PLASMA SPRAY COMPOSITE COATING ON METALS USING FLY ASH AND ILLMENITE

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ABSTRACT

In spite of all its advantages, plasma spray coatings find limited adoption due to the high cost of the spray grade powders. In the present investigation, attempts has been made to explore the possibility of using some low grade ore mineral and industrial wastes as coating material, with an aim to reduce the cost of raw material used for coating. Conventional atmospheric plasma spray technique is used to develop coatings of fly ash (an industrial waste) mixed with illmenite (a low grade ore mineral) on mild steel and copper substrates. Coatings are characterized with adhesion tests, phase composition analysis, & surface and interface morphology using scanning electron microscopy. This work establishes that, Fly ash-illmenite mixture can be used as a potential coating material suitable for depositing plasma spray coating. It also opens up a new pathway for value added utilization of this industrial waste and low grade ore mineral.

Keywords: fly ash, illmenite, plasma, erosion wear, ceramic coatings.

INTRODUCTION

Silica and aluminous-silicate bricks are preferred as refractory materials in many industrial applications, due to their high wear resistance and load bearing capacity at high temperatures. In recent years, large number of studies have been carried out on deposition of ceramic coatings on metal components to combat wear, thermal shock etc [1,2]. Conventional atmospheric plasma spray technique is widely used to develop coatings of ceramic materials [3–6]. In the present case the plasma spray deposition of alumino-silicate composite coatings onto metal substrates is done using industrial waste such as fly ash with addition of illmenite, a titanium bearing ore mineral. The objective of this work is to reduce the cost of the spray grade powders (i.e. raw material) required for coating. To overcome difficulties such as poor interface mechanical properties, arising due to the mismatch between the thermal expansion coefficients of ceramics and metals, metallic bond coat is provided onto the substrate for better interface adherence of the coating[7,8]. Studies have shown an improvement of coating properties when pre-mixed metal–ceramic powders are used [9]. Some studies have been made to deposit fly ash premixed with aluminum powder [10]. It is well established that, addition of titania to alumina provide dense coating & better adherence on substrate [11]. In this case illmenite, a low grade ore mineral which is also plentily available in India, is premixed with fly ash so as to further reduce the raw material cost. In the present investigation coatings are deposited on metal substrates using atmospheric plasma spraying system at different operating power levels of the plasma torch.

To characterize the coatings, Coating interface bond strength is measured using coating pull out method [12] confirming to ASTM C-633 standard. To ascertain the phases present and phase changes / transformation taking place during plasma spraying, X-ray diffractograms are taken on the raw material and on coatings. The coating quality and behavior depends on coating morphology and inter-particle bonding of the sprayed powders.The surface and interface morphology of the coatings are studied by using Scanning Electron Microscope.

EXPERIMENTAL DETAILS

Fly ash-40% illmenite are mixed in a planetary ball mill for 3 hours to get a homogeneous mixture. The particle size of the powders is in the range of ~40 to ~100 micron. Commercially available copper and mild steel are chosen as substrate materials. The circular disc specimens of 1 inch dia and 3mm thick are grit blasted at a pressure of 3 kg/cm^2 using alumina grits.

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The standoff distance in shot blasting is kept between 120-150 mm. to get the average roughness of the substrates about 6.8 µm. The grit blasted specimens are cleaned with acetone. Spraying is carried out immediately after cleaning. Conventional 40kW power atmospheric plasma spray (APS) system is used. The plasma input power is varied from 11 to 21 kW by controlling the gas flow rate, voltage and the arc current. The operating parameters during coating deposition are shown in Table 1.

Table-1. Operating parameters of the plasma spray unit.

Operating Parameters	Values
Plasma Arc Current (amp)	280-500
Arc Voltage (volt)	40-45
Plasma Gas (Ar) Flow Rate (Lpm)	28
Secondary Gas (N_2) Flow Rate (Lpm)	3
Carrier Gas (Ar) Flow Rate (Lpm)	12
Powder Feed Rate (gm/min) Torch to	15
Base Distance TBD (mm)	100

The coating adhesion strength is measured by coating pullout test using a special zig for holding the sample. The test was performed as per ASTM C-633 standard. X-ray diffraction technique is used to identify the different (crystalline) phases present in the coatings. XRD analysis is done using Ni-filtered Cu-Kα radiation. The surfaces as well as the interface morphology of all coatings are investigated with JEOL JSM-6480 LV scanning electron microscope in secondary electron imaging mode.

