A STUDY OF THERMAL METAL SPRAYING

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Abstract Metal spraying is a type of metal finishing/surface treatment in which the kinetic energy obtained by the sprayed molten particles provides metallurgical bond with the substrate material. In the present work various methods of thermal spraying such as Flame spraying, Plasma spraying, Electric arc spraying and Detonation spraying are reviewed as recorded in literature and Flame spraying method is investigated in detail. In the flame spraying method, the metallic powder is directed on to a high velocity oxy-acetylene flame, so that the metallic powder assumes the molten state and then impinges on to the specimen. In the current investigation two types of torches namely Rototec and Eutalloy are used to spray the powder at low and high temperature applications respectively. The spray is applied to a flat specimen with the specimen being stationary and to a round specimen while it is set to rotation on a lathe. The coatings used are bronze and steel powders on mild steel base metal. The parameters of study include the setting of flame nature (such as carburising, neutral and oxidizing flame), the flame speed, the torch distance from the specimen, the rotational speed of the specimen and the number of cycles of coating involved. The specimen were tested for their bonding strength, surface hardness and microstructure. The results indicate a poor quality coating which peels off after some time with the low temperature spray (Rototec) when it is applied on to a stationary flat mild steel plate while indicates good bonding when applied to a rotating member. The quality of bonding is improved with the use of high temperature spray (Eutalloy) in case of stationary plate. The reasons are analysed for the same. Thermal spraying is advised for specimens in cases of repair/reclamation rather than replacement of the component.

Keywords: Thermal spray, Rototec, Eutalloy

INTRODUCTION

Surface coating a commonly adopted method to protect the component from wear, corrosion, chemical abrasion etc [Steffens, H.D. and Mullar, K.N, 1971]. The surface coating on a metal may be done using either metallic or non-metallic powders or plasma. Metal spraying is a type of metal finishing/surface treatment in which the kinetic energy obtained by the sprayed molten particles provides metallurgical bond with the substrate material [Washerman and Rene, 1976]. The process involves melting the coating powder using flame or electrical arc and then spraying the same on to the specimen under high kinetic energy. Metal spraying method has advantage over other conventional methods of coating in terms of possibility of coating any type of alloy with ease.

Various methods of thermal spraying that are in practice are Flame spraying, Plasma spraying, Electric arc spraying and Detonation spraying [Apetion, D., 1985]. Flame Spraying is a deposition process using Oxy-fuel gas flame, the depositing material may be in the form of metallic wire (Fig. 1), ceramic rod and metallic and non-metallic powders. Most of the materials can be sprayed with the exceptions of those which cannot be melted with Oxy fuel Flame and those that will not burn when melted in the presence of air jet.

In Plasma Spraying the material to be deposited (such as powders, wire, rod, metals, alloys) is melted in a plasma arc, and then spraying the molten particles on the substrate in order to produce an adherent coating (Fig. 2). The temperature levels in this method may reach as high as 15,000^o C, thereby allowing any metallic and/or non-metallic material to melt. However, this method suffers form a few limiting factors such as high poroisity (6-12%), relatively low bonding strength (20-30 MN/m^2) and not being cost effective when compared to other methods [Washerman and Rene, 1976].

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Electric arc spraying method is another metal deposition process in which wires of metals or alloys are melted in an electric arc, and the molten particles are sprayed on the substrate (Fig. 3). Theorotically, the presence of increased temperature and velocity of particles makes it possible to spray all metals and alloys produced in a wire form, particularly those with higher melting points which cannot be sprayed by the flame method. However, the increase in temperature and velocity leads to undesirable oxidation process of sprayed particles [Apetion, D., 1985].

Detonation spraying or plating is a process based on applying high kinetic energy generated by the explosion of gasses to inorganic materials in powder form to produce adherent coatings [Apetion, D., 1985]. Theorotically, all inorganic materials in powder form including metals, alloys, cermets, ceramics and their mixtures, which are stable at detonation temperatures and will form an adherent coating can be used in the detonation plating. In practice, this method is limited by the requirement of low hardness of substrate (less than 50-60 Rockwell Units). Other limitations include inability of coating non-metallic substrate, high thickness of adhesion (as high as 0.8 mm), and over and above non-tolerable noise of operation [Apetion, D., 1985].

