Plasma Spray Deposition of Fly Ash + Aluminum Coatings on Steel Substrates

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Abstract

Through plasma spray technology, it is possible to develop metallic and ceramic coatings on a wide range of substrates and it also has the advantage of being able to process various low grade ore minerals and wastes to obtain value added products like near-homogeneous coatings of desired microstructure. Fly ash is such an industrial waste which is produced in huge quantities during power generation in a coal based power plants. The chemical analysis of fly ash indicates its tremendous potential to be used as a coating material on structural and engineering components, which are generally used in aggressive environments. In view of this, the present work describes the development and characterization of a new class of coatings made of fly ash pre-mixed with aluminium (Al) powder in different weight proportions (0, 5, 10, 15, 20, 25 and 30 wt%) on mild steel substrates by atmospheric plasma spraying route. The coating depositions are made at different torch input power levels ranging from 9 kW to 18 kW DC. The coatings are characterized in terms of their thickness, adhesion strength and deposition efficiency. Maximum adhesion strength of about 29 MPa is recorded with fly ash + 15 wt% Al mixture deposited at 12 kW power level. Similarly, coating deposition efficiency as high as about 35% is obtained for fly ash + 30 wt% of Al mixture at 18 kW power level. It is further noticed that the quality and properties of the coating are significantly affected by the operating power level of plasma sprayer and also by the Al content in the feed-stock. This work opens up a new avenue for the utilization of an industrial waste by identifying fly ash and fly ash pre-mixed with Al as potential and cost effective coating materials for engineering applications.

INTRODUCTION

Plasma sprayed ceramic coatings find wide applications these days not only in R&D area but also in the industrial work places ranging from textile industries to even medical applications. In the automotive industries of many industrially advanced countries, these coatings are used to improve the wear resistance, thermal resistance and resistance to corrosion of machine components and structures. In thermal plasma, it is possible to spray all metallic and non metallic materials such as metal oxides, carbides, nitrides, silicides etc [1-3]. During recent years, although a large number of investigations have been carried-out on production of ceramic coatings using these metal oxides, not much effort has been given to plasma processing of low grade materials and industrial wastes for this purpose. Mishra et al. in 1998, made the first successful attempt to spray coat raw fly ash on copper and stainless steel substrates through plasma processing [4]. They further repeated the plasma spraying of fly-ash mixed with ilmenite, graphite and alumina powder respectively in different proportions leading to the development of protective coatings of high effectiveness [5]. Satapathy et al. reported the development of plasma spray coating of another industrial waste called red mud on various metal substrates [6]. Krishna et al. [7] reported the coatability of fly ash on steel substrates by detonation spraying. Still, research/study on development of thermal spray coatings using low grade mineral and/or industrial waste is meager. Industrial wastes like fly ash, being rich in metal oxides, have tremendous potential to be used as coating materials and this aspect needs to be explored. More so because many of the conventional coating materials are relatively expensive, to the extent that cost of spray grade powders alone can account for even 50-60% of the operating cost of a plasma spray unit. On the contrary, an industrial waste like fly ash is not only cheap but also is abundantly available. Against this background, the present study has been undertaken to produce and characterize plasma sprayed composite coatings of fly ash premixed with aluminum powder on steel substrates. Fly ash is an industrial waste available in the form of finely divided powders generated in huge quantities during power generation in coal based power plants. The chemical analysis of fly ash indicates its coating potential, because metal oxides are its major constituents which are known to have high hardness, high wear resistance and good corrosion resistance, which are desirable properties for protective coatings.

EXPERIMENTAL DETAILS

The fly ash used in the present work is of cenosphere type and has been collected from the Captive Power Plant of National Aluminium Co. (NALCO) located at Angul in India. The chemical analysis of fly ash sample, given by the source industry suggests its composition as silicon oxide (51.2%), aluminium oxide (32.8%), iron oxide (6.5%), titanium oxide (4.5%) and traces of CaO, Na_2O and P_2O_5 etc. The as-received fly ash is screened through sieves so as to obtain particles in the size range of 75-93 µm. Six compositions are made by pre-mixing fly ash with 5, 10, 15, 20, 25 and 30 wt.% of aluminum powder (average particle size 75 µm), procured from NICE, India Ltd. The raw materials are mixed and preheated thoroughly prior to spraying.

Mild steel (≈0.25% C) samples are used as the substrate. Prior to coating, the samples are vapor degreased, grit blasted (with alumina grits) to produce a surface roughness of Ra value about 4.0 - 5.0 µm and subsequently cleaned with acetone in an ultrasonic cleaner. Plasma spray coatings are deposited with a non-transferred arc plasma torch operating at various power levels ranging from 9 to 18 kW DC. The powder is fed at a rate of about 12 g/min using argon as the carrier gas flowing at a rate of 10 lit/min. The torch-to-base distance is kept constant at 100 mm. The thickness of the coatings is measured by a traveling microscope averaging over a length of 10 mm on the polished cross-section of the specimens. The coating pull-out test is carried out on all specimens to evaluate the coating adhesion strength as per ASTM C 633.

