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Thermal Spray Process - A Wear Combating Solution

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Thermal Spray refers to a group of coating techniques whereby droplets of molten or partially molten material are sprayed on to a solid substrate to develop the coating. Based on the applied heat source and the process characteristics, a large number of thermal spray techniques are commercially available enabling a wide range of material ranging from metal to polymer including ceramics, cermets and carbides which can be used as coating material. The coating develops resistant to various wear factors affecting the substrate. Thermal Spray has revolutionized the design of machine in practically all the industry. The technology has not only brought down the cost of machine development but has also enhanced the working life of many critical machine parts detrimental to machine performance and overall viability of the process. The small droplet of metal created a ripple effect which led and augmented development of many 'state of the art' processes influencing our lives from travelling in an aircraft to going to a dentist for an implant.

The way thermal spray technology is influencing our machine design and lifestyle, it becomes very interesting to know how and why this process is developed and how it is enriching itself.

Before we go to the chronology of development, let us look at what exactly a thermal spray process is:

The two schematic diagrams given in **Fig.1** and **Fig. 2** show typical thermal spray process by using powder feedstock and wire:

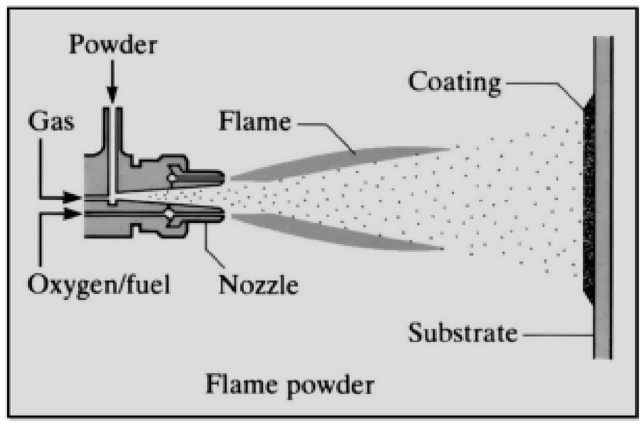

Fig. 1 : Thermal Spray Coating using powder

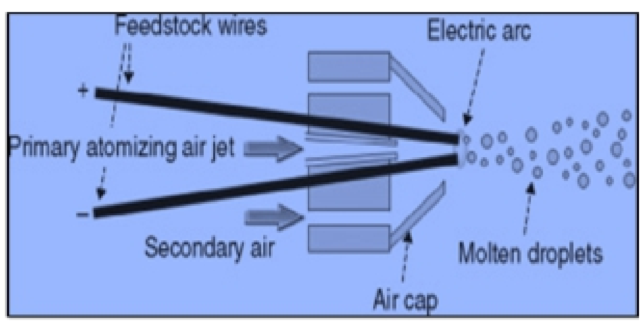

Fig. 2 : Thermal Spray Coating using wire

From **Fig.1** and, it is clear that the major variables for a thermal spray process are:

1. Material Feedstock which can be powder or wire
2. Heat Source which can depend upon the process
3. Meting and acceleration of particles which also depend on the process adopted
4. Impact of molten or partially molten particle with the substrate primarily depends on the travel speed and acceleration of the particle
5. Formation of bond or interlocking with the substrate

In most of the thermal spray processes the basic bonding mechanism is mechanical interlocking except some of the processes like Spray/Fuse and Plasma Transferred Arc where the bonding is metallurgical because of the sufficient heating of the substrate.

As we see from the process and the variables, the bonding between splats can be improved to the desired requirement by increasing temperature or particle impact velocity. However, a very high increase in temperature while coating with metallic or composite feedstock is not preferred to avoid oxidation.The thermal spray process is now so advanced that it can spray even difficult to melt material like ceramics and carbides and achieve a coating of thickness as low as few microns without heating the substrate. Because of these unique features, the process finds great application in machine component designing, reclamation of worn out components and the highly advanced manufacturing processes like additive manufacturing and medical implants.Development of thermal spray process is like any other development driven by the quest for improvement and built slowly over the years. The credit of development is shared between two material scientists. Oerlikon was the first person who melted lead and sprayed on a substrate. This was a patented process and so remained confined to a close set of people.The liberalization and democratization of thermal spray started happening from 1908 when Max Ulrich Schoop used flame spray process to spray pure metal, in form of wire, was melted and sprayed at a high speed on substrate using compressed air. This produced a coating of low bond strength and high porosity. Thought it still had a long way to go but this experimental gave the direction to material scientists and engineers for further research and develop thermal spray as a robust technology to change the surface properties to economize on the selection of the base material for machine components and still get an enhanced working life and also to reclaim the worn out components. Max Schoop's experiment started a revolution in material science and led the foundation for research and trials in using different material and alloys to get different surface properties. The question comes here why this development was needed. The industrial revolution was taking place and post-world war one, the machine development was getting momentum. Material scientists were busy and engaged in finding the best material and solution to enhance the working life of machine by extending the mean life before failure of major components.

This (**Fig.3**) is a typical life cycle of any machine part. The initial failures are generally attributed to design issues or misalignment with other components. Once these issues are addressed, machine performs and reaches the end of its life mainly on account of different kind of industrial wear acting on the various components which causes loss of material from surface of machine components, cracks or breakage and make the machine inoperative or slows down the operation. To economize the machine building and enhance life of the machine, the importance of study of industrial wear was realized to select the most appropriate and optimum material which can resist the wear and enhance the working life. The wear factors identified were:

Impact, Abrasion, Friction, Erosion, Cavitation, Corrosion and Heat.