Literature survey indicates that surface treatment processes like electrochemical and vapour deposition have been studied in great detail, whereas not much work seems to have been done in thermal spraying except in a few such as [Behniser, H., 1971, Saywell, W.A., 1973 and Steffens, H.D. and Mullar, K.N., 1971]. Thermal spraying today seems to be in the hands of manufacturers who make high claims for their recommendation. An attempt is made in this study to understand types of flame spraying, nature of spray deposits, their bonding characteristics and mechanical properties.

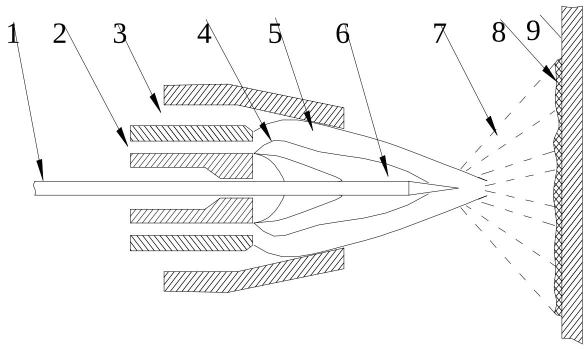

Fig. 1. Schematic of flame spraying process. (1)Wire, (2) Fuel gas,(3) Compressed air,4)Flame cone,(5)Air envelope, (6)Burning gas, (7)Atomized spray, (8)Sprayed metal and (9)Base metal.

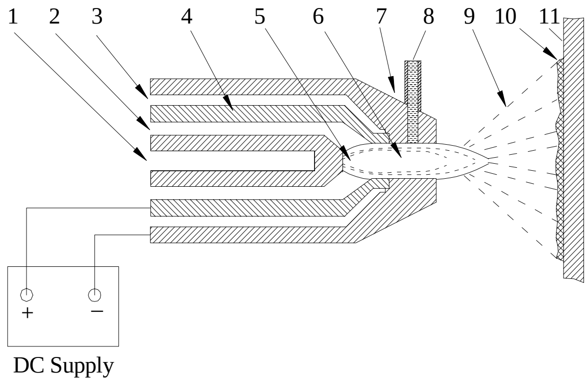

Fig. 2. Schematic of plasma spray process. (1)and(3) Circulating coolant, (2)Plasma gas, (4)Electrod,e (5)Arc, (6)Plasma flame, (7)Nozzle, (8)spray powder suspended in carrier gas, (9)Spray, (10)Deposit (sprayed material) and (11)Base metal

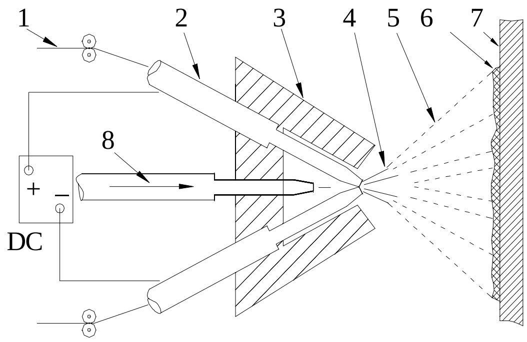

Fig. 3. Schematic of Electric Arc spraying process. (1)Consumable wire, (2)Electrode, (3)Shield (4) Electric arc, (5)Atomized spray, (6)Sprayed metal, (7) Base metal.

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EXPERIMENTATION

The experiments were conducted with surface treatment of a circular shaft and a flat plate using flame spraying process. Two different types of torches commercially available in the names Rototec and Eutalloy which are operated at low and high temperatures respectively have been used in this study for flame spraying. In Rototec torch (Fig.4) the fusing powder meets the flame outside the torch, whereas in Eutalloy torch (Fig.5) the fusing powder meets the flame inside the torch and the atomized molten metal spray emerges out. The Rototec process was studied with spraying on both circular shaft and flat plate whilst the Eutolloy process was implemented in the flame spraying on flat specimens. The bonding test was carried out on flat specimen with variation in three parameters viz., surface preparation, type of flame and distance between nozzle and work piece. Round specimens were sprayed with recommended parameters and studied for bonding, soundness etc.