RESULTS AND DISCUSSION

Coating thickness

The variation of coating thickness with input power level is shown in Figure 1. It is evident that with increase in torch input power the thickness of the coating increases, such a trend is generally being observed with plasma spray coatings [3, 8, 9]. From the figure it is observed that the coating thickness is largely affected by the torch input power and also by the aluminium content. The thicknesses of the coatings are found to be varying in the range of about 190 µm to 370 µm with the operating power changing from 9 to 18 kW. The feed material with 30 wt% Al powder resulted in thicker coatings, with a maximum thickness of 367.8 µm at the 18 kW power level. This may be because of melting of the aluminium powders during the in-flight traverse through the plasma and resulting in better inter-particle bonding giving rise to a higher rate of deposition.

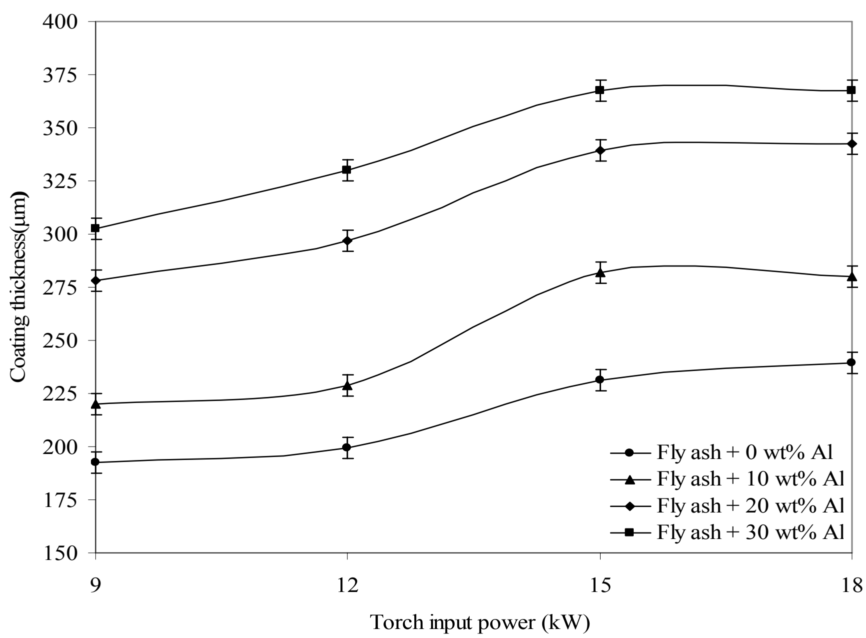

Figure 1 Variation of coating thickness with plasma torch input power

Coating adhesion strength

The variation of coating-substrate interface adhesion strength is shown in Figures 2 and 3, where the initial increase in adhesion strength with the aluminium content in the feed material is evident. The strength has increased with power level up to 12 kW and a maximum value of 28.9 MPa is recorded with fly ash + 15 wt% Al powder. Further increase in the operating power exhibited a detrimental effect on the adhesion strength.

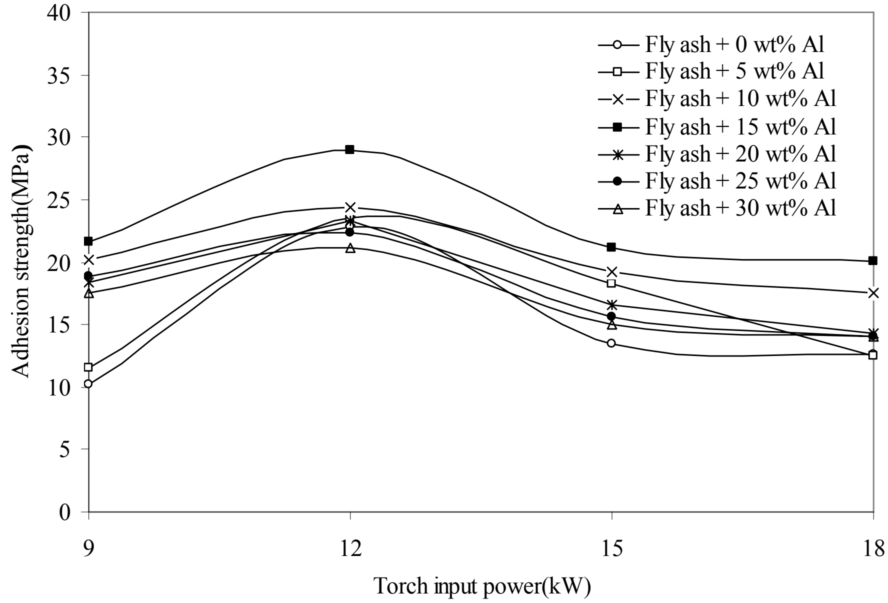

Figure 2 Variation in coating adhesion strength with plasma torch input power level

Initially, when the operating power level is increased from 9 to 12 kW, the melting fraction and velocity of the particles also increase. Therefore there is better splashing and mechanical inter-locking of molten particles on the substrate surface leading to increase in adhesion strength. But, at much higher power levels (beyond 12 kW), the amount of fragmentation and vaporization of the particles are likely to increase. There is also a greater chance of smaller particles (during in-flight traverse through the plasma) to fly off during spraying. This results in poor adhesion strength of the coatings.

