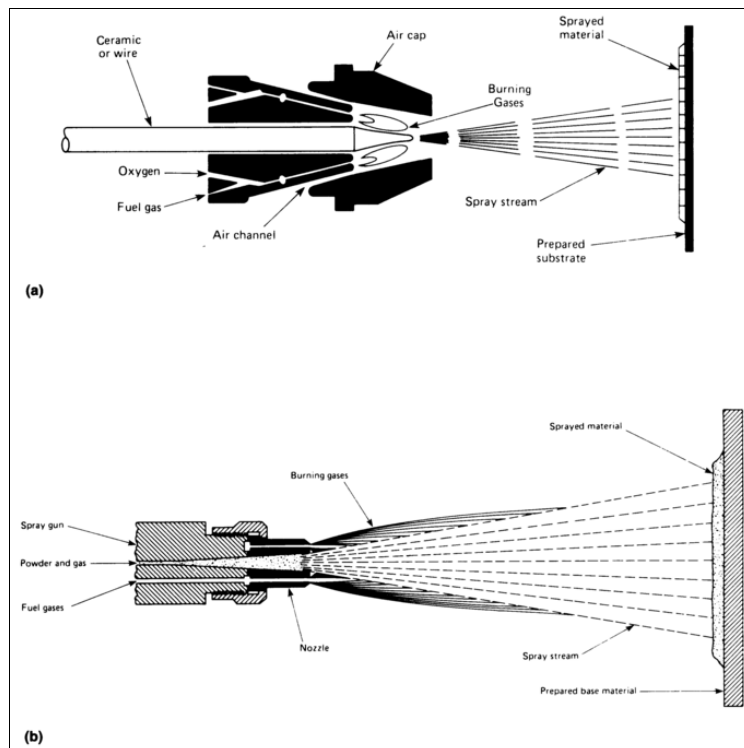


Thermal Spray Methods

Flame spray

In the flame spray process, a combustible gas serves as the heat source that melts the coating material, which may be in rod, wire, or powder form. Commonly selected gases include acetylene, propane, methyl-acetylene-propadiene (MAPP) gas, and hydrogen, along with oxygen. In general, changing the nozzle and/or air cap is all that is required to adapt the gun to different alloys, wire sizes, or gases. For all practical purposes, the rod and wire guns are similar.



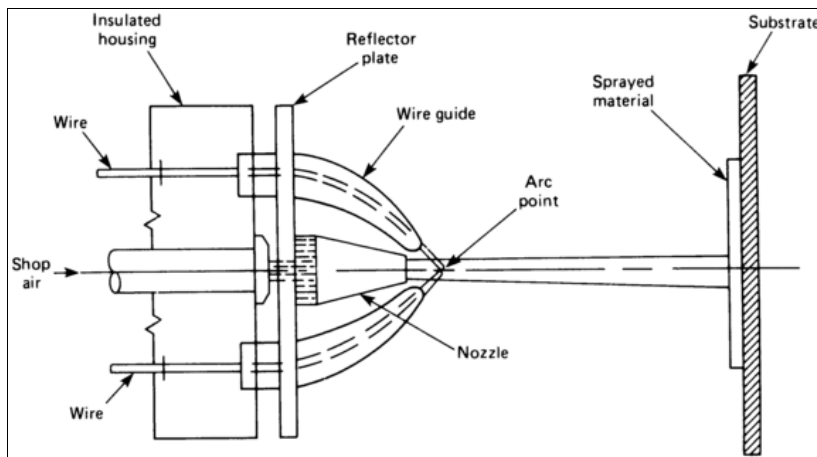
Cross sections of typical flame spray guns. (a) Wire or rod (b) Powder

The flame spray process is characterized by low capital investment, high deposition rates and efficiencies, low cost of equipment maintenance, and relative ease of operation. In general, as-deposited (or cold spray) flame-sprayed coatings exhibit lower bond strengths, higher porosity, a narrower working temperature range, and higher heat transmittal to the substrate than most other thermal spray processes.