Each type of wear identified affects the machine parts in different way. Impact and abrasion act with certain angle of impingement which result in either heavy loss of material from the surface, cracks, or breakage.

The other five wears friction, erosion, cavitation, corrosion and heat causes damage mainly to the surface and reduces the life span of the machine. The development so far made was based on the feedstock of molten metal and wire. These had their own limitations like huge constraint in melting or making wire with metals and alloys having high hardness, melting temperature and oxidation in addition to the deposit porosity and adhesion. Each of these limitations created a huge challenge in the acceptance of thermal spray process by the industry. Every wear factor need different surface properties like low coefficient of friction, adhesion, porosity free deposits, resistant to corrosive media and high macro and micro hardness of the coating depending on the wear or the combination of wears acting on the machine parts. Such coating could only be possible with the development of powder feedstock using atomization (**Fig. 4**).

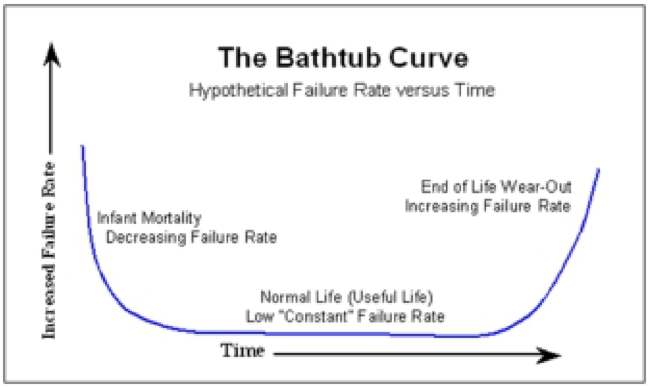

Fig. 3 : Typical life cycle curve

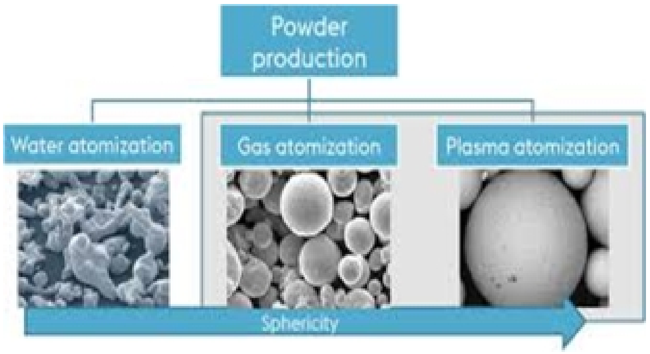

Fig.4 : Types of Atomisation Process

Atomisation process was a landmark development which emerged as a turning point in the success of thermal spray as a solution provider not only in economizing the design of machine components but also to enhance working life by providing a superior surface coating which could match the friction coefficient of nickel or as hard as deposit of tungsten carbide, minimizing the deposit porosity to second decimal and resistance to high and very high working temperature. It was now possible to make feedstock of any material even as hard as tungsten carbide and ceramics and melt any metal to make coating feedstock. The limitations with wire as feedstock were overcome.

The development of powder feedstock made possible a deposit having thickness as low as few microns and the advancement made in spray processes can do coating with practically no heat affected zone at substrate. For most of the processes the substrate temperature does not go beyond 200 degrees Celsius which means the base material temperature hardly attains the temperature which can develop heat affected zone while cooling.

Thanks to the development of powder feedstock and atomization process, the industry has today a wide range of thermal powder made of metal, alloys, carbides, ceramics, cermet and even polymer which can provide coating on any component whether it is conventional machine part, moulds, steel mill rolls, gas turbine, industrial valves or equipment as sophisticated as aircraft turbines and also widely used in additive manufacturing for development of medical implants and other critical components (**Fig.5**).

Fig.5 : One of the regular machine components coated with thermal spray powders

Thermal Spray is considered today as one of the most potent and effective solutions to protect any metal parts from decay by industrial wear and is also playing a very significant role in economizing the cost of machines by selecting economical material and enriching the surface by thermal powders.

The other feedstock which is also extensively used for some of the voluminous jobs is wire made of metal and alloying elements which can be drawn to wire for providing coating mainly for resisting corrosion and also friction, sometimes used also for comparatively smaller jobs. The development of powder feedstock has also made possible manufacturing of flux cored wire giving hard deposit for providing coating resistant to erosion encountered in applications like boiler tubes, industrial fan blades etc. The spray process used is arc spray commercially known as metallizing. Some of the big jobs recently coated by Indian industry using arc spray processes are oil & gas platforms (**Fig.6**) for providing coating resistant to sea water corrosion and columns of bridges.

Fig.6 : Oil and gas platforms

The progress made in the development of powder feedstock led to the development of spraying processes around the core objectives of minimizing porosities, high deposition rate, ability to spray a wide range of material and minimizing the heat output on the substrate. The industry today has a process which does not even melt the powder and still makes very cohesive bond with the substrate without any application of heat known as Cold Process. The other major advantage one gets from this process is no oxidation of the coating material.

The chronological order of the development of spray processes can be noted as follow:

1. Arc Spray
2. Spray and Fuse
3. Flame Spray
4. Plasma Spray
5. Plasma Transferred Arc
6. High Velocity Oxy Fuel
7. Laser Cladding
8. Cold Spray

Arc Spray uses wire as consumables, rest of the processes use thermal spray powders. The selection of spray process largely depends on the kind of coating required for getting certain surface properties depending on the wear or combination of wears the surface is subjected to. Other than Spray & Fuse and PTA, the substrate is not exposed to any direct heat that makes thermal spray process a great asset to industry in combating wear.