



COLD SPRAYING

Chemical Science

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ABSTRACT

Breaking the norms of typical thermal spraying process, cold spray processes are a solid state micron sized particles deposition process at a temperature very low than the melt temperature of the particle. It uses more kinetic energy i.e spray particle needs to attain a velocity more than the critical velocity and very less thermal energy. A large variety of materials (metals, alloys, ceramics) can be deposited on almost any substrate surface. Not only a coating process, it also is a type of additive manufacturing, luring the eyes of not only researchers but of industries too. A relatively young entrant, it has proved to be more efficient than other thermal spraying process. A comparison illustrated in the Figure 1. It can help to observe material behavior under high strain rates, pressure or cooling rates.

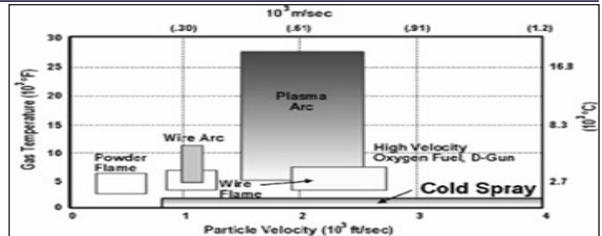


Figure 1: Comparison between different spraying process Source :Harminder et al.

KEYWORDS

INTRODUCTION

Abating the demands of the other thermal spraying techniques, Cold spray method had begun to have its known aura in 1980s. James Browning mentioned in his book that till the time people were unaware of the cold particles, all the focus was on creating ways to maximize the particle temperature. Least did the people thought of increasing the velocity, we would have combined the concept of high velocity with combustion technologies much earlier. Within a very short time span, Cold Spray techniques become useful in almost in every field be it Surface rebuilding/restoration, complex surface generation, protection against hot and erosion corrosion, resistance to wear and tear, reducing oxidation, component reclamation, etc. It had widespread application in the field of Biomedical, metallization of glass or ceramic, rebuilding the worn out parts, reworking mismatched parts, manufacturing new designs, working on metal/ ceramic or glass joints.

Cold spraying is a solid state coating technique in which metals or any other composite particles are deposited over another surface in the form of solid microscopic powder. The deposition or the bonding is due to the high velocity impact of these micron size particles. This high kinetic energy is achieved by preheating high pressurized gas (generally N or He). After this, converging, diverging nozzle also known as De Laval type is expanded. The micron size solid powder is accelerated by this gas stream which is fed into the nozzle. These accelerated powdered form particles impacts the surface on which it is coated with very high kinetic energy or velocity. Due to more importance of kinetic energy than thermal energy and as the process works under comparatively low temperatures it is termed as cold spraying. The process is undertaken relatively in inert process gases and a low temperature proves to be too beneficial. The coated substance more or less retains almost all the properties it had earlier. Oxidation is limited and this leads to savings of a huge amount of money gone into to prevent oxidation. Oxidation ensures that there are less chances of crack nucleation and thus prevents cracking of the welding joints and other quality related issues. The major difference between cold spraying and other conventional thermal spraying techniques are that the spray particles are solid in case of cold spray while coated on the surface whereas partially or fully molten in case of other thermal spraying processes. It has also been observed that some mechanical properties like yield strength of the processed surface is as good as highly deformed cold worked bulk material.

Since, the sprayed particles are solid and not molten much, there is no complex effect on the surface. Solidification, shrinkage, and other changes like oxidation are minimal and there models simulating the results can be easily process with precision and analysed. The process control is fairly simple and can be optimized by regulating the gas temperature and pressure. Unlike in flame spraying, plasma spraying or HVOF (i.e High Velocity oxy fuel flame spraying), there is no need for considering combustion reactions, heat transfer, or expansion of multicomponent gases.

LITERATURE SURVEY

Researched by Prof. Papyrin and few others at Institute of Theoretical and Applied Mechanics (ITAM), cold spraying process was developed in 1985. Result of which was the advancement in this field due to the development of better version technology of cold spray. A lot of patents and research paper were filed in this domain around in the early 2000s. Not just it was a simple process, but it also had huge applications in a wide variety of fields.

The discovery of this phenomenon was the result of some of the observations of the wind tunnel experiments conducted by Prof Papyrin. While studying the changes in flow structure under a particle influence and the interaction of two phase (solid and gas) flow with a body. After this discovery, various research and patents on the subject was conducted to get insights about the gas dynamics, types of nozzles, heat transfer, flow of the particles, impact of the supersonic jet, production of high velocity flow, improvising the particle-substrate bonding, improvised commercially visible technological device, studying variety of materials and their efficiency, impact on changing particle size, optimizing velocity of the gas flow, etc. Many books started publishing like Cold spray technology by Prof. Anatolii. New application areas were explored.

Even though the advancement in the field of thermal spray was happening around from the year of 1900s, cold spray was a major revolution of 1985 as people had not imagined that the coating can be done without the requirement of melting down the particle using some thermal energy. People started understanding that not only can substrate erosion take place using cold spray, but if optimized properly it can act as one of the best methods for coating particles on a substrate resulting in very fine finish, low risk of oxidation, low residual stresses, particle can be very different from the substrate it wants to be coated on, cold worked, scrap machines can now be reworked effectively, etc. The patent and use in industry was majorly a phenomenon of 2000s where various different industries started appreciating this method. A detailed evolution of this domain is described in below subsections.

Wind Tunnel Experiment

Wind tunnel experiment was the major breakthrough experiment which hinted people that coating of substrate does not necessarily requires thermal energy. If some critical velocity can be reached, then coating of micro sized particle on substrate can be achieved using supersonic jet particle flow at relatively very low temperature without reaching the melting point of the substrate. Initially the experiment was aimed at studying the supersonic two-phase flow of particles, its interaction and affect on the flow pattern.

