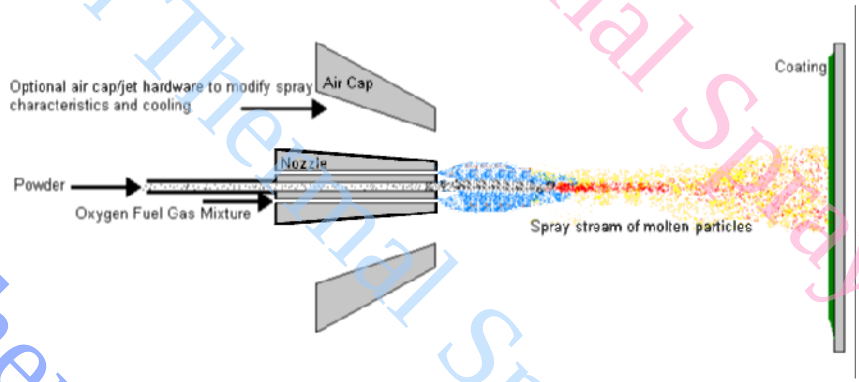
Classification

According to the differences of mechanisms especially for thermal and kinetic energy source, thermal spray techniques can be mainly divided into the following categories.

Flame spraying
Arc spraying
Plasma Spraying (APS, VPS, lPPS)
Detonation-gun spraying
High Velocity oxy-Fuel spraying
Cold spray

Flame Spray Process

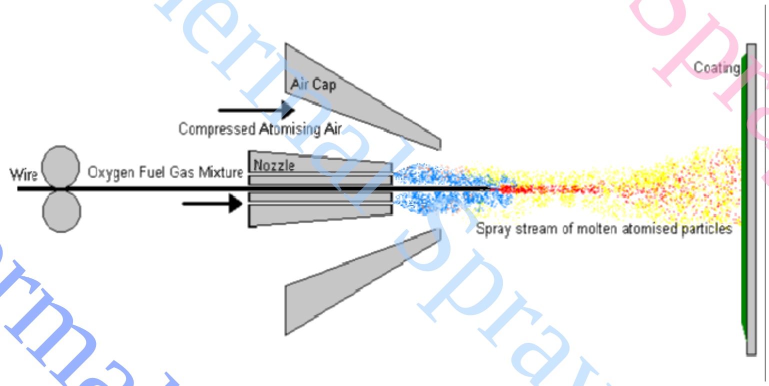


Schematic Diagram of Combustion Powder Thermal Spray Process

This process is basically the spraying of molten material onto a surface to provide a coating. Material in powder form is melted in a flame (oxy-acetylene or hydrogen most common) to form a fine spray. When the spray contacts the prepared surface of a substrate material, the fine molten droplets rapidly solidify forming a coating. This flame spray process carried out correctly is called a "cold process" (relative to the substrate material being coated) as the substrate temperature can be kept low during processing avoiding damage, metallurgical changes and distortion to the substrate material.

The main advantage of this flame spray process over the similar Combustion wire spray process is that a much wider range of materials can be easily processed into powder form giving a larger choice of coatings. The flame spray process is only limited by materials with higher melting temperatures than the flame can provide or if the material decomposes on heating.

Combustion Wire Thermal Spray Process
Metal Spraying



Schematic Diagram of The Combustion Wire Thermal Spray Process

(also known previously as Flame Spray, Metallizing, and Metal Spray Processes)

Recent Gun Spraying 13% Chromium Steel

The flame spray process is basically the spraying of molten metal* onto a surface to provide a coating. Material in wire form is melted in a flame (oxy-acetylene flame most common) and atomised using compressed air to form a fine spray. When the spray contacts the prepared surface of a substrate material, the fine molten droplets rapidly solidify forming a coating. This flame spray process carried out correctly is called a "cold process" (relative to the substrate material being coated) as the substrate temperature can be kept low during processing avoiding damage, metallurgical changes and distortion to the substrate material.

This flame spray process has been extensively used in the past and today for machine element work and anti-corrosion coatings.

* Ceramics and cermets can be used in rod or composite wire form.

