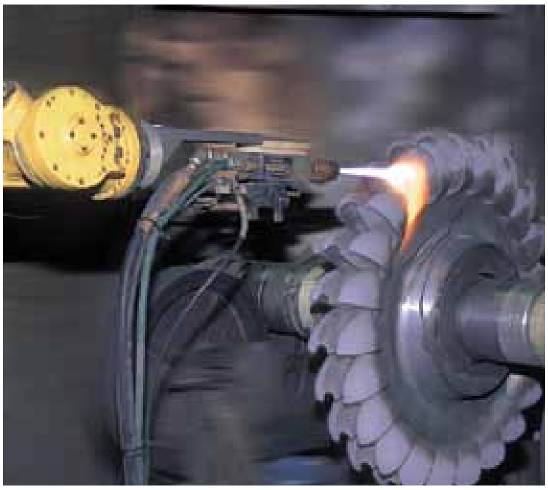
Combustion thermal spray processes

This article outlines the combustion thermal spray processes and has been extracted from a longer article by Frank J Hermanek, published by the International Thermal Spray Association. It is the first part of a two-part series.



The HVOF process being used to coat a pump impellor.

Engineering components are subject to degradation by wear, corrosion, oxidation and cavitation in service, which results in a reduced service life. All these degradation processes are active on the surface of the component, and it follows that a suitably selected and correctly applied surface coating can be a powerful tool in improving the performance and extending the service life of such components. One method for applying such coatings is through the thermal spray process, whereby the coating material is melted in a heat source, and the liquid or molten material propelled by process gases onto a base material. The molten stream solidifies on the surface of the component and forms a solid layer.

Dr Max Ulrick Schoop of Zurich first recognised that a stream of molten particles impinging upon themselves could create a coating. His work, and that of his collaborators, resulted in the establishment of thermal spray processes, which fostered a worldwide industry serving over thirty technology sectors and generating sales of over US$2-billion per year.

Thermal spraying is a group of coating processes in which finely divided metallic or non-metallic materials are deposited in a molten or semi-molten condition to form a coating. The coating material may initially be in the form of powder, ceramic rod, wire, or molten materials.

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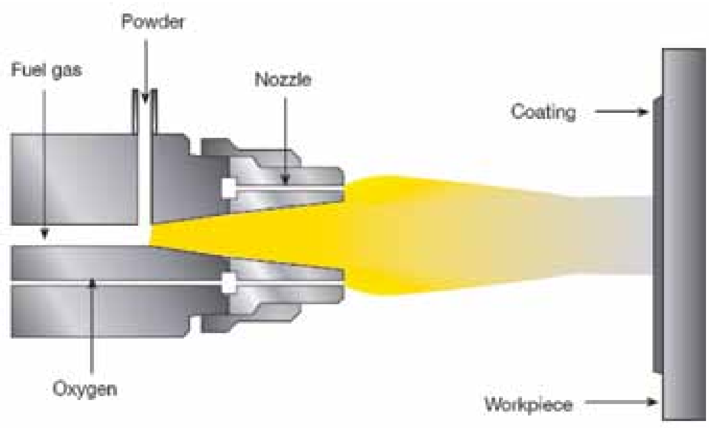
Molten metal flame spraying is a thermal spraying process in which metallic material is sprayed in the molten condition. It has long been recognised that fluids may be broken up into very fine particles by a stream of high velocity gas emanating from a nozzle.

The first spray technique developed by Schoop was the outcome of experiments in which molten metal was poured into a stream of high velocity gases. Schoop's apparatus consisted of a compressor supplying air to a heated helical tube. The heated air was used to pressurise a crucible filled with molten metal and eject it out as a fine spray that would adhere to a suitable surface. Then a Dutch patent, describing equipment for spraying low melting point metals, was granted in 1924 to Jung and Versteeg. Mellowes Ltd commercialised the process in the UK. This system consisted of a gun, a furnace, an air compressor and a fuel supply. The gun had many air and gas valves, a heating chamber (burner), nozzle, handle and a melting pot. Metal exited the pot through a front orifice where it was directed into a nozzle. Compressed air surrounded the nozzle, atomising the molten metal and propelling it to the surface to be coated.



Schematic diagram of the powder flame spray process.

The molten metal process has advantages and disadvantages. Advantages include: cheap raw materials; use of inexpensive gases; and very simple gun design.

Noteworthy disadvantages are that the gun is cumbersome to use in manual mode and can only be held in a horizontal plane; it requires high maintenance due to high temperature oxidation and molten metal corrosion; and the process can only be used with low melting temperature metals.

Uses for the molten metal thermal spray process include the fabrication of moulds, masks and forms for the plastics industry, using low melting point bismuth based alloys (the Cerro family of alloys); the deposition of solder alloys to joints that would be coalesced using torches or ovens; and the production of metal powders.

Powder flame spraying is a thermal spray process in which the material to be sprayed is in powder form. It is probably the simplest of all the spray processes to describe: a powder is fed through the centre bore of a nozzle where it melts and is carried by the escaping oxy-fuel gases to the work piece.

Unfortunately, this approach yields coatings high in oxides and with void contents approaching 20% by volume. Coating quality can be improved, however, by feeding air to the nozzle through a small jet, which reduces the pressure in a chamber behind the nozzle. This chamber is connected to the powder feed hopper. In this way a gentle stream of gas is sucked into the gun and carries powder with it. This concept was developed by Fritz Schori in the early 1930s.

Wire flame spraying uses feedstock in wire or rod form. First developed by Schoop in about 1912, the apparatus consisted of a nozzle in which a fuel, probably acetylene or hydrogen, was mixed with oxygen and burned at the nozzle's face. A stream of compressed air surrounding the flame atomised and propelled the liquefied metal. Process continuation depended on feeding the wire at a controllable rate so it could be both melted and propelled in a continuous stream. Schoop approached this problem by using a turbine to actuate gears and drive rolls that pulled the wire into the nozzle.

