Overview: Thermal Spray Technology

Thermal spray is a versatile, adaptable, potentially cost-effective technology in which a wide range of metals, ceramics, polymers, and composites can be applied to almost any metal to protect against wear, corrosion, abrasion, high temperature, chemicals, and erosion. It can also rebuild worn parts of almost any metal, and can be applied by hand or by robots, in the field or in the factory. Because of these capabilities, the technology has increased part life, improved efficiency, and reduced repair costs in the aircraft, automotive, mining, and power generation industries, as well as other industries and many consumer products.

The thermal spray process requires a material in wire or powder form that is transferred to the surface by heat and/or kinetic energy, forming a protective layer. Thermal spray equipment basically consists of a spray gun, materials that are sprayed, a carrier gas, and simple to highly sophisticated controls. Equipment, materials, processes, and controls may be designed for specific applications. This versatility enables engineers in almost every industry throughout the world to improve the function of their equipment and structures.

How does thermal spray affect everyday life?

Thermal spray technology improves the quality of an astonishing array of products that we see or use every day. In products ranging from jet engines to automotive components to biomedical implants, thermal spray technology reduces cost and extends useful life. Industrial machinery, chemical process equipment, power generation equipment, and other products that we don't see every day last longer and are more productive because of reduced corrosion and wear.

Examples: Medical implants, additive manufacturing, and jet engines

Medical implants can now be sprayed with porous coatings that encourage the ingrowth of bone, thus facilitating implant fixation and reducing the need for bone cements and screws. Titanium is the most widely used coating because it has essentially no reaction with bone or soft tissue. Both commercially pure titanium and the workhorse Ti-6Al-4V alloy are deposited with about 30% porosity and typical pore size ranging from 0.05 mm. The technology allows for tight control of particle size, porosity, and thickness. Coatings up to 1.25 mm are deposited on hip implants, but dental implants are much thinner. These materials are typically sprayed by low-pressure plasma spray (LPPS, described in the addendum, as the process eliminates the need for heat treatment.

In some implants, biomedical coatings with compositions similar to that of bone are needed to actively encourage bone ingrowth. In these cases, hydroxyapatite ceramic, a calcium phosphate similar to bone, may be sprayed. Hydroxyapatite is usually applied by LPPS, and may be sprayed directly onto the implant or over another coating.

Additive manufacturing represents a family of technologies in which layers of powder are built up to form a net-shape or near-net-shape part. Two growing areas of this technology for thermal spray are direct fabrication of parts and tool repair.

Thermal spray has been used in combination with stereolithography (SLA) patterns made of polymers. The polymer pattern can be sprayed with zinc or aluminum to make tools for plastic parts. For such applications, tooling costs can be half to only 5% of conventional tooling.

Air plasma spray (APS) has been used to repair tooling such as casting molds. For example, APS coatings (described in the addendum) consisting of 70% yttria-stabilized zirconia and 30% CoNiCrAlY have significantly improved service life of centrifugal casting molds, in one case extending life from 20 to 200 runs.
The cold spray process (described in the addendum) has produced aluminum metal matrix composites (MMC) to net shape. Cold spray can produce almost any MMC as a coating or in bulk form by simply blending the matrix and dispersant powders.

Jet engines are major consumers of thermal spray, with hundreds of components protected. For example, refractory metals such as molybdenum, tungsten, and rhenium are applied in both the cold and hot sections of engines to reduce friction. Such coatings offer a secondary benefit by facilitating disassembly of the component group at rebuilding time. They are typically applied by air plasma spray (APS) or high-velocity oxy fuel (HVOF), described in the addendum.

For protection against high temperatures and metal fatigue in the hot sections of engines, MCrAlY alloys may be applied by low-pressure plasma spray. M represents nickel, molybdenum, cobalt, iron, or alloys of these elements such as NiCo and CoNi. Coatings over 3 mm thick are heat treated after spraying, which results in increased bond strength, and improved density.

Thermal barrier coatings consist of a low thermal-conductivity ceramic layer deposited over an MCrAlY bond coat. The ceramic coating is usually zirconia (ZrO_2), but pure zirconia exhibits a phase change as the temperature approaches 800°F, resulting in a substantial volume change that can subsequently generate internal stresses and lead to premature coating failure. Oxide stabilizers are therefore added to the zirconia. Yttria (Y_2O_3) is the most widely used stabilizer, and the material is commonly known as yttria-stabilized zirconia, or YSZ.

Automotive Applications

Thermal spray protects dozens of parts in automobiles, including piston rings, cylinder bores, exhaust components, alternator covers, brake disks, and many others. For example, exhaust headers are metallized with aluminum via the wire-combustion process. As a result of the coating, stock engines show a 6 to 10% increase in power, and more than a 5% increase in gas mileage.

To protect cast aluminum-silicon cylinder bores, a plasma coating process called Rotoplasma has been developed. The plasma coating typically consists of iron/molybdenum composites or iron/iron-oxide composites. The coefficient of friction against the piston ring is reduced by as much as 30%, and fuel consumption is reduced by 2 to 4%.

Materials Research and Collaborations with Industry sectors

In an effort to advance the technology and increase applications, industries are collaborating with thermal spray providers, universities, and government. One such collaboration is the Consortium for Thermal Spray Technology, headquartered at the Center for Thermal Spray Research at Stony Brook University in New York. OEMs such as Alcoa, Caterpillar, General Electric, and Boeing are collaborating with thermal spray equipment makers such as Sulzer Metco, carrier gas providers such as Praxair, powder makers such as Saint-Gobain, and coating applicators such as Cincinnati Thermal Spray.

The consortium also includes government entities such as the National Institute of Standards and Technology and Oak Ridge National Laboratory, as well as universities such as the University of California at Santa Barbara and the University of Modena Italy. (For a complete list, please see the appendix.)

How Thermal Spray Processes Work

The three main families of thermal spray technologies are combustion spray, arc spray, and plasma spray. In combustion spray, a fuel such as acetylene is combusted in oxygen or air to melt a wire. The melted wire is atomized by a jet of an inert gas, which accelerates the molten particles out of the gun onto a substrate. Arc spray also involves melting a wire, but in this case a continuous direct current melts the tip of the wire, and a gas jet accelerates the melted particles onto the substrate. Plasma spray is based on a superheated inert gas jet that propels materials in powder form onto a substrate.

Materials for combustion spray and arc spray consist of anything that can be made into a wire. For plasma spray, any material that can be atomized into a powder can be used, including metals, ceramics, composites, and polymers.

Some of the first applications for thermal spray were in the aerospace industry, specifically for the hot sections of jet engines. To make these engines smaller and more efficient, they had to run hotter, but this meant that materials had to withstand higher temperatures, more corrosion attack, and greater fatigue stress. To enable materials to survive in this environment, a plasma spray technology called low-pressure plasma spray (LPPS) was developed to coat the hot sections of jet engines with MCrAlY alloys, where M is a metal element such as nickel or molybdenum, or an alloy such as NiCo. The LPPS technology produces the lowest oxide levels and the highest density of all the thermal spray processes, as well as excellent bond strength. Typical thickness of this coating is only 0.125 mm.