The flame spray process is widely used for the reclamation of worn or out-of-tolerance parts, frequently with nickel-base alloys. Bronze alloys may be sprayed for some bearings and seal areas. Blends of tungsten carbide and nickel-base alloys are applied for wear resistance. Zinc is commonly coated on bridges and other structures for corrosion resistance.

Wire-arc spray

The electric-arc (wire-arc) spray process differs from the other thermal spray processes in that no external source such as gas flame or electrically induced plasma provides heat. Instead, two electrically opposed charged wires, comprising the spray material, are fed together in such a manner that a controlled arc strikes at the intersection. The molten metal on the wire tips is atomized and propelled onto a prepared substrate by a stream of compressed air or other gas.



Typical electric-arc spray device

In general, electric-arc spray exhibits higher bond strengths than flame spray, in excess of 69 MPa (10,000 psi) for some materials. Deposition rates of up to 55 kg/h (120 lb/h) have been achieved for some nickel-base alloys. Substrate heating is lower than in flame spray processes, due primarily to the absence of a flame touching the substrate. The electric-arc process is generally less expensive to operate than the other processes. Electrical power requirements are low, and with few exceptions, no expensive gas such as argon is necessary.

However, the process most commonly entails relatively ductile, electrically conductive wire about 1.5 mm (0.060 in.) in diameter. Therefore, electric-arc spray coatings of carbides, nitrides, and oxides are not currently practical; however, the recent development of cored wires permits the deposition of some composite coatings containing carbides or oxides. By using dissimilar wires, it is possible to deposit pseudo-alloys. A less expensive wear surface can be deposited when one wire, or 50% of the coating matrix, is an inexpensive filler material.

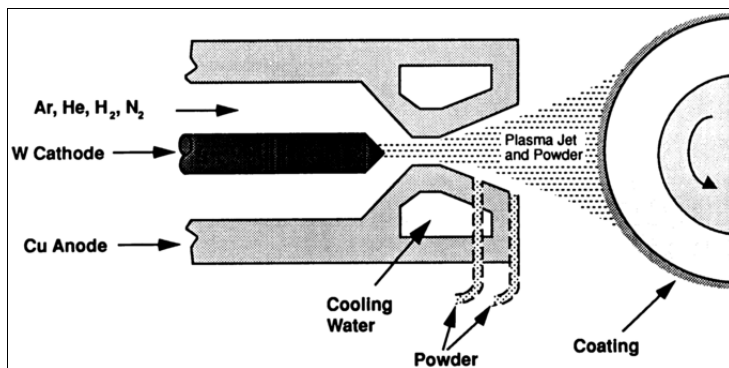
Electric-arc coatings are widely chosen for high-volume, low-cost applications such as zinc corrosion-resistant coatings. In a more unusual application, metal-face molds can be made with a fine spray attachment available from some manufacturers. Molds made in this way can duplicate extremely fine detail, such as the relief lettering on a printed page.

Plasma Spray

Plasma spray is based on a superheated gas known as a plasma. A gas, usually argon but occasionally including nitrogen, hydrogen, or helium, is allowed to flow between a tungsten cathode and a water-cooled copper anode. An electric arc is initiated between the two electrodes by a high-frequency discharge and then sustained with dc power. The arc ionizes the gas, creating a high-pressure gas plasma. The resulting increase in gas temperature, which may exceed 30,000°C, expands the volume of the gas and increases its pressure and velocity as it exits the nozzle. (Gas velocities, which may be supersonic, should not be confused with particle velocities.)

Powder is usually introduced into the gas stream either just outside the torch or in the diverging exit region of the nozzle (anode). It is both heated and accelerated by the high-temperature, high-velocity plasma gas stream. Torch design and operating parameters are critical in determining the temperature and velocity achieved by the powder particles.

The powder velocities usually achieved in plasma spray deposition range from about 300 to 550 m/s. Temperatures are usually at or slightly above the melting point. Generally, higher particle velocities and temperatures above the melting point, but without excessive superheating, yield coatings with the highest densities and bond strengths.