Common materials Sprayed:

- Zinc and aluminium for anti-corrosion cathodic coatings on steel
- Nickel/aluminium composite wire for bond coats and self-bonding coatings
- Molybdenum for bond coats
- Molybdenum for hard bearing applications, excellent resistance to adhesive wear, used on piston rings, syncromesh cones and journals.
- High Chromium steel for many applications requiring hard and wear resistant coating
- Bronzes, babbitt for bearing applications
- Stainless steels, nickel and monel for anti-corrosion and wear
- Aluminium, nickel/aluminium for heat and oxidation resistance

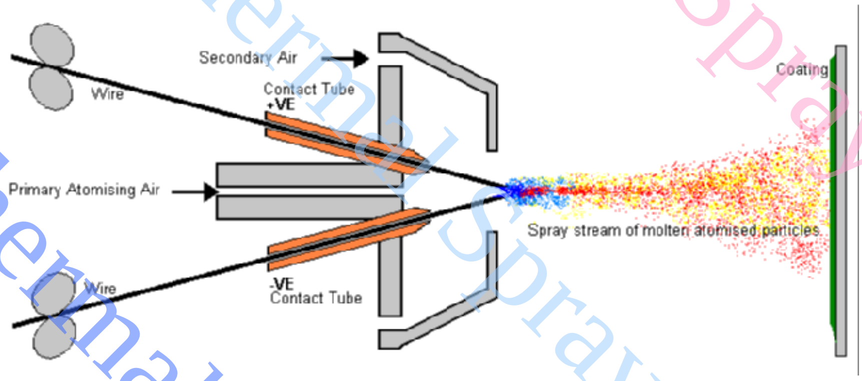
Process Advantages:

- Low capital investment
- Simple to operate
- Wire form cheaper than powder
- Deposit efficiency very high
- Possibly still best for applying pure molybdenum coatings for wear resistance.
- Portable system
- Preheating facility built in, unlike arc spraying
- Possible to use system in areas without electricity supply

Process Disadvantages:

- Limited to spraying materials supplied in wire or rod form

Arc Spray Process



Schematic Diagram of the Electric Arc Wire Thermal Spray Process

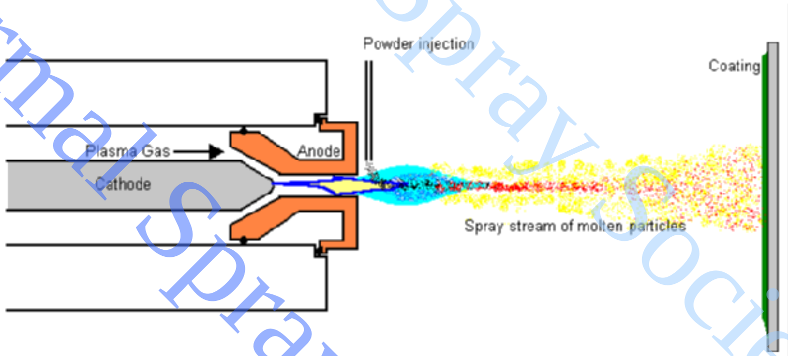
In the Arc Spray Process a pair of electrically conductive wires are melted by means of an electric arc. The molten material is atomised by compressed air and propelled towards the substrate surface. The impacting molten particles on the substrate rapidly solidify to form a coating. This arc spray process carried out correctly is called a "cold process" (relative to the substrate material being coated) as the substrate temperature can be kept low during processing avoiding damage, metallurgical changes and distortion to the substrate material.

Electric arc spray coatings are normally denser and stronger than their equivalent combustion spray coatings. Low running costs, high spray rates and efficiency make it a good tool for spraying large areas and high production rates.

Disadvantages of the electric arc spray process are that only electrically conductive wires can be sprayed and if substrate preheating is required, a separate heating source is needed.

The main applications of the arc spray process are anti-corrosion coatings of zinc and aluminium and machine element work on large components.

Plasma Spray Process



Schematic Diagram of the Plasma Spray Process

The Plasma Spray Process is basically the spraying of molten or heat softened material onto a surface to provide a coating. Material in the form of powder is injected into a very high temperature plasma flame, where it is rapidly heated and accelerated to a high velocity. The hot material impacts on the substrate surface and rapidly cools forming a coating. This plasma spray process carried out correctly is called a "cold process" (relative to the substrate material being coated) as the substrate temperature can be kept low during processing avoiding damage, metallurgical changes and distortion to the substrate material.