RESULTS AND DISCUSSION

COATING ADHESION STRENGTH

Coating interface bond strengths was evaluated and the variation of adhesion strength of the coatings deposited at various power levels is shown in Fig.1. From the Fig.1, it is clear that the adhesion strength varies with operating power of the plasma torch. Maximum adhesion strength of 6.732 MPa on mild steel substrate and of 5.842 Mpa on copper substrate is recorded on the coatings deposited at 18 kW power level. It can be visualized that, the interface bond strength increases with the input power of the torch up to a certain power level and then shows a decreasing trend in coating adhesion irrespective of the substrate material. This might be due to the fact that, when the

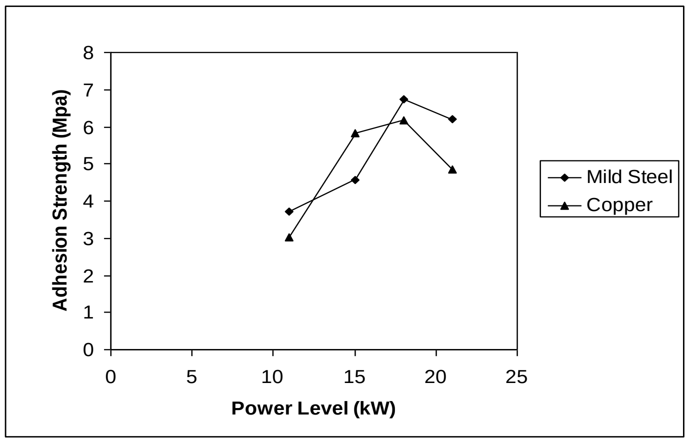
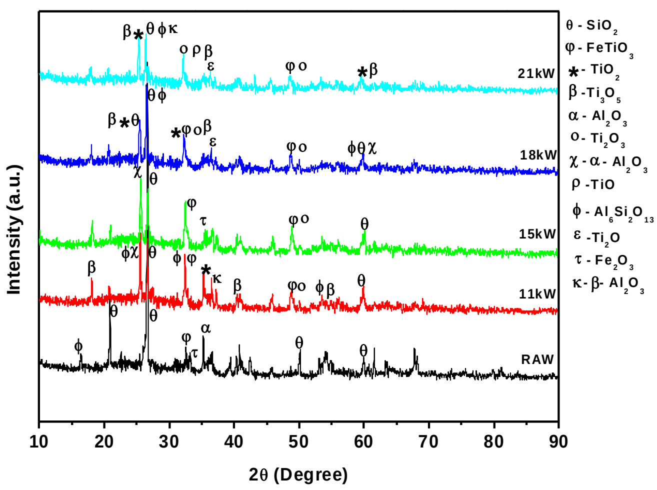


Fig.1. Variation of adhesion strength of fly ash-illmenite coating.

operating power level is increased, larger fraction of particles attain molten state as well as the velocity of the particles also increase. Therefore there is better splat formation and mechanical inter-locking of molten particles on the substrate surface leading to increase in adhesion strength [13]. But, at a much higher power level, the amount of fragmentation and vaporization of the particles increases. There is also a greater chance to fly off of smaller particles during in-flight traverse during plasma spraying and results in poor adhesion strength of the coatings. Coating adhesion strength is more in case of mild steel substrate than that of copper substrate may be due to the dependence of thermal conductivity for melted particle for dissipation of heat at metal interface and also may be due to thermal expansion coefficient mismatch at the ceramic metal interface [14].

XRD PHASE COMPOSITION ANALYSIS

The XRD results taken on the raw material and fly ash-illmenite coatings at different power level are shown in Fig. 2. The XRD of the feed material SiO_2, $FeTiO_3$, etc. Coating made at lower power level i.e. at 11kW shows the presence of α- Al_2O_3, SiO_2, $FeTiO_3$, Ti_2O_3 and some new phases such as TiO_2, Ti_3O_5 & mullite. With increase in power level the percentage of inter-oxide phases i.e. Ti_3O_5, Ti_2O_3 and mullite are found to increase. It may be due to the availability of high temperature which has accelerated the phase transformation, with increase in torch input power during coating deposition. Generally, Al_2O_3 transforms



to different allotropic phase (α-Al_2O_3 and β-Al_2O_3) and TiO_2 reduces to Ti_3O_5, Ti_2O_3, Ti_2O, TiO etc. depending on enthalpy/environment and transformation conditions [15,16]. During plasma spraying the different phase transformations are taking place, so it is expected that a ceramic composite coating from low grade materials could be made which can have better wear resistance properties.