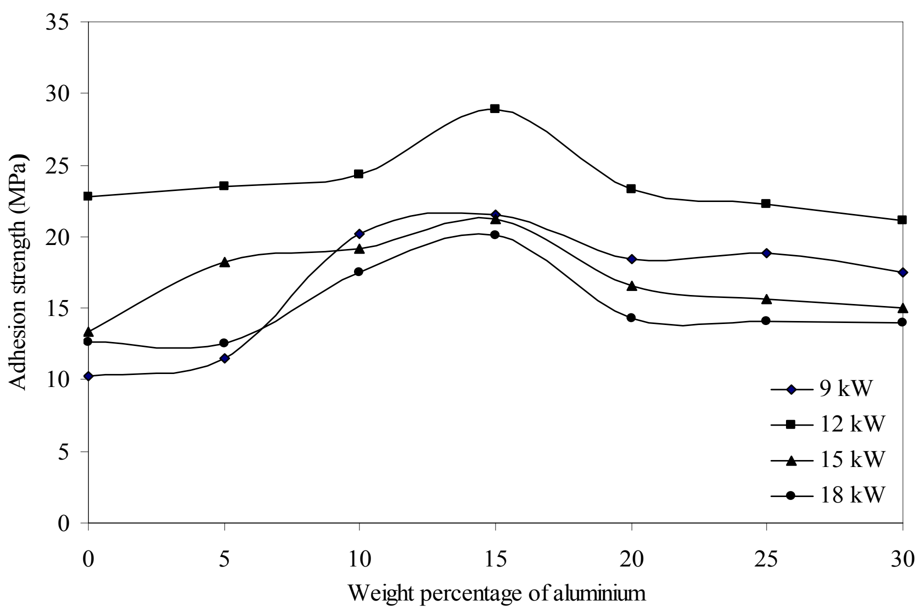

Figure 3 Variation in coating adhesion strength with aluiminum content in the feed stock

The presence of a suitable proportion of metal powder is also found to have helped in inter-particle as well as interface bonding. This could be one of the reasons for the greater adhesion strength with 15 wt% Al powder in the raw material. Similar investigations have been carried out to study the effect of metallic bond coating and coating with pre-mixed metal powder on the interface strength of thermal barrier coatings [10], where the adherence strength was found to be greater with certain optimum proportion of the metal powder in the pre-mixed feed stock.

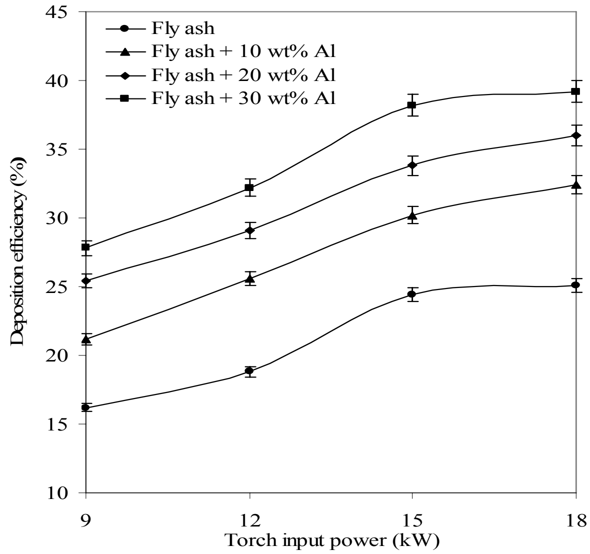

Figure 4 Coating deposition efficiency of fly ash-Al mixture at different power levels

Coating deposition efficiency

Deposition efficiency is defined as the ratio of the mass of coating deposited on the substrate to the mass of the expended feedstock. Weighing method is accepted widely to measure this. In this investigation, the deposition efficiency presents a sigmoid-type evolution with the torch input power (Figure 4).As the power level increases, the net available energy in the plasma jet increases leading to a better in-flight particle molten state and hence to higher probability for particles to flatten. The deposition efficiency reaches a plateau for the highest current levels due to the plasma jet temperature increasing which in turn increases both the particle vaporization ratio and the plasma jet viscosity.

CONCLUSIONS

This study shows that fly ash pre-mixed with aluminium powder can be used to produce plasma spray metal-ceramic coatings on mild steel substrates. Maximum adhesion strength of 28.9 MPa is recorded in such coatings with 15 wt% of aluminium content in the fly ash-aluminum mix. The coating thickness, adhesion strength and deposition efficiency are found to be greatly affected by the plasma torch input power level.

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