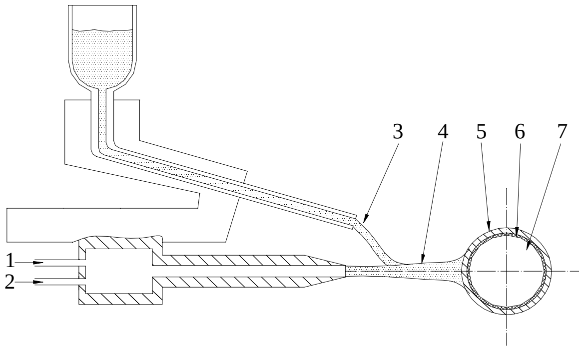

Fig.4.Flame spraying with Rototec torch (as-sprayed flame spraying process). (1)Oxygen, (2)Acetylene, (3)Powder, (4)Metal spray, (5)Final coating, (6)Base coating and (7)Rotating work piece.

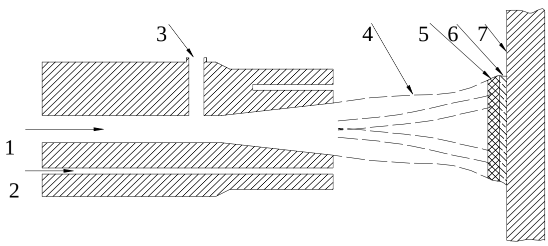

Fig.5. Flame spraying with Eutalloy torch (spray and fuse type process). (1)Compressed air, (2)Oxyacetylene gas, (3)Powder, (4)Fused metal spray, (5)Final coating, (6)Base Coating and (7)Work piece.

Procedure for Round Specimens with Rototec Torch

As mentioned earlier, the Rototec method involves flame spraying with the powder being poured onto the oxyacetylene flame oozing out of a torch and depositing the same onto the work piece. The flame spraying on a round job requires special care since the quality of the deposit depends on many factors such as deposition rate, the surface preparation, the correct choice of type of flame and the treatment after the spray process. The round jobs are usually mounted on to the lathe (see Fig.6) so that the spraying can be done on to the job, when the job is rotating at required speed.

The work piece (steel rod of diameter 50 mm) is treated with acetone in order degrease the surface. This is a very important process since the bonding between the base metal and the substrate is very sensitive to the presence of oil, grease or dirt [Apps, R.L., 1974]. After a thorough cleaning of the work piece it is mounted on to the lathe, and checked to run true using dial indicator and magnetic stand. The affected portion of the work piece is given an undercut to a depth of 0.5 mm over a length of 100 mm. The under cutting is required to produce a uniform cylindrical surface and to remove the upper layer of strained material which might have been affected by the inclusions of oxides and scales.

Fig.6.The thermal spraying using Rototec torch on to a circular job mounted on the lathe and rotated at optimized speed. Note the protective equipments used by the operator.

It further provides a deep basin for the deposited material so that sufficient thickness of the coating is maintained. Then the undercut surface is given a rough threading of 1 mm pitch. This operation leads to the increased surface area available for bonding and significantly improves the final coat's resistance to shear stresses when in operation. Then the job was rotated at 90 rpm and the surface was preheated with the carbonizing flame to about 200^{o}C. The temperature was checked using thermal chalk.

The job was then given a bond coat (primary coat) using the spray pack module of EWAC BONDTEC, an alloy of aluminum-bronze. Bond coating is essential to provide a strong base for final coat, which forms the metallurgical bond to the base metals. This primary coat helps in increasing the shear resistance of the thermal deposit. The working parameters were optimized for a good bond as follows. The speed of the job: 90 rpm, flame: carburising, linear speed of the gun mounted on the carriage: 100 mm/min, and the distance between the job and nozzle: 150 mm. Care was taken to maintain the temperature of the job so as to not to exceed 250^{o}C. Three layers of BONDTEC were sprayed to get a good deposition. Soon after, the job was sprayed with final coat using spray pack module EWAC 2002RF, (bronze powder). The parameters set for the final coat were same as those for primary coat. The sprayed job was let to rotate in free air during cooling so as to avoid the slipping or dripping of deposit due to gravity. The sprayed job appears as shown in Fig. 7.

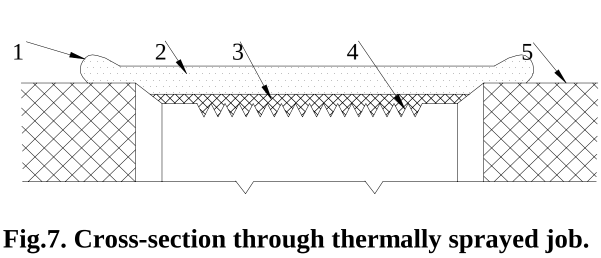

Fig.7. Cross-section through thermally sprayed job. (1)Coating high spots, (2)Final coat, (3)Primary coat, (4)Rough thread cutting on the job before spraying, (5)The job masked at undesired portion to prevent spraying at these regions.

