ACMFMS 2012
NEW DELHI
3rd Asian Conference on Mechanics of Functional Materials and Structures
December 5-8, 2012
Indian Institute of Technology Delhi, India

Coating Material Interaction on Metal Substrate by Application of Plasma Spraying

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In this paper, Fly-ash+quartz+illmenite with weight percentage ratio: 60:20:20, is deposited on mild steel and copper substrates by atmospheric plasma spraying at various operating power level ranging from 11 to 21 kW. The properties of the coating depend on the interaction of coating powder with plasma, operating condition and the process parameters. The coating quality and behavior depends on Coating surface & interface morphology are studied with Scanning Electron Microscope. For Mild Steel the adhesion strength has varied from 3.5MPa to 6.56MPa and for Mild steel a maximum of 6.56MPa at the power level of 21 kW. In plasma spraying, injected powder size must be large enough not to be vaporized, and not small enough to be completely melted. Each droplet is flattened on impact at the substrate surface and solidified, and the coating consists of many layers of the flattened particles.

Keywords: *Plasma Spray, particle-plasma interaction, Copper, Mild steel, fly-ash+quartz+illmenite.*

1 Introduction

Plasma spray is a process by which the high temperature of plasma is employed to melt powders of metallic/non-metallic materials and spray them onto a substrate, forming a dense deposit. Different plasma spraying process variants allows their working with all kind of materials, from low melting temperature i.e. plastics to high melting temperature metals and ceramics. The process is commonly used to apply protective coatings on components to protect the materials from corrosion, wear, and high temperatures. Coatings greater than 50 micron in thickness are used for a remarkable number of application [1]. Coating adhesion usually considers the result of a combination of three fundamental mechanisms, related to the nature of the interface bonding i.e. via mechanical, chemical and physical forces [2].

A major challenge in development of plasma coating technology is to meet the requirement for new materials to sustain in progressively more sever operating conditions. Since few decade research has been continuing for developing thermal plasma spray coatings by using different type of low cost materials [3-9]. It utilizes the exotic properties of plasma medium to affect physical, chemical or metallurgical reactions to produce new materials or impart new functional properties to conventional materials. The chemical analysis of a mixture of fly-ash, quartz and illmenite shows that major constituent in these industrial wastage and low grade ore are iron oxide (Fe_3O_4), titanium oxide (TiO_2), Silicon oxide (SiO_2), aluminum oxide (Al_2O_3) etc [10]. Since all these are metal oxides, it was felt that the mixture of fly-ash+quartz+illmenite can possibly be spray coated. Since fly-ash, quartz and illmenite are plenty available from industrial wastage and low grade ore, the cost involvement will spring down.

Present investigation aims at depositing plasma spray coating on metals using low cost/waste materials. A mixture of fly-ash+ 20 weight percent of Quartz+ 20 weight percent of illmenite is used for coating on Copper and Mild steel substrates. The powder mixture is plasma sprayed by different operating power level from 11 to 21 kW.

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2 Moltel particle impact and Solidification

Development of protective coating is a stochastic process in which particles with certain size, pressure, and temperature distributions impact on a substrate. Current investigations, efforts are underway to predict microstructure of coatings by using Monte-Carlo simulation technique. We expect a model of splat formation can answer the following questions:

- What is the relationship between the final splat shape and impact parameters?
- How is property of powder and substrate?
- How much substrate roughness?
- What causes splashing and break-up?
- How do splats interact?
- How much adhesion strength for protection?

Prediction of splat shapes involves numerical simulation of fluid flow and heat transfer of an impacting droplet. In general, this is a three dimensional, time dependent problem. The tipical plasma spray system is given in figure-1.

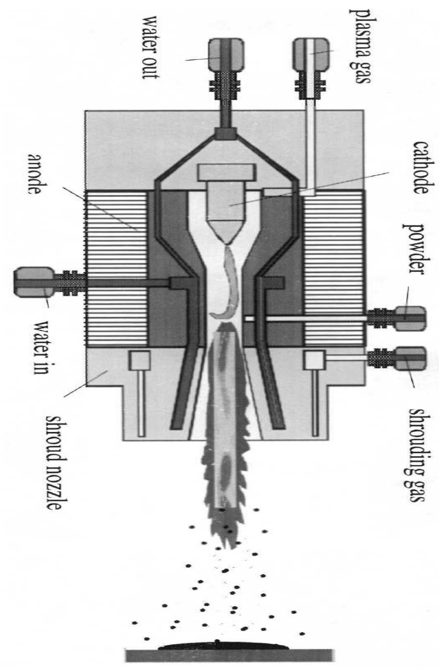

Figure 1: Schematic diagram of DC plasma spray process [11].

3 Wettability

Wettability can be defined as the ability of a liquid to spread on a solid surface, and represents the extent of intimate contact between a liquid and a solid. This can be explaining by the angle of contact between a drop of liquid resting on a solid substrate, as shown in figure-2 and figure-3. The contact angle at equilibrium is determined by the following equation, which is referred to as the Young-Dupre equation [12]:

$$Y_{sv}=Y_{sl}+Y_{lv}\cos\Theta. \qquad (1)$$

Where Y_{sv}, Y_{sl}, and Y_{lv} is the specific energy of the solid-vapour interface, specific energy of the liquid-solid interface, and specific energy of liquid-vapour interface respectivelly. Each specific energy represents surface tension force.

