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Plasma Spray Coating of Fly Ash on Metals for Tribological Application

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Abstract

Thermal spray coating of fly-ash was deposited on various substrate viz. copper, mild steel, stainless steel and aluminum by plasma spraying (atmospheric plasma spraying) at at Laser & Plasma technology Division, BARC-Mumbai. Subsequently, coatings were evaluated for deposition efficiency, adhesion strength (coating to substrate), microhardness of different phases. Phase composition analysis was made using XRD technique.Deposition efficiency up to ~60 % was achieved. The quality of the coatings has a strong dependence on input power to the plasma torch and particle size of the feed material. Adhesion strength of 7-12 MPa was obtained.. The hardness measured on the polished cross-section of the coating on optically distinguishable phases, varies between 800-1000 Hv for different phases. Phase composition analysis was done using XRD technique and reveals that, along with silica, α-γ Alumina and Mullite phases are present in the coatings. The surface and interface morphology of the coatings are examined with SEM.

INTRODUCTION

Ceramic coatings greater than 50 micron in thickness are used for a remarkable number of application[1] viz. wear/erosion and corrosion resistance, thermal barriers etc. Plasma sprayed ceramic coatings are used for handling liquids metals and increasingly for electrically insulated metal substrate in automotive industry. The unique feature of plasma spray coating is that it combines the process of melting, quenching and consolidation into a single operation, potentially retaining the rapid quench structure. Although, plasma spraying offers a high quench rate, the deposit annealing occurs due to both the hot plasma flame and adiabatic recalescence during particle solidification,[2] enables in formation of complex/multiphase products of the feed powders. The suitability of a ceramic coating on metal substrates depends on (i) the adherence strength at coating-substrate interface, and (ii) stability at operating conditions. Since long Silica and alumino-silicate bricks are preferred as refractory materials in many industrial applications due to their high wear resistance and high load bearing capacity at high temperature. During the last decade, although a large number of investigators have been carried out on processing plasma spray ceramic coating,[1-4] not much efforts have been made to use waste materials. In view of increasing interest in developing technology for waste material utilization in research arena across the globe, an attempt has been made to utilize fly ash, a waste from thermal power plant, for thermal spray coating. So far, fly ash has fetch attention mostly for its application as a building material. But fly ash as coating material can open up novel front for its application. Fly ash as a premixed coating material has been established. In the present investigation, attempts are made to deposit fly ash on metal substrates with varying the particle size; and the coatings were characterized for its adhesion strength, deposition efficiency, phase composition analysis and using scanning electron microscopy for micro-structural changes.

EXPERIMENTAL

Flyash powder to be used as feed stock for coating was first screened through +53 to -125 µm sieves and then two size range powder +53 to -75 µm and +75 to -106 µm was separated. The substrate (stainless steel, mild steel and copper coupens 50x25x3 mm) surface was prepared by sand blasting to produce a surface roughness of ~5 Ra. Plasma spraying was done with a non-transferred arc plasma torch (thermal plasma section, L&PTD, BARC, Bombay) operated at various power levels ranging from10 to 20 kW D.C. The powder was fed at a rate of 11.5 g/min using Ar as carrier gas at a flow rate of 10 LPM. Ar and ($Ar + N_2$) were used as plasma forming gas. Substrate to torch distanced was fixed at 100mm, and with torch traverse rate of ~ 300 mm/min the coatings were deposited layer wise. Depending on operating conditions, the layer thickness varied between 15-30 µm. The coated samples were subjected to various analysis. Thickness of the coating was measured by traveling microscope averaging a distance of 10 mm on polished cross-sections of the specimens. XRD were taken on selective specimens for phase analysis/identification. Surface and interface morphology was studied through SEM. Coating adhesion test was carried out first with Elcometer and secondly on tensometer on all specimens to evaluate coating-substrate interface adherence strength after fixing the coating side of the samples on cylindrical tensile specimen with two different adhesives the details are mentioned elsewhere.

RESULTS AND DISCUSSION

Deposition Efficiency

Deposition efficiency of the powder i.e. feed stock, implies that how a particular size powder can be best deposited with minimum of material loss.

For the fly ash the deposition efficiency for powder (fly ash) of two size range, are shown in fig. 1. It may be seen that, the deposition efficiency has attained ~60 % for the coatings deposited with particle size range of +75—106 micron. The adherence strength is maximum at an intermediate power level irrespective of the particle size of the feed stock.