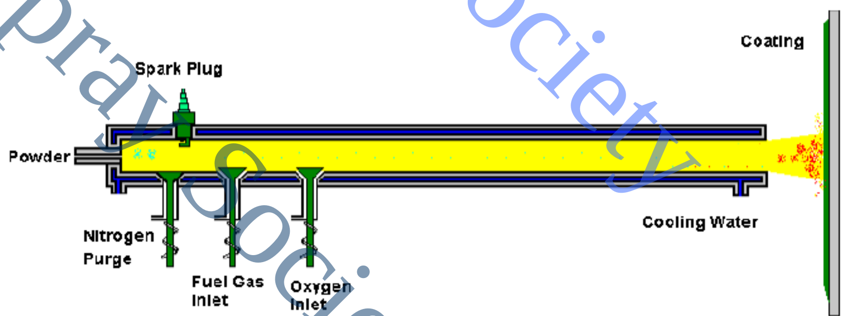
The plasma spray gun comprises a copper anode and tungsten cathode, both of which are water cooled. Plasma gas (argon, nitrogen, hydrogen, helium) flows around the cathode and through the anode which is shaped as a constricting nozzle. The plasma is initiated by a high voltage discharge which causes localised ionisation and a conductive path for a DC arc to form between cathode and anode. The resistance heating from the arc causes the gas to reach extreme temperatures, dissociate and ionise to form a plasma. The plasma exits the anode nozzle as a free or neutral plasma flame (plasma which does not carry electric current) which is quite different to the Plasma Transferred Arc coating process where the arc extends to the surface to be coated. When the plasma is stabilised ready for spraying the electric arc extends down the nozzle, instead of shorting out to the nearest edge of the anode nozzle. This stretching of the arc is due to a thermal pinch effect. Cold gas around the surface of the water cooled anode nozzle being electrically non-conductive constricts the plasma arc, raising its temperature and velocity. Powder is fed into the plasma flame most commonly via an external powder port mounted near the anode nozzle exit. The powder is so rapidly heated and accelerated that spray distances can be in the order of 25 to 150 mm.

The plasma spray process is most commonly used in normal atmospheric conditions and referred as APS. Some plasma spraying is conducted in protective environments using vacuum chambers normally back filled with a protective gas at low pressure, this is referred as VPS or LPPS.

Plasma spraying has the advantage that it can spray very high melting point materials such as refractory metals like tungsten and ceramics like zirconia unlike combustion processes. Plasma sprayed coatings are generally much denser, stronger and cleaner than the other thermal spray processes with the exception of HVOF and detonation processes. Plasma spray coatings probably account for the widest range of thermal spray coatings and applications and makes this process the most versatile.

Disadvantages of the plasma spray process are relative high cost and complexity of process.

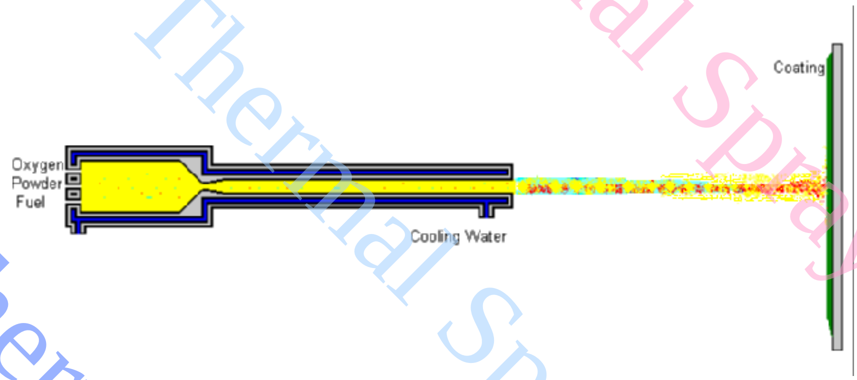
Detonation Thermal Spraying Process



Schematic Diagram of the Detonation Thermal Spray Process

The Detonation gun basically consists of a long water cooled barrel with inlet valves for gases and powder. Oxygen and fuel (acetylene most common) is fed into the barrel along with a charge of powder. A spark is used to ignite the gas mixture and the resulting detonation heats and accelerates the powder to supersonic velocity down the barrel. A pulse of nitrogen is used to purge the barrel after each detonation. This process is repeated many times a second. The high kinetic energy of the hot powder particles on impact with the substrate result in a build up of a very dense and strong coating.

High Velocity Oxygen Fuel Thermal Spray Process



Schematic Diagram of the HVOF Process

The HVOF (High Velocity Oxygen Fuel) Thermal Spray Process is basically the same as the combustion powder spray process (LVOF) except that this process has been developed to produce extremely high spray velocity. There are a number of HVOF guns which use different methods to achieve high velocity spraying. One method is basically a high pressure water cooled HVOF combustion chamber and long nozzle. Fuel (kerosene, acetylene, propylene and hydrogen) and oxygen are fed into the chamber, combustion produces a hot high pressure flame which is forced down a nozzle increasing its velocity. Powder may be fed axially into the HVOF combustion chamber under high pressure or fed through the side of laval type nozzle where the pressure is lower. Another method uses a simpler system of a high pressure combustion nozzle and air cap. Fuel gas (propane, propylene or hydrogen) and oxygen are supplied at high pressure, combustion occurs outside the nozzle but within an air cap supplied with compressed air. The compressed air pinches and accelerates the flame and acts as a coolant for the HVOF gun. Powder is fed at high pressure axially from the centre of the nozzle.