Plasma Spray

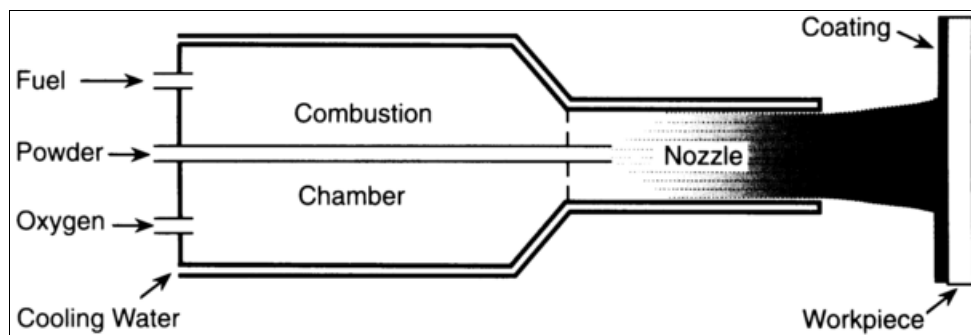
The density of plasma spray coatings is usually much higher than that of flame spray coatings and is typically in the range of 80 to 95% of theoretical. Coating thickness usually ranges from about 0.05 to 0.50 mm (0.002 to 0.020 in.) but may be much thicker for some applications (e.g., dimensional restoration or thermal barriers). Bond strengths vary from less than 34 MPa (5000 psi) to greater than 69 MPa (10,000 psi).

Plasma spray done in an inert atmosphere and/or low-pressure chamber has become a widely accepted practice, particularly in the aircraft engine industry. Inert-atmosphere, low-pressure

plasma spray systems have proven to be an effective means for applying complex, hot corrosion-resistant coatings of the Ni-Co-Cr-Al-Y type to high-temperature aircraft engine components without oxidation of the highly reactive constituents. In fact, plasma spray can be used to produce coatings of virtually any metallic, cermet, or ceramic material.

High-Velocity Oxyfuel (HVOF)

In the high-velocity oxyfuel (HVOF) process, fuel such as propane, propylene, or hydrogen is mixed with oxygen and burned in a chamber. (In some cases, liquid kerosene may be used as a fuel and air as the oxidizer.) The products of combustion expand through a nozzle where the gas velocities may become supersonic. Powder is introduced into the nozzle and is heated and accelerated, achieving velocities of up to about 550 m/s.



High-velocity oxyfuel

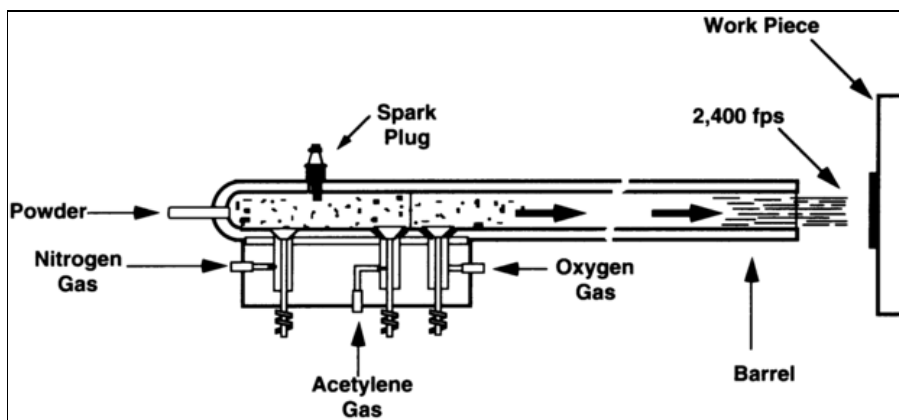
With appropriate equipment, operating parameters, and choice of powder, coatings with high density and with bond strengths frequently exceeding 69 MPa (10,000 psi) can be achieved. Coating thicknesses are usually in the range of 0.05 to 0.50 mm (0.002 to 0.020 in.), but substantially thicker coatings can occasionally be used when necessary with some materials.

