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KINETIC SPRAYING – EQUIPMENT AND PERFORMANCE DATA

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ABSTRACT

Kinetic spray has tremendous potential overcoming many limitations and the deleterious effect of conventional thermal spray. This is a new technology in the family of surface modification and is still in preliminary research stage, yet to come to industry as a viable coating technique. In the present work, some basic facilities for kinetic spray has been developed and coating have been obtained. Aluminium powder of 200 mesh was used as the coating material on mild steel substrate. Coatings were of zero dimension (single point of diameter 8mm) .Confirmation of the coating was obtained by EDAX. The process parameters like pressure and standoff distance were varied. Two pressures of 8bar and 10bar were selected for coating. Standoff distances of 5,10 and 15mm were selected. Coating thickness was obtained for all pressures and Standoff distances. Porosity measurement was done for the best coating thickness obtained.

***Keywords**: Kinetic Spray, coating thickness, inlet pressure, microstructure.*

I. INTRODUCTION

The process of modifying the surface of a material by changing the physical, chemical or biological characteristics different from the ones originally found on the surface of a material is called surface modification.Solid materials usually undergo this modification technique, but examples of modification of liquids also exists. Different methods are employed to alter a wide range of characteristics of the surface, such as: roughness, improvement in wear, corrosion resistance, electrical conductivity, surface charge, surface energy, biocompatibility and reactivity.

Thermal Spray technology is one such coating technology used extensively in defence, aerospace and gas turbine industries. Typical applications of thermal spray include fabrication of components, preparation of protective surfaces, refurbishment of mis-machined and service-damaged parts, etc. Thermal Sprayingis a group of coating processes in which finely divided metallic or non metallic materials are deposited in a molten or semi-molten condition on to a substrate to form a coating. The coating material may be in the form of powder , ceramic –rod, wire or molten materials.

The Cold Spray process is the next progressive step in the development of high kinetic energy coating processes.This process is also known by different names such as: Cold Gas Dynamic Spraying, Kinetic Spraying, High Velocity Particle Consolidation (HVPC), High Velocity Powder Deposition and Supersonic Particle/Powder Deposition (SPD). The basic principle of the cold spray process is that a high velocity gas jet, formed using a de-Laval or a converging/diverging nozzle, is used to accelerate the powder particles and spray them onto a substrate, located at a certain distance from the exit of the nozzle where they impact and form a coating. The kinetic energy of the particles rather than high temperature, helps these particles to plastically deform on impact and form splats, which bond together to produce coatings and thereby avoids or minimizes many harmful shortcomings of traditional thermal spray methods such as high-temperature oxidation, evaporation, melting, crystallization, residual stresses, gas release etc. The powder particles are accelerated by the supersonic gas jet at a temperature that is always lower than the melting point of the material, resulting in coating formation from particles in the solid state and hence no melting and solidification process is experienced by the powders like in traditional thermal spray process.The footprint of the cold spray beam is very narrow typically around 5 mm diameter due to small size of the nozzle (10-15 mm^2) and spray distance (5-25 mm), yielding a high-density particle beam, results in precise control over the area of deposition over the substrate surface. This process is similar to a micro shot peening and the coatings are produced with compressive stresses, rather than tensile stresses, which results in dense and ultrathick (5-50 mm) coatings without adhesion failure. The low temperature formation of coating leads to oxide -free coatings with wrought-like microstructure. Cold gas spraying can be grouped under rapid solidification processes wherein the cooling of the particles takes place at room temperature.

Unlike other thermal sprayed materials, cold sprayed materials experience "little to no defect causing oxidation" during flight and exhibit remarkably high densities and conductivities once fabricated. Some of the other features of cold spray materials are

- Low temperature process, no bulk particle melting
- Retention of composition/phases of initial particles.
- Very little oxidation.
- Elimination of solidification stresses and ability to obtain thicker and low defective coatings.
- Lower heat input to work piece reducing the cooling requirement.
- Possible elimination of grit blast substrate preparation.
- Reduced need for masking.
- No fuel gasses or extreme electrical heating is required.