When a liquid droplet is put on a solid substrate, it will replace a portion of the solid-vapour interface by a liquid-vapour interface and liquid-solid interface. The spreading of liquid will occure only if this results in a decrease in the free energy of the process. The bonding force between the liquid and the solid phase, i.e. the work of adhesion (Wa) can be defind as [12] :

$$W_a = Y_{lv} + Y_{sv} - Y_{sl} \qquad (2)$$

Combining equs. (1) and (2) give

$$W_a = Y_{lv}(1+\cos\Theta) \qquad (3)$$

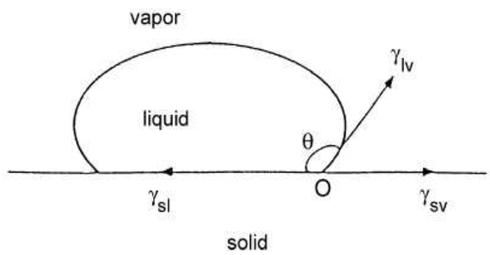

Figure 2: Schematic of solid-liquid contact angle.

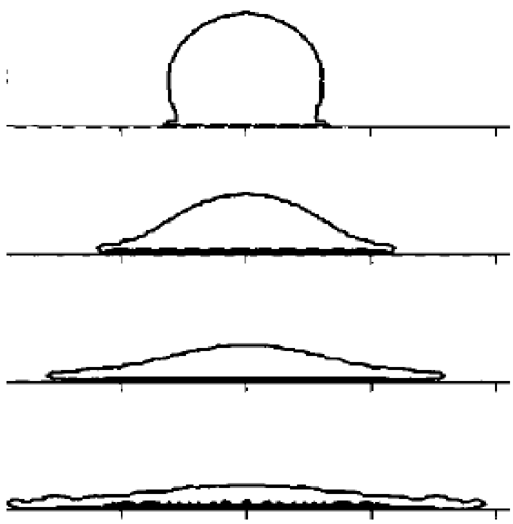

Figure 3: Shematic diagram of progressive splat formation on the substrate surface from molten droplet.

The bonding/adhesion force between the solid and liquid phase can be expressed in terms of the contact angle, and surface tension of liquid. The magnitude of the contact angle (Θ) will describe the wettability:

- $\Theta = 0°$, for perfect wetting
- $\Theta = 180°$, no wetting
- $0 < \Theta < 180°$, partially wetting.

Hence it is clear that for good wettability, a low contact angle should be necessary. A liquid is said to wet solid surface when cos ϴ > 0°, i.e. when $Y_{sv} > Y_{sl}$. In a vacuum, the driving force for wetting is affected by only two factors: (a) the surface tension of the liquid and (b) the strength of the solid-liquid interaction at the interface . Typical wetting properties are measured by the sessile drop technique, which is based on the measurement of the work of adhesion. This test is generally carried out in the temperature range 400°C-2000°C. To measure the dihedral angles, the system is rapidly cooled in order to freeze the equilibrium shapes.

4 Experimental Procdure

fly-ash, quartz, illmenite mixture in 60:20:20 weight ratio was Plasma sprayed on Copper and Mild steel substrates. The substrates have dimensions 1 inch diameter and 3 mm thickness. The powders are mechanically milled in a FRITSCH- planetary ball mill for 3 hours to get a homogeneous mixture. The specimens were grit blasted at a pressure of 3 kg/cm^2 using alumina grit to make the surface roughness ~5.00 Ra. After grit blast, substrate surface cleaned by acetone and spraying process immediately carried out. Spray coating was done using a 40 kW plasma spray system at the Laser & Plasma Technology Division, BARC, Mumbai. This is a typical atmospheric plasma spray system working in the non-transferred arc mode. The major subsystems of the set up include the plasma spray torch, powder supply, powder feeder, plasma gas supply, control console, cooling water and spray booth. A current regulated DC power supply was used. The plasma input power was varied from 11 to 21 kW by controlling the gas flow rate and arc current. The powder deposited normally with the substrate surface. A four stage closed loop centrifugal pump at a pressure of 10 kg/cm^2 supplied cooling water for the system. Plasma spray coating of fly-ash+quartz+illmenite mixture, in the size range of approximately 40 - 100 µm are deposited over metal substrates. The adhesion strength of the coating is measured using coating pull-out method [14], which was carried out using the set up Instron 1195 at a crosshead speed of 1 mm/min (performed as per ASTM-633). The morphology of substrate was studied using JOEL T-330 scanning electron microscope. Operating parameters used for coating deposition are given in table 1.