HVOF processes can produce coatings of virtually any metallic or cermet material and, for some HVOF processes, most ceramics. Those few HVOF systems that burn acetylene as a fuel are necessary to apply the highest-melting-point ceramics such as zirconia or some carbides. HVOF coatings have primarily been used for wear resistance to date, but their field of applications is expanding.

Detonation Gun

In the detonation gun process, a mixture of oxygen and acetylene, along with a pulse of powder, is introduced into a barrel and detonated by a spark. The high-temperature, high-pressure detonation wave moving down the barrel heats the powder particles to their melting points or above and accelerates them to a velocity of about 750 m/s.

By changing the fuel gas and some other parameters, the Super D-Gun process achieves velocities of about 1000 m/s. This is a cyclic process, and after each detonation the barrel is purged with nitrogen and the process is repeated at up to about 10 times per second. Instead of a continuous swath of coating as in the other thermal spray processes, a circle of coating about 25 mm (1 in.) in diameter and a few micrometers thick is deposited with each detonation. A uniform coating thickness on the part is achieved by precisely overlapping the circles of coating in many layers. Typical coating thicknesses are in the range of 0.05 to 0.50 mm (0.002 to 0.02 in.), but thinner and much thicker coatings can be used.



Detonation gun

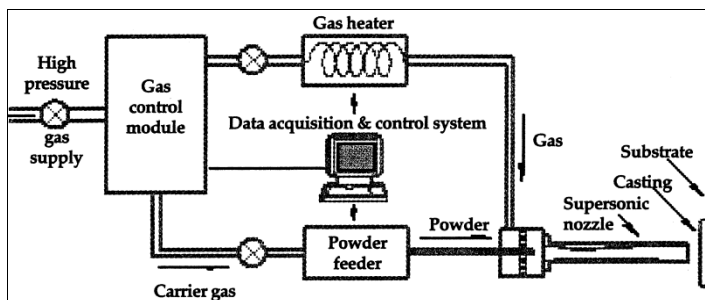
Detonation gun coatings have some of the highest bond strengths and lowest porosities of the thermal spray coatings. In fact, they have been the benchmark against which the other coatings have been measured for years.

In the Super D-Gun process, the extremely high velocities and consequent kinetic energy of the particles cause most of the coatings to be deposited with residual compressive stress, rather than the tensile stress typical of most thermal spray coatings. This is particularly important relative to coating thickness limitations and the effect of the coating on the fatigue properties of the substrate.

Virtually all metallic, ceramic, and cermet materials can be deposited by detonation gun processes. Detonation gun coatings are used extensively for wear and corrosion resistance as well as for many other types of protection. They are frequently specified for the most demanding applications, yet often can be the most economical choice because they provide such long life.

Cold Spray

The distinguishing feature of the cold spray process compared with conventional thermal spray processes is its carrier gas preheat temperatures in the range of 0 to 700°C (32 to 1290°F), a range that is generally lower than the melting temperature of the coating particle materials. The nozzle exit temperature is substantially lower than the gas preheat temperature, further lowering the temperature excursions of the feedstock particles. Consequently, deleterious effects of high-temperature oxidation, evaporation, recrystallization, residual stresses, and other concerns are minimized or eliminated.



Cold spray system

Materials applied by the cold-spray process include pure metals, ferrous and nonferrous alloys, composites, and cermets. Current and potential applications for cold spray coatings include electrical/electronic applications (copper and Fe-NdFeB), aerospace (MCrAlY), automotive (Al and Zn), chemical (Ti), free-standing structures for rapid prototyping, multilayered sleeves (Zn-Cu-Al), and conductive polymers.

Copper is perhaps the most studied feedstock material for the cold-spray process, as these coatings combine very low porosity and low oxygen content, which contribute to excellent electrical properties. Cold-sprayed copper deposits also display excellent tensile properties. Direct-write electrical metallization of copper was one of the earliest envisioned applications for cold-spray technology.