Kinetic spraying can be used for producing various metals and alloys with superior properties. This technique is mainly used for military applications. The process is being extensively used for producing coatings of copper, zinc, titanium, ceramic particles and other materials on to different substrates. The technology has not yet been commercialized for industry and still is in the laboratory. Most of the aspects of cold gas spraying are under patented literature and the technology has still not come to India. With this view, an attempt has been made to fabricate the equipment and bring out the results. A nozzle has been designed to the supersonic velocity, air at compressed pressure delivered by a compressor, a basic fabricated powder feeder (manual) has been arranged to obtain a coating on a Mild Steel substrate by using Aluminum powder . The coating has been confirmed by EDAX analysis . Two different pressures and three stand off distances were studied and coating thicknesses were obtained.

II. EXPERIMENTAL SET UP

The details of the cold spray process were studied and an experimental setup was fabricated. The setup consists of

- Nozzle
- Air Compressor
- The powder feeder and
- The nozzle assembly
- Heating coil and Temperature sensor

Nozzle

The designing of supersonic nozzle is the most important thing in the cold gas process. The length and the contour of the divergent part of the convergent-divergent nozzle are the two most critical aspects in the supersonic nozzle. The numerical technique of method of characteristics was followed for the designing of the supersonic nozzle.
The Area-Mach relation was used to obtain the inlet and exit area ratios by suitably substituting the exit Mach numbers. The equations have been given detail in the literature survey.

$$\left(\frac{A}{A^*}\right)^2 = \frac{1}{M^2}\left(\frac{2}{\gamma+1}\left(1+\frac{\gamma-1}{2}M^2\right)\right)^{\left(\frac{\gamma+1}{\gamma-1}\right)}$$

$$\text{Exit Area, } A_E = \left(\frac{A}{A^*}\right)_{Exit} A^*$$

$$\text{Inlet Area, } A_I = \left(\frac{A}{A^*}\right)_{Inlet} A^*$$

The throat area was fixed suitably in order to obtain the inlet and exit areas. In this way, the nozzle dimensions were obtained. The condition of critical temperature ratio, temperature and maximum mass flow rate were obtained by the equations given below.

$$\left(\frac{p}{p_o}\right) = \left(1 + \frac{\gamma - 1}{2}M^2\right)^{-\gamma/\gamma - 1}$$

$$\left(\frac{T}{T_o}\right) = \left(1 + \frac{\gamma - 1}{2}M^2\right)^{-1}$$

$$m_{max} = A^* \sqrt{\gamma\left(\frac{2}{\gamma + 1}\right)^{(\gamma+1)/(\gamma-1)} p_o^2 / RT_o}$$

It is a tedious task to calculate manually all the points for different angles from the throat to the exit diameter. Hence, a program in FORTRAN was written in order to calculate the contour of the divergent portion of the nozzle. The divergent portion of the nozzle is not straight but is a contour to prevent shock waves and also to see to it that the exit velocity is same throughout the outer portion of the nozzle.

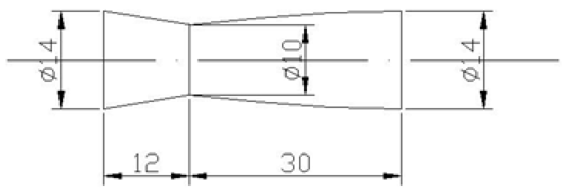

Figure : 1 Dimension of the nozzle

Air Compressor

Double acting reciprocating air compressor was used for the purpose of supplying air at high pressures. Two pressures of 8 and 10 bars were selected for the study.

Powder feeder

Another important aspect in the setup is the powder feeder. The powder feeder should be such that there must be suction of powder at high pressures. For this purpose, a Y-nozzle was used as shown in figure 2. The Aluminum powder was sieved using ASTM mesh no. 60 (size of 250µm)

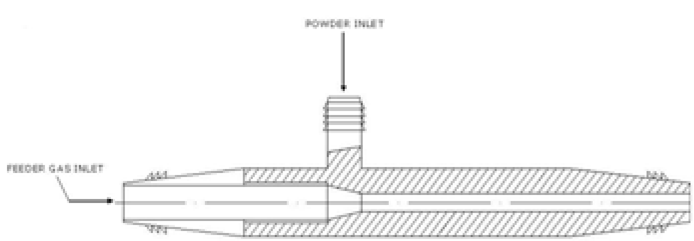

Figure 2 : Y type powder feeder

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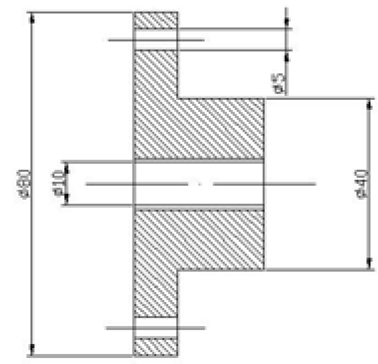

