extend the service life. Acting as a barrier to a corrosive liquid or gas, coatings are typically highly alloyed Ni-based materials, and elimination of porosity that extends to the substrate is critical. In selecting the coating and application process, the inherent porosity of the coating must be taken into account and use of fusing or sealants considered.

Valve applications

HVOF coated ball valve and seat.

In addition to coating newly manufactured valve gates to increase their wear resistance, thermal sprays can refurbish them to their original condition using HVOF coatings, and seat faces can be resprayed to ensure an effective sealing surface.

HVOF coatings on the external surfaces of ball valves protect them from wear and corrosion, and used ball valves can be returned to their original condition eliminating the need to purchase new parts. HVOF coatings are also sprayed onto sealing surfaces and valve bodies to extend their service life.

For the past three decades, valves for service in severe conditions such subsea applications in the oil and gas industry have been protected by chrome plating on corrosion-resistant substrates, nickel plating with heat treatment, or Ni-based weld overlays. Hard chrome can have a crack- like microstructure, and corrosion beneath the plating is possible. Nickel plating can induce galvanic corrosion when in contact with a dissimilar metal in the valve body, and also poses the potential for crevice corrosion. Overlays dissolve some of the substrate alloy into the overlay alloy, so their thickness is generally high to minimize iron dilution at the surface. As operating conditions in many industries become more severe with higher temperatures and more corrosive chemicals, the demand for and cost of high nickel alloys is increasing, driving consideration of hard coatings on lower cost substrates.

Hard ceramic materials such as titanium dioxide are used in the chemical processing industry where the environments are highly aggressive. The oil and gas industry uses predominantly carbide-based and hard metallic coatings. Hard coatings applied to critical surfaces such as valve stems, gates and seats protect against the corrosive wear environments that contain combinations of salt water, sand, hydrogen sulfite, hydrochloric acid and carbon dioxide. In the case of valves that have allowable leakage rates upon installation, hard coatings can maintain these rates better than soft-seated valves. This improves reliability and can offset the high initial cost of the coating.

Summary

A wide range of materials and process flexibility enable coatings to be designed for specific applications, optimizing hardness, toughness, corrosion and temperature resistance and cost. Advances in materials and deposition technology have achieved porosity levels below 1%, and automated processing provides uniform, repeatable results.

As operating environments become more severe and the cost of Ni-alloys continues to increase, thermal spray coatings provide a cost-effective solution to protecting and extending the service life of valves and other industrial machinery and equipment.

About the author

Elaine Motyka is a Principal Materials Engineer at Technetics Group with expertise in thermal spray coating selection, development, characterization, and optimization. She received her B.S. in Mechanical Engineering from Worcester Polytechnic Institute in Worcester MA in 1988 and her M.S. in Materials Engineering from Rensselaer Polytechnic Institute in Troy NY in 1990. Her career in materials engineering over 20 years includes thermal spray coating selection and development for a broad range of industries including aerospace, industrial gas turbines, oil & gas, pulp & paper, and medical in which understanding of wear, corrosion, and environmental and material interactions was key to engineering the solution.