The cooled job was then processed with finishing operation. Finishing operation is as important as the previous steps followed in thermal spraying. An improper finishing operation may lead to peel off of deposited layer. Initially, the job was chamfered at the ends of the sprayed deposit on either side to 45^o to remove the flashing. Outer layer of the coating was machined starting from the center of the deposited length and traversing towards left and again starting from the center and traversing towards the right. This method of machining was done to avoid the peeling off of the coated layer. The final machining was done from left to right to get the required dimensions.

Procedure for Flat Specimens with Rototec Torch

Mild steel plates of 10 mm thick were sprayed with EWAC 2002 RF (bronze) powder. The plate was positioned vertically upright during coating. The surface preparation, preheating, bond coating and final coat spraying were similar to those adopted in case of round specimens. The change adopted was the use of carburising, neutral and oxidizing type of flame and the optimized distance of 75 mm to 250 mm from the nozzle to the plate.

Procedure for Flat Specimens with Eutalloy Torch

As mentioned earlier, the thermal spraying by Eutalloy torch is of Spray and Fuse type, in which the powder meets the flame inside the torch and then sprayed in the form of molten metal on to the job. The job was preheated to dull red colour and then coated with three to four layers of EWAC 1003 EBZ (bronze). In the entire process the job was maintained around 450^0C, which was constantly checked by a thermal chalk. The job was allowed to cool to room temperature after spraying.

RESULTS AND DISCUSSIONS

The completed jobs were inspected visually for quality and soundness. With fused deposits lack of bonding may be detected by localized torch heating of the suspected area. The quality and the properties of thermal sprayed deposits were found to largely depend on the size, temperature and velocity of the spray droplets and on the degree of oxidation of both the droplets and the substrate during the spraying. With several test runs, the optimized parameters of nozzle to job distance, the rotary speed of the job and the feed rate of traverse were obtained and recorded as indicated in the previous section.

The physical and mechanical properties of spray deposit normally differ greatly from those of the original material. The micro hardness of the deposit and that of base metal were obtained using superficial Rockwell and Vickers hardness tests. The ASTM standard was followed in these tests.