MICROSTRUCTURAL INVESTIGATION

Surface Morphology

The interface adhesion of the coatings depends on the coating morphology and inter-particle bonding of the sprayed powders. SEM micrograph of Flyash-illmenite coating surfaces are shown in Fig.3.The coating deposited at 11kW power level (Fig-a) on copper substrate, shows a uniform distribution of molten/semi molten particles. More amount of cavitations is observed, other than some large pores found on the inter particle boundaries and triple particle/grain junctions. These may have originated during solidification of particles from molten/semi-molten state. The coating made at 15 kW bears a different morphology. Some flattened regions are observed, indicative of particle melting during spray deposition. The grains/particles are mostly equi-axed type with little boundary mismatch between them. Amount of cavitations is less**.** Coating deposited at further higher power level i.e. at 18 kW bears a different morphology. . Larger portions of the coatings exhibit flattened regions, which might have been formed during solidification of molten particles that have fused together in lumps. Less cavitation is observed at inter grain boundary. This may be the reason for increase of adhesion strength of the coating. For the coatings deposited at further higher power level i.e. at 21 kW the surface morphology is completely different. A large number of spheroidal particles of varied diameters are seen, which might have been formed due to breaking / fragmentation of bigger particles during in flight traverse through the plasma jet and then solidified in form of spheres due to very fast rate of quenching. The amount of porosity appears to have increased again. Amount of cavitations is more than that observed in the previous case. This might be the cause for the improper inter-particle bonding and poor stacking to the substrate which have resulted in lowering the interface bond strength

Interface morphology

The coating substrate interface plays the most important role on the adhesion of the coating. The surface morphology of the coating cannot predict the interior (layer deposition) structures. The polished cross-sections of the samples are examined under SEM and are shown in Fig. 4.