The wire flame spray gun has not radically changed since the days of Schoop. While there have been changes in nozzle and air cap design, replacement of the air turbine with an electrical motor and even the use of barrel valves, the basic principal remains the same: a wire is pushed or pulled into a flame, melted and atomised and then deposited as molten droplets to form an adherent coating.

Ceramic rod flame spraying dates back to the early 1950s when a demand arose for heat resistant refractory coatings. Plasma had not come into its own and flame sprayed powder coatings, due to their porous nature, lacked the integrity and protection required. The solution was rather simple. Coors Ceramic and Norton developed ceramic rods, referred to as Rokide, while the Metallising Engineering Company (Mogul), modified a wire gun to spray rods. The principle of operation is similar to that of wire flame spraying – the nozzle's flame is concentric to the wire or rod in order to maximise uniform heating. A coaxial sheath of compressed gas around the flame atomises the molten material and accelerates it to the workpiece,

Particle velocities in both the wire and rod process are approximately the same at around 185 m/sec, while coating densities have been measured at approximately 95% by volume. Ceramic compositions include several stabilised zirconias, white and gray alumina, and a spinel.

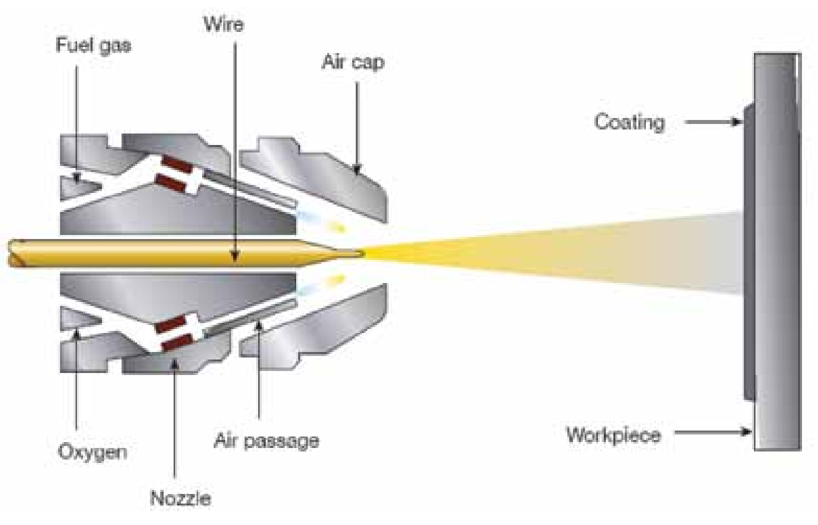
Detonation flame spraying involves the controlled explosion of a mixture of fuel gas, oxygen and powdered coating material to melt and propel particles to the workpiece. The procedure is initiated by a gas/powder metering system that measures and delivers the mixture to the combustion chamber, where it is ignited. The resulting shock wave accelerates the powder particles to over 700 m/sec and produces temperatures in excess of 4 000°C. Pressures from the detonation close the controlling valves until the chamber pressure is equalised. The cycle may be repeated at a rate of 4 to 8 times per second.

Each detonation deposits a dense and adherent layer several microns thick and about 2,5 centimetres in diameter. Repeating the cycle produces thicker coatings. Detonation coatings are designed for applying hard materials, especially carbides, on surfaces subject to aggressive wear.

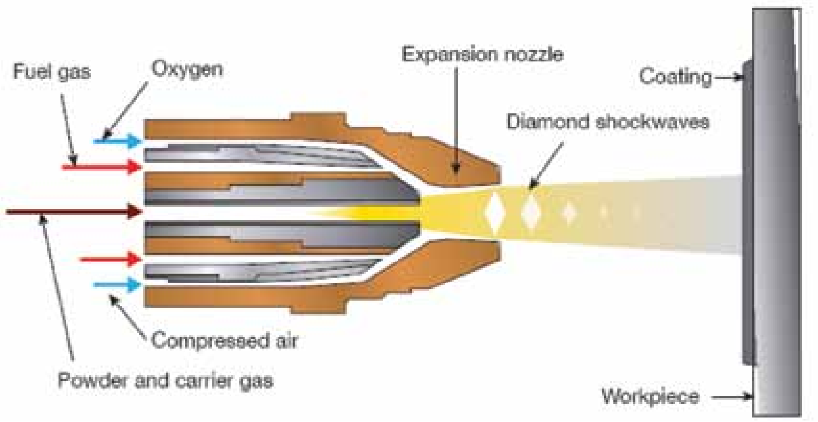
High velocity oxyfuel spraying (HVOF) is a high velocity flame spray process introduced in the early 1980s by Browning and Witfield, using rocket engine technologies. Today, it is by far the dominant spraying process. A combination of oxygen with various fuel gases – including hydrogen, propane, propylene, hydrogen and even kerosene – is used. In a combustion chamber, burning by-products are expanded and expelled outward through an orifice where very high velocities are achieved. Powders to be sprayed are injected axially into the expanding hot gases where they are propelled forward, heated and accelerated onto a surface where they form a coating. Gas velocities exceeding Mach 1 have been reported with temperatures approaching 2 300°C. The coupling of inertially driven/highly plasticised particles can achieve coatings approaching that of theoretical density. Disadvantages include low deposition rates and the in-flight oxidation of particles.

Future efforts are focusing on applying thicker coatings and improvements in process control including in-flight transit time and exposure to atmospheric oxygen.

Part 2, dealing with the electric spraying techniques will be published in the next edition of *African Fusion*.



Schematic diagram of the wire flame spray process.



Schematic diagram of the HVOF process.