Figure :3 Schematic of the nozzle flange

Nozzle assembly

The material for the nozzle was chosen to be EN8 steel of diameter 80mm. The machining of nozzle was the most important task for the whole process. The divergent part was not a straight taper and the contour had to be done by a CNC boring machine. First a hole of 9.5mm drilled and then a reamer of 10mm was used to obtain the through bore. The other dimensions were machined as shown in the figure The divergent portion was machined by the help of a CNC boring machine. A hole of 6mm was drilled just before the convergent part as shown in figure for supplying high pressure air into the nozzle.

In order to support the nozzle, a flange was made of EN8 steel of diameter 80mm. Figure below shows the flange used for the trials. A thread of diameter 10mm was machined inside the flange. Through this thread, a threaded bolt having through hole of 6mm was machined. Through this hole, powder was fed from the powder feeder. Three holes were drilled in the flange at 120^0 each of diameter 5mm.

The main purpose of providing a thread in the flange was to adjust proper distance of the powder coming in contact with the high pressure air supplied at the convergent portion of the nozzle. Fig 4 shows the complete nozzle assembly.

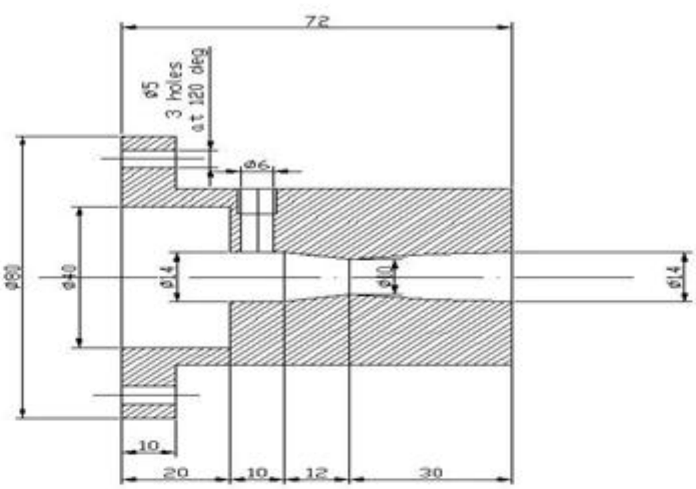

Figure :4 Complete Nozzle assembly

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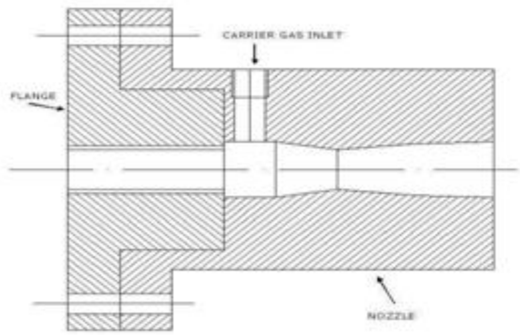

Figure : 5 Nozzle and flange assembly

Heating Coil and Temperature Sensor

Gas heater consists of tubular heating coil heated resistively by a high power supply. The tubular heating coil must be thermally insulated and appropriately housed however the heating of gas is optional feature and not a necessary. Using this setup it is possible to maintain a required temperature for the coating process, and a constant temperature and time is maintained throughout the coating process. Temperature of required degree is controlled using a device shown in figure. The thermocouple sensors, the heating coil is shown in Digital form.

Figure 6 Heating coil and temperature measurement.

Coating Material

The coating material used in this coating process is Aluminium which has following properties,Aluminium is a soft, lightweight metal normally with a dull gray appearance caused by a thin layer of oxidation that forms quickly when the metal is exposed to air. Aluminium oxide has a higher melting point than pure aluminium. Aluminium is nontoxic (as the metal), nonmagnetic, and non sparking. It has a tensile strength of about 49MPa in a pure state and 400MPa as an alloy.