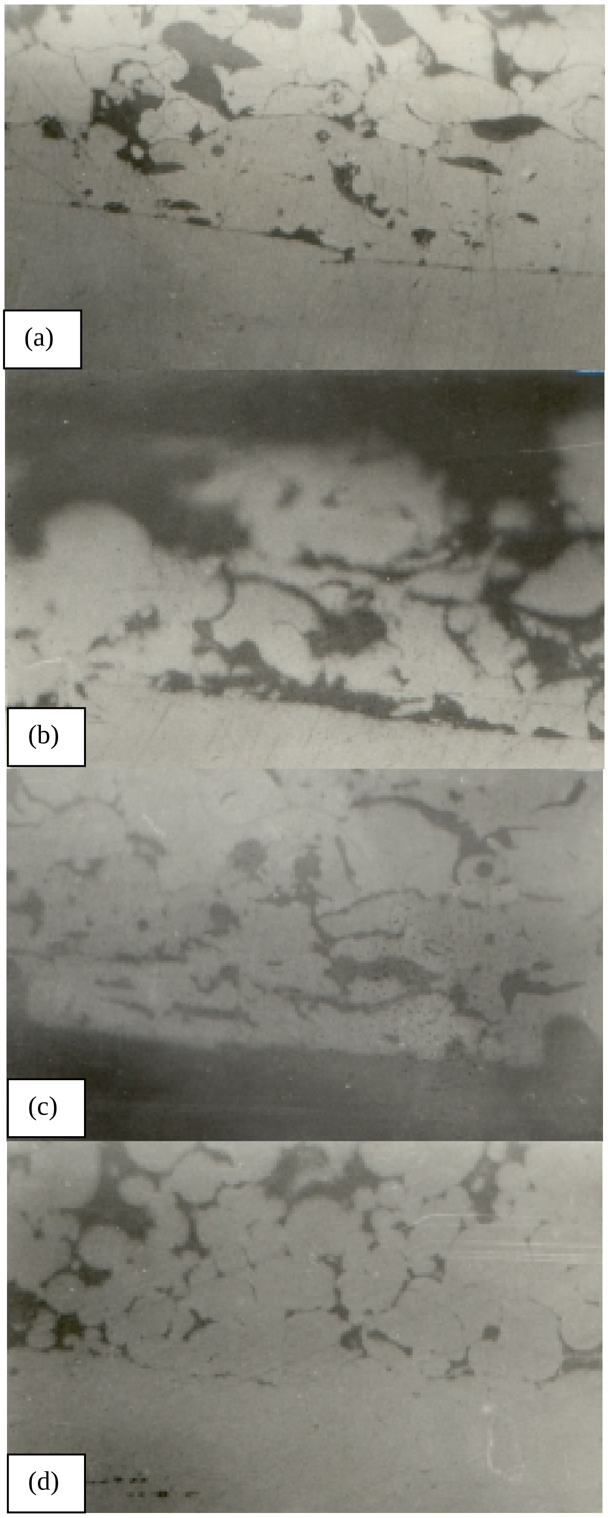

Fig. 8. Photographs showing the microstructure.
(a)Bronze deposit on steel substrate (Rotototec, round job),
(b)Steel deposit on steel substrate (Rototec, round job),
(c)Bronze coat on bond coat (Rototec, flat plate)
(d)Bronze deposit on steel flat plate (Eutalloy).

The physical structure was verified using metallurgical microscope Neophot 21. The metallographic samples were sectioned from the specimens. Care was taken to avoid peeling off of the coating. The specimens were then mounted on cold set resin and then ground using different grade emeries and finally polished. The microstructures of the deposits with the base metal are shown in Fig. 8.

The microstructure of sprayed metal deposit shows heterogeneous mixture of layered metal particles (white), metal oxide inclusions (gray) and pores (black). The deposit structure in these is lamellar and non-homogeneous. Its adhesion is generally the result of mechanical interlocking, some point-to-point fusion and sometime oxide-to-oxide bonding as seen in the photographs.

Rototec on Round Specimens

Bronze coating: Metallographic observations (Fig. 8a) indicate that coating adherence has been good. The thickness of the deposit was 0.85 mm. Voids in the deposits is about 25%. The hardness of the coating is 312 VHN and that of base metal is 251 VHN.

Steel Coating: Mettallographic observation (Fig. 8b) shows a poor adherent and the coating thickness was less than 0.1 mm. Hence the hardness and soundness tests were abandoned.

Rototec on Flat Plate

Experiments with variations in spray distances and type of flames were conducted with bronze powder. The coatings in this set of experiments peeled off and indicated that surface preparation by grinding is inadequate. Microstructure of the flaked deposit is shown in Fig. 8c. Grit blasting is suggested for future experiments.

Eutalloy on Flat Plates

Bronze coating: The microstructure of the base metal and the coating is shown in Fig. 8d. As-sprayed , self fluxing alloy deposits are similar in appearance to any typical metal deposit, except that there is significantly less oxide. After fusing, the deposit shows an equiaxed cast structure with some porosity and inclusions. The void density of the deposit is 15%. The adherence to the substrate is excellent. The hardness of the deposit is 571 VHN and that of base metal is 326 VHN.

Nature of Coating

Deposits in low temperature spray (Rototec Process) indicate that small grains either molten or semi-molten solid conform to the surface and mechanical interlocking occurs between the grains. Because the effectivity of this interlocking is poor the deposit is more porous. Deposits in high temperature process (Eutalloy) indicate good bonding between grains and the base metal as well. Because of the high temperature of the process, the grains melt well for bonding and also diffuse into base metal to farm sound bonding with the base metal as also indicated by [Marimoto, J. and Yamaguchi, A.,. 1986].

CONCLUSIONS

- Various methods of thermal spraying such as Flame spraying, Plasma spraying, Electric arc spraying and Detonation spraying are reviewed as recorded in literature and Flame spraying method is investigated in detail.
- The parameters such as the setting of flame nature (such as carburising, neutral and oxidizing flame), the flame speed, the torch distance from the specimen, the rotational speed of the specimen and the number of cycles of coating involved have been optimized.
- Coatings of bronze and steel powders were successfully employed on steel parts by high temperature and low temperature processes.
- The results indicate a poor quality coating which peels off after some time with the low temperature spray (Rototec) when it is applied on to a flat mild steel plate while indicates good bonding when applied to a rotating member.
- The quality of bonding is improved with the use of high temperature spray (Eutalloy) in case of flat plate. The reasons are analysed for the same.
- Thermal spraying is advised for specimens in cases of repair/reclamation rather than replacement of the component.

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