HVOF PROCESS

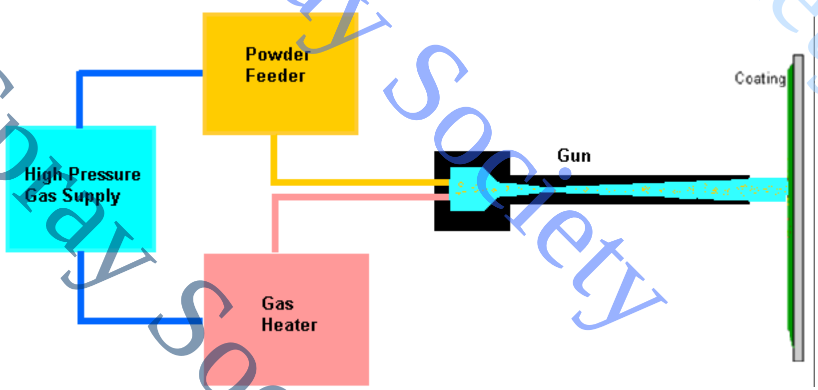
The coatings produced by HVOF are similar to those produce by the detonation process. HVOF coatings are very dense, strong and show low residual tensile stress or in some cases compressive stress, which enable very much thicker coatings to be applied than previously possible with the other processes.

The very high kinetic energy of particles striking the substrate surface does not require the particles to be fully molten to form high quality HVOF coatings. This is certainly an advantage for the carbide cermet type coatings and is where this process really excels.

HVOF coatings are used in applications requiring the highest density and strength not found in most other thermal spray processes. New applications, previously not suitable for thermal spray coatings are becoming viable.

- Not capable of the low oxide, high density and high strength coatings of plasma and HVOF

COLD SPRAY COATING PROCESS



Schematic Diagram of Cold Spray Process

The Cold Spray or cold gas-dynamic spraying process is the next progressive step in the development of high kinetic energy coating processes. Similar in principle to the other thermal spray methods, it follows the trend of increasing particle spray velocity and reducing particle temperature as with the HVOF/HVAF processes, but to a more extreme level that it could be asked whether the process fits under the description of thermal spray.

The Cold Spray process basically uses the energy stored in high pressure compressed gas to propel fine powder particles at very high velocities (500 - 1500 m/s). Compressed gas (usually helium) is fed via a heating unit to the gun where the gas exits through a specially designed nozzle (laval type convergent-divergent nozzle mostly) at very high velocity. Compressed gas is also fed via a high pressure powder feeder to introduce powder material into the high velocity gas jet. The powder particles are accelerated and moderately heated to a certain velocity and temperature where on impact with a substrate they deform and bond to form a coating. As with the other processes a fine balance between particle size, density, temperature and velocity are important criteria to achieve the desired coating.
The particles remain in the solid state and are relatively cold, so the bulk reaction on impact is solid state only. The process imparts little to no oxidation to the spray material, so surfaces stay clean which aids bonding. No melting and relatively low temperatures result in very low shrinkage on cooling, plus with the high strain induced on impact, the coatings tend to be stressed in compression and not in tension like liquid/solid state reactions of most of the other thermal spray processes. Low temperatures also aid in retaining the original powder chemistry and phases in the coating, with only changes due deformation and cold working.

Bonding relies on sufficient energy to cause significant plastic deformation of the particle and substrate. Under the high impact stresses and stains, interaction of the particle and substrate surfaces probably cause disruption of oxide films promoting contact of chemically clean surfaces and high friction generating very high localised heating promoting bonding similar to friction or explosive welding.

Coatings at present are limited to ductile materials like aluminium, stainless steel, copper, titanium and alloys. Hard and brittle materials like ceramics can not be sprayed in the pure form, but may be applied as composites with a ductile matrix phase. Substrate materials are also limited to those that can withstand the aggressive action of the spray particles. Soft or friable substrates will erode rather than be coated.

The cold spray process is still primarily in the research and development stage and only now becoming commercially available.

Cold Spray Process Advantages:

Low temperature process, no bulk particle melting

- Retains composition/phases of initial particles
- Very little oxidation
- High hardness, cold worked microstructure
- Eliminates solidification stresses, enables thicker coatings
- Low defect coatings
- Lower heat input to work piece reduces cooling requirement
- Possible elimination of grit blast substrate preparation
- No fuel gases or extreme electrical heating required
- Reduce need for masking

Cold Spray Process Disadvantages:

- Hard brittle materials like ceramics can not be sprayed without using ductile binders
- Not all substrate materials will accept coating
- High gas flows, high gas consumption.
- Helium very expensive unless recycled
- Still mainly in research and development stage, little coating performance/history data

Possible Uses for Cold Spray Coatings:

- Corrosion protection, where the absence of process-induced oxidation may offer improved performance
- Electrical and thermal, where the absence of process-induced oxidation may offer improved conductivity
- Pre-placement of solders and coatings where purity is important

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