Aluminium is about one-third as dense as steel or copper; it is malleable, ductile, and easily machined and cast. It has excellent corrosion resistance and durability because of the protective oxide layer.

The metal used in our process (Aluminum)was having 200mesh size and atomic weight of 26.98.The grain size of Al powder used was approximately 75microns.

Substrate

The substrate used in this process was Mild Steel of size 75*75mm and 3mm thickness. Sharp edges, and corners were rounded or smoothed by grinding. The surfaces were free from any foreign matter such as weld flux, residue, slivers, oil, grease, salt etc. prior to blast cleaning. The oil and grease contamination was removed by solvent.

Parameters

- Pressure 8 and 10 bar
- Stand Off Distance 5, 10, 15m

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The time of coating was kept a constant at 25 seconds. It was found that at room temperature, the Al powders did not adhere to the substrate and by trial and error , a temperature of 300c was found to be appropriate .

III. RESULTS AND DISCUSSION

The coatings obtained were of zero dimension since there was no mobilisation of the substrate. The coatings were confirmed by means of EDAX spectrum which showed high Al peaks. The thickness of the coating was obtained in microns. Graphs were plotted with pressure as constant and varying stand off distances of 5,10 and 15mm .Maximum coating thickness was found at15mm stand off distance for a pressure of 8 bars. The same trend was found even at the other pressure studied ie at 10bars. The thickness of the coating increased with increase in pressure.The thickness increased due to enhanced bonding strength.The substrate – particle bonding strength is the result of plastic deformation of the substrate and nascent bonding.Porosity measurement was done for the specimen with best coating thickness obtained and figure shows the SEM photo of the coated specimen which shows that the porosity is less than 3%.

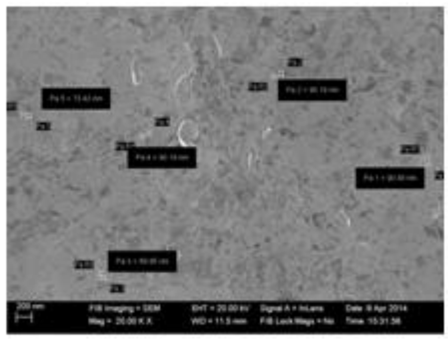

Figure 7 : SEM showing porosity measurements

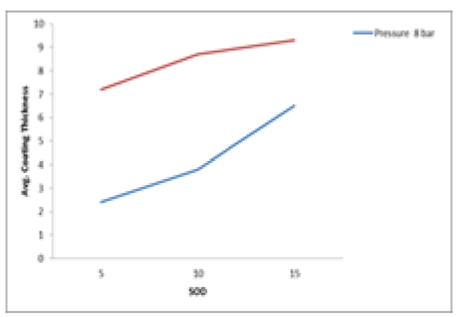

Figure 8 : Coating thickness vs SOD for two pressures

Pressure	SOD	Thickness(μ)
8	5	3
	10	4
	15	7
10	5	7
	10	9
	15	10

Figure 9

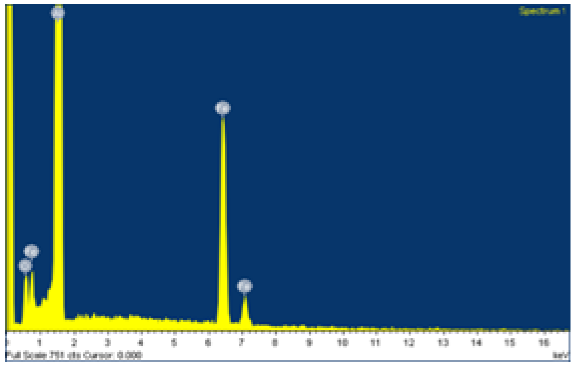

Figure 10

IV. CONCLUSION

- It was found that the prototype developed was successful in obtaining the coating.
- obtained was 9.2micro meter at a pressure of 10kg/cm^2 and a SOD of 15mm.
- The porosity was found to be less than 3% which suggests that it is a good coating technique and can be used in many applications.
- There is scope for further improvement in the prototype of the equipment designed and developed.
- Different nozzles can be tried with varying convergent –divergent lengths and for different exit velocities.
- The coating can be tried for different powders.
- The stand off distances and pressures applied can be varied and results obtained.

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