Table 1: operating parameters during coating deposition of fly-ash+ quartz+ illmenite

Operating parameters	values
Plasma arc current (Amp)	260-500
Arc voltage (volt)	40-44
Torch input power (kW)	11,15,18,21
Plasma gas(argon) flow rate (IPM)	28
Secondary gas(N2) flow rate (IPM)	3
Carrier gas(Ar) flow rate (IPM)	12
Powder feed rate (gm/min)	15
Torch to base distance (mm)	100

5 Results discussion

5.1 Splat morphology Study

Figure-4 and figure-5 shows splat-surface morphology and inter-particle bonding of fly-ash+ quartz+ illmenite molten particle on the mild steel and copper substrate respectively. The surface morphology of the coatings is examined under scanning electron microscope. The coating deposited at 18 kW power level on steel substrate (shows in figure-4), shows a uniform distribution molten particle. Some cavitations observed at this power level. Some open pores are found on the inter particle boundaries and at grain junctions. The splat on the copper substrate (shown in figure-5), have lath structured splat morphology with less cavitation. Along with the key physical parameters such as the particle size, velocity, and temperature, the substrate temperature, and the state of substrate surface, the splat formation is substantially influenced by the type of powder materials and mixing homogeneity [13] of powder elements in the material used in the synthesis of the fly-ash+ quartz+ illmenite mixture.

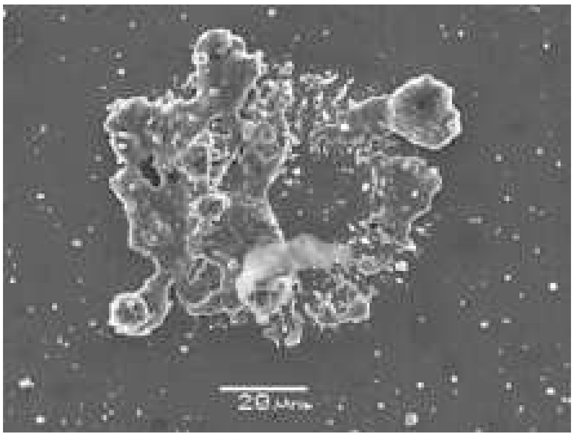

Figure 4: Typical splats formed from fly-ash+ quartz+ illmenite mixture particles on mild steel (Spray at 18 kW power level).

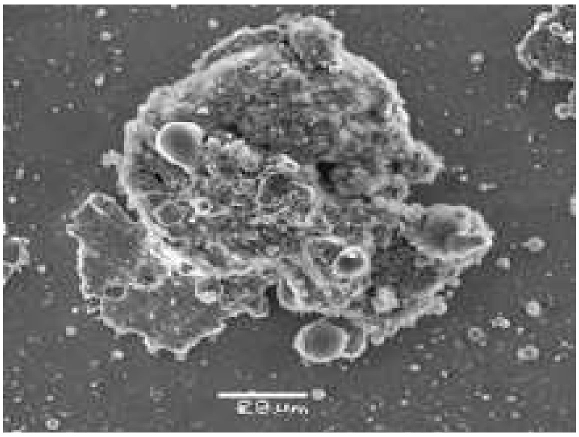

Figure 5: Typical splats formed from fly-ash+ quartz+ illmenite mixture particles on mild steel (Spray at 18 kW power level).

5.2 Adhesion strength study

The variation of adhesion strength with operating power level for mild Steel and copper substrate is shown in figure-6. It is observed that, with increasing operating power level, the adhesion strength increases up to a certain power level, and then it is remain nearly steady with further increase in torch input power. Again by comparing adhesion strength of mild steel against copper (figure-6), it is found that at 11 kW, 18 kW and 21 kW power level; the adhesion strength of Mild Steel is greater. A maximum of 6.56 MPa adhesion strength is obtained on the coating developed on Mild steel.

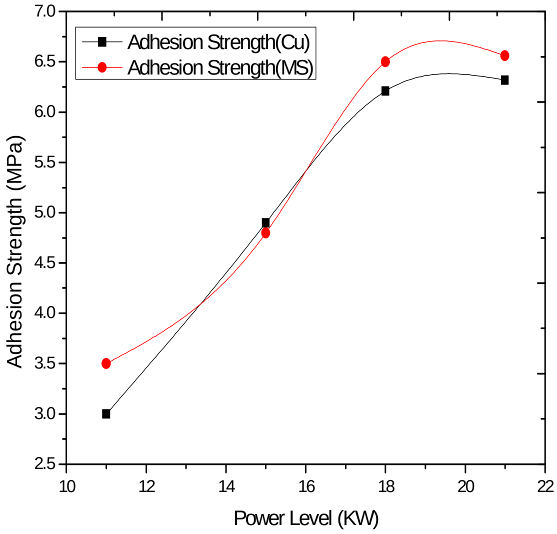

Figure 6: comparison of adhesion strength of mild steel and copper with respect to power level

6 Conclusions

Fly-ash+quartz+illmenite mixture was found to be a suitable material for depositing thermal spray coating on metals. These coating have wide range of applications in chemical barrier, thermal barrier. Power level has the main role on solid-liquid interaction on the substrate and on the adhesion strength.

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