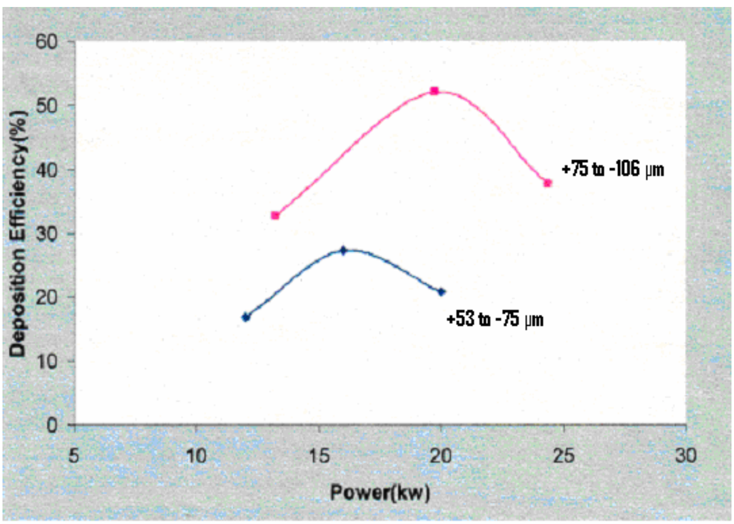
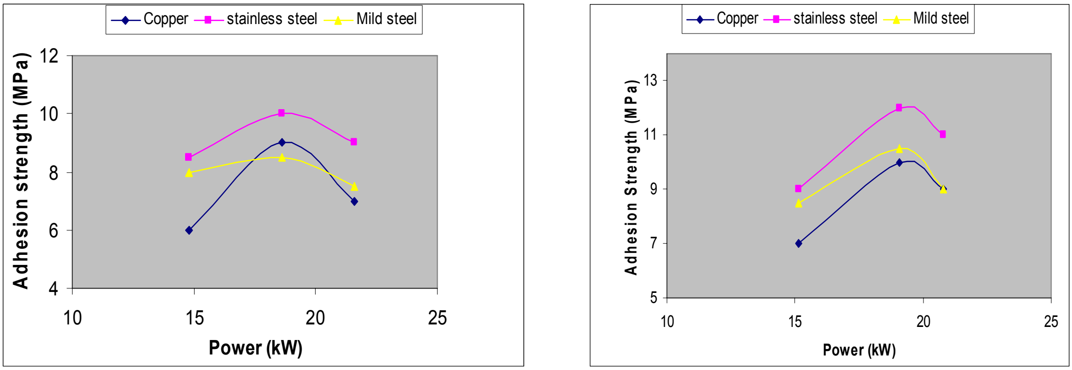


Fig. 1: Particle Size Dependence of Coating Deposition Efficiency with Operating Power

Coating Adhesion

The coating –substrate interface adhesion strength was measured using pull out test method**(5)**.The coating-substrate adhesion strength is shown in figure-2(a) & (b).



(A) **(B)**

Fig. 2: The Variation of Coating-Substrate Adhesion Strength for the Coating of Particle Size Range (A) +75 to -106 Mm and (B) +53 to -75 Mm on Copper, Stainless Steel and Mild Steel

It is observed that coating adherence has varied from 6 MPa to 11 MPa. for power levels from 12 kW to 22 kW. For the powder of particle size range +53 to -75 μm, the maximum adhesion strength is obtained (12 MPa for stainless steel at 19 kW). It is also observed that maximum adherence is obtained in the range of 15 to 20 kW power levels irrespective of the particle size. There is a drop in the adherence at low (below 15 kW) and at very high (above 20kW) power level of the plasma torch. Adherence of coating to substrate is best obtained at an optimal power level. The plot between power and adhesion strength shows an inverted/sinusoidal pattern and maximum adherence is obtained for an optimal power level of 15 kW.

Hardness

Hardness is taken on the transverse cross section of the coated samples with Leitz Microhardness tester using 50 Pa load and are tabulated in table 1. There are three different phases (optically distinguishable) are worth observing. The microhardness of these phases has been measured. It is known that Alumina and Silica posses different (allotropic) structural morphology viz. Alumina has α and γ phases, Silica from crystabolite to trydamite & also with different orientation etc. which is a result of consolidation with temperature gradient i.e. formation/solidification from higher temperatures. During plasma spraying at different power levels, the temperature of plasma jet has influenced the phase transformation of alumina and silica particles (major constituents of fly ash) for which difference in hardness is obtained. It may be accounted for the transformation of alumina and silica during spray deposition. At lower power level, some amount of silica remain in a glassy phase, Mullite formation is also less and γ alumina least stabilized. Whereas at higher power levels γ alumina is well stabilized and mullite also forms so as to result in higher hardness. The observation of glassy phase during flyash coating deposition has been documented in literature [7].

Table 1: Micro-Hardness of the Phases in the Coating.

Phase	Lower power level	High power level
Gray (Silica)	750	850
Mixed (Mullite)	900	900
Bright(Alumina)	1100	1350

Morphology

The surface and interface morphology of the coatings of some typical samples are shown in figure 3 and 4. The coatings made at lower power (12 kW) and the coatings made at higher power level (25 kW) reveal more amount of cavities at inter particle boundaries and in between coagulated power species. But for the coatings deposited at the power 20_kW,_the particle/phases are equiaxed type and homogenously distributed, with less porosity on surface layer. It also appears that the particles have solidified from molten state so as to provide good inter particle bonding/matching. This might have provided better interface adherence of the fly ash coating with metal substrate. From the interface