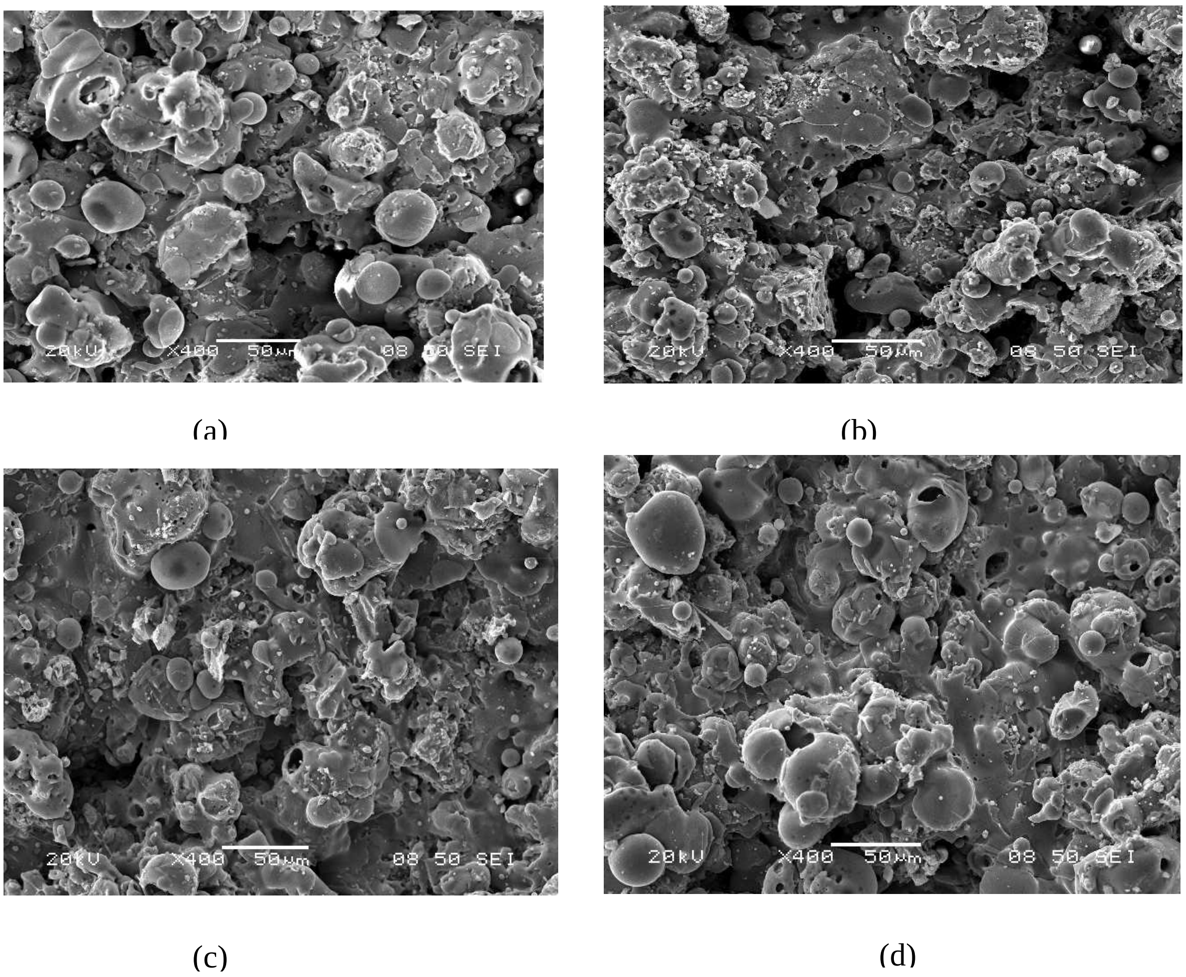
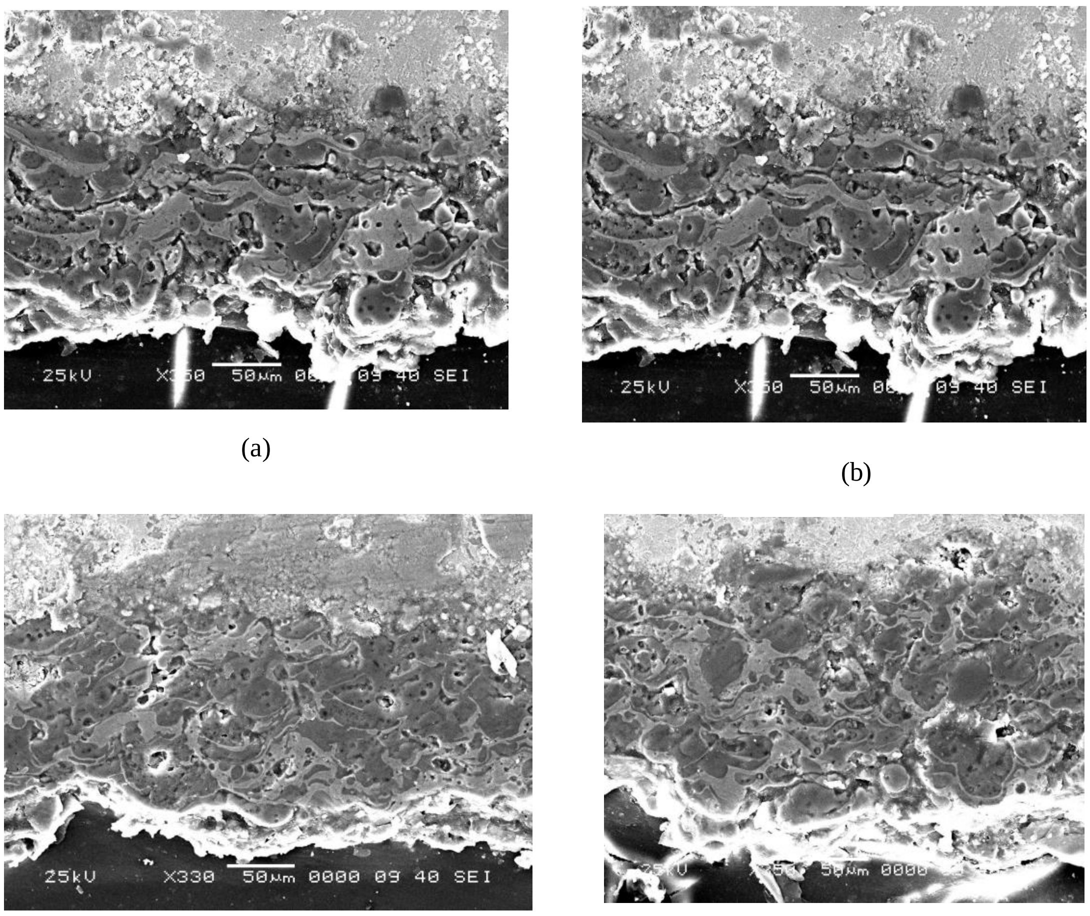


Fig.3. Surface Morphology of flya sh-illmenite coatings deposited at different power level i.e. (a)11kW (b)15kW(c) 18kW, (d) 21kW.

From the micrograph good interface matching is seen. Lamellar structure confirms the solidification of molten particles to form splats during coating deposition. The coating is homogenous through out the length for the coating deposited at 18kW, hence has shown higher adhesion strength.

CONCLUSIONS

From this study it has been found that fly ash with low grade ore mineral (illmenite) additions can be used to provide plasma spray ceramic composite coating on metal substrates. The maximum adherence strength of 6.732 MPa on mild steel substrate and of 5.842 Mpa on copper substrate is recorded in such coatings. Inter-oxide transformations of the raw materials do occur and their amount varies with operating power of the plasma torch. The operating power level of the plasma torch affects the coating morphology and mechanical properties of the coating.



(a) (b)

(c) (d)

Fig.4. Interface morphology of fly ash-illmenite coatings deposited on mild steel substrates, at (a) 11kW (b) 15kW (c) 18 kW (d) 21kW power level.

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