The experiment was conducted using the available laser-based technique at that time. Doppler Velocimeter was used for measuring the solid spray powder particles velocity. Shift in Doppler frequency and changes in microstructure was also analysed. Schlieren technique

was used for analysis of wave structure w.r.t time. Laser sheet technique was used to study the trajectories of particle

Upon doing surface analysis, it was found that there is a coating of the sprayed particle on the surface. So, instead of just coming the conclusion that a higher pressure region is developed when the particle passes to a shock wave, both of which showed conical structure, the interest of the researchers shifted to this continuous coating of these micro- solid spread particles. It was also observed that this layer of coating was only observed in aluminium and not in Bronze or Plexiglas particles. Instead these showed significant erosion of the surface. Researchers found it interesting that why the particles are showing two different phenomenon, one of coating (with aluminum) and surface erosion with Bronze or Plexiglas particles.

A remarkable feature of this experiment was that the particle flow temperature was roughly 137 degree Celsius while the speed of the aluminum particle was around 450m/s. A uniform, dense and strongly deformed coating of the spray particle was observed without any voids or pores. It was these two fabulous observations which attracted the eyes of many researchers and industrialist and lead to the development of cold spraying techniques. The mystery was resolved by the concept of critical velocity. It was as follows-

- If the particle has velocity which is above that materials critical velocity, it will bond with the surface and form a layer if coating
- If the particles velocity is less than its critical velocity, phenomenon of surface erosion would be observed

Jet Spray onto Target and Commercialization Concepts

With the new possibilities of cold spray coating at room temperature and in solid state, deep research started on identifying the characteristics of interaction of the solid particles with the surface body at very high impact velocity. Research started on the jet technology. Deducing ways to interconnect the velocity and its impact on coating.

Cold spray setup was unsuitable for industrial application back then. Two major reasons

1. Application field were restricted due to the small fraction of particles bonding with the surface in wind tunnel. It could not have been applied on a large scale due to not so suitable set up which was devised at the time of wind tunnel experiment.
2. Test section size was too small. So, only small sized bodies could have been coated. It was observed that the body size was not much improved even after increasing the test section size. This was due to the deceleration ahead of surface

Velocity Control Techniques

Since it was found that critical impact velocity is very important for the coating of particle to take place on the substrate surface, a large group of people started finding out ways and techniques to control velocity, maximize it and measure it accurately. Significant changes in test gas composition was made and computed to get different velocity.

Different particle sizes, nozzle sizes, exit size and a lot of other variations were done to improvise control of velocity. It was observed that a change from 0 to 1 in (He/air) can cause particle impact velocity to change around 200 m/s -1200 m/s. It was deduced that to achieve high particle impact velocity, two things are required-

1. Using a correct nozzle having sufficient length for high velocity accelerated particles.
2. Compressed gas shows immediate decelerating effect just before the substrate surface. This effect needs to be reduced.

Shift from Aluminium to Other Materials

After the wind tunnel experiment, most of the experiments were conducted on aluminum. Few years down there was a shift in the research work from aluminum to other materials.

Aluminum was suited for research work as-

1. Since the result of the breakthrough wind tunnel experiment was observed on aluminum, re- searchers focused on aluminum to study, compare and analyze the further results. It was because they observed the coating of aluminum in the previous experiment.
2. Aluminum has a low density. This implies that it can achieve high velocity when gas flow is accelerated. Around 1000 m/sec can be attained by aluminum particles.
3. Aluminum has a low melting point of 943.15 K. So, there can be a possibility of its effect on material particle surface or bonding at the time of collision.

Concept of Critical Velocity & Deposition Efficiency

It was found out that if the particle has velocity higher than a critical velocity, it will bond with the surface and form a layer if coating. Otherwise, it will erode the surface.

Researchers started studying the deposition efficiency k_d and computed it as follows-

$$k_d = \Delta m_s / M_p$$

where Δm_s is change of substrates weight, M_p is weight of particles coated on the surface

Patents and Spreading in Industries Summary

YEAR	DEVELOPMENT PROCESS	PERSON/COMPANY
1900-1902	Method of impacting one metal upon another (Patented on March 23, 1900)	Thurston
1901	"Process of coating one metal with another metal" improvement in the previous method	Thurston
1915	"Thermal Spray Process" - If Schoop hadn't overlooked solid state deposition by impact energy, Cold spray would have been the first thermal spray process and not the most recent one.	Schoop
1958-1963	"Device for treating the surface of a workpiece"	Rocheville
1970-1980	"Method of applying coating", by converting the wind tunnel experiments into a viable coating technique	A. P. Alkhimov, Anatoli Papyrin, V.F. Kossarev and their team
1986-1991	"SU1618778: Method for deposition of coatings" and "SU1618777: Device for applying coatings"	Alkhimov and team
1990-2000	Improvement of the coating device like nozzle and powder feeding system	Alkhimov and team
1990-2000	Obninsk Center for Powder Spraying (OCS) became a leading Russian company producing selling and supporting DYMET gas-dynamic coating equipment	A. I. Kashirin, O. F. Kijuev, A. V. Shkodkin, and T. V. Budzdyar
1990-2000	Sponsorship of collaborative research and development agreement (CRADA) under the National Center for Manufacturing Sciences (NCMS) brought cold spray out of Russia	US Government
2000-2006	Consortium of Federal Armed Forces University, Hamburg; Linde R&D, and GGT Technologies to pool their respective specialties in materials science, gas technology and process control equipment to evolve the Kinetic 3000 cold spray system.	Germany
2006-Present	Viable coating process to produce protective coatings, performance enhancing layers, ultra-thick coatings, freeforms, and near net shapes	Worldwide

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