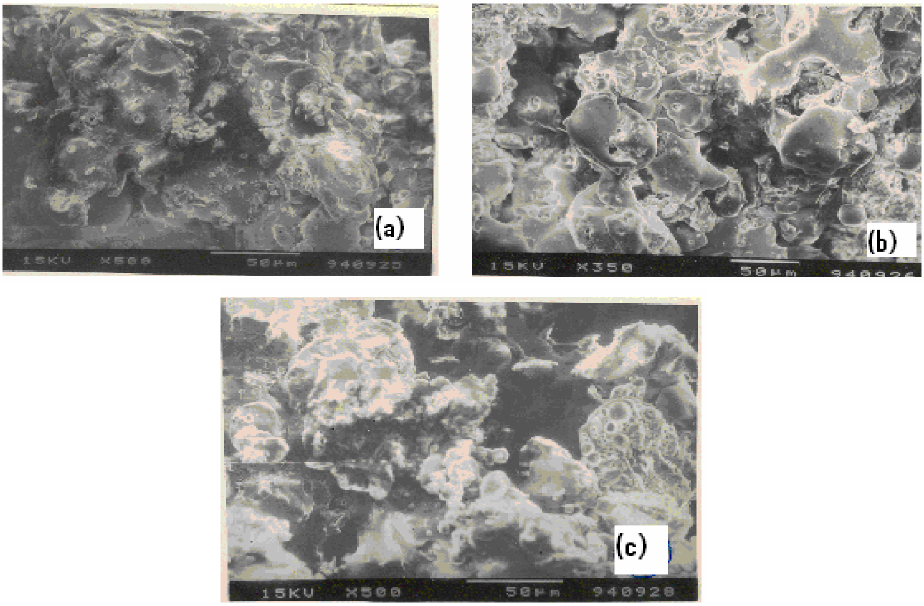


Fig. 3: The Surface Morphology of Fly-Ash Coating Made at (A) 15kw, (B) 18 Kw and (C) 22 Kw Operating Power of the Torch

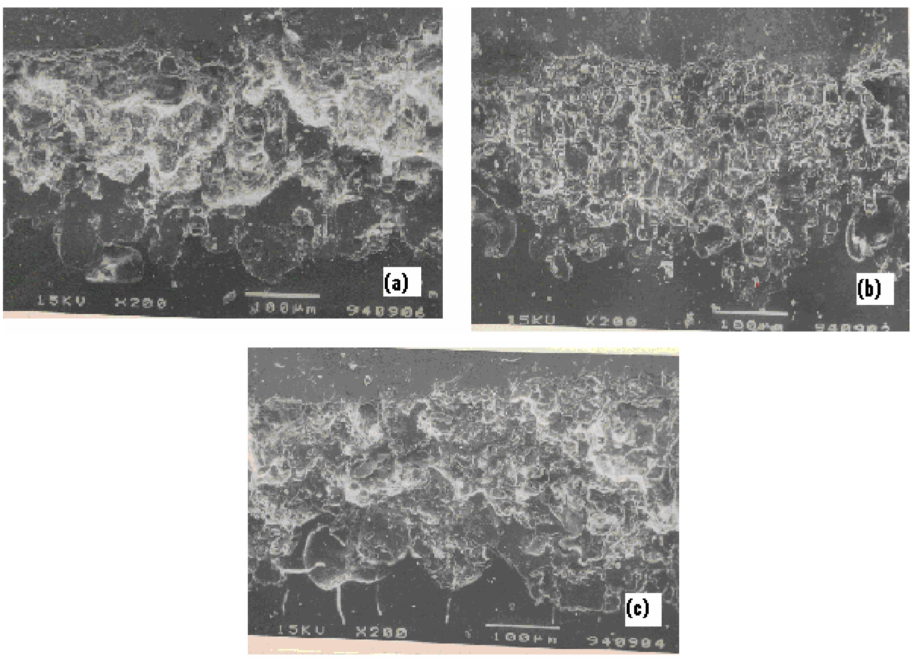


Fig. 4: The Interface Morphology of Coatings Made at (A) 15KW (B) 19 KW and (C) 20 KW Power Level

structures i.e. fig. 4 (a, b & c), it can be well visualized that, there is a considerable change in the morphology of the deposited layers. The coating made at 12 kW power level (of plasma torch), fig.4 (a), shows a distribution of glassy phase of SiO_2 in flyash coatings are also observed by Mishra et al.[2,7]. This might have also affected the coating adhesion with the metallic substrates. From metallurgical constraints it is well understood that fine grain/phase structure provides better homogeneity in the morphology. So, all these factors might have been responsible for higher adherence strength of the coatings (deposited at 20 kW power level). It may also be noted that, coating could not be produced with powder of particle size range +106 to -125 µm & above and also below 53 µm due to poor flowability of flyash. From XRD analysis of the presence and variation of α Alumina, γ Alumina and Silica phases are confirmed.

CONCLUSIONS

Fly ash can be utilized to develop ceramic coatings on metal substrate. Particle size range from +53 µm to -106 µm are well suited for plasma spray deposition. Coating adherence has varied from 6 MPa to 12 Mpa with highest adherence at 19kW power. Good quality coating and homogeneously distributed phases are observed in the coatings made at power levels between 12 to 20 kW. Difference in the hardness of different phases is also observed which signify allotropic transformation (of Alumina and Silica) during plasma spraying of fly ash, which is confirmed with XRD analysis.

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