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Erosion Wear Studies on Plasma Spray Industrial Waste Coatings

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Abstract

Thermal spray coating of fly-ash was deposited on different substrates viz. copper, mild steel, stainless steel and aluminum by atmospheric plasma spraying. Subsequently, coatings were evaluated for deposition efficiency, adhesion strength (coating to substrate). Phase composition analysis was made using XRD technique. 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 coatings on optically distinguishable phases, varies between 800-1000 Hv. Solid particle erosion wear behavior was studied on the coatings. It is observed that, the erosion wear rate varies with stand off distance, angle of attack the velocity of the erodent and also with coatings deposited with different particle sizes.

Keywords : fly ash; erosion wear rate; plasma; allotropic transformation; coatings.

1. Introduction

Ceramic coatings greater than 50 micron in thickness are used for a remarkable number of applications[1]viz. wear/erosion and corrosion resistance, thermal barriers etc. The unique feature of plasma spray coating is that it combines the process of melting, quenching and consolidation in 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 use as a building material. But fly ash as coating material can open up novel front for its application. In the present investigation, attempts are made to deposit fly ash on metal substrates with varying the particle size. The coatings were characterized for its adhesion strength, phase composition analysis etc. Erosion wear tests were carried out on the coatings to ensure its applicability.

2. Experimental

Fly ash used as feed stock for coating was first sieved and two size range powder +53 to -75 μm and +75 to -106 μm was separated. The substrate (stainless steel, mild steel and copper 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. Depending on operating conditions, the layer thickness varied between 15-30 μm. The coated samples were subjected to various analysis. XRD were taken on selective specimens for phase analysis/identification.

3. Results and Discussion

Hardness is taken on the transverse cross section of the coated samples with Leitz Microhardness tester using 50 Pa load, 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. 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 fly ash coating deposition has also been documented in literature[5].

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

Solid particle erosion is a wear process where particles strike against a surface and cause material loss. During flight, a particle carries momentum and kinetic energy, which is dissipated during impact due to its interaction with a target surface. In case of plasma spray coatings encountering such situations, no specific model has been developed and thus the study of the erosion behavior has been based on mostly experiment data [6]. In this work, room temperature solid particle erosion trials on a few selected coated specimens are carried out using a compressed air blasting type rig under three different impact angles (30°, 60° and 90°).The nozzle (0.2mm ID) is kept at 200 mm stand-off distance (SOD) from the substrate and 50 μm average size dry silica sand particles are used as erodent, with an average velocity of 30 m/s as measured by double disc method [7]. Coatings of area 6.25 cm^2 is exposed to the compressed air jet carrying dry sand particles. Weighing of samples at regular interval of time during impact is done with a precision electronic balance of ±0.1 mg accuracy level to determine cumulative mass loss. Erosion rate, defined as the coating mass loss per unit erodent mass (mg/g) is calculated. Figure 1, shows a typical erosion curve for different (particle size) fly-ash coatings at 30° angle of impact, on coatings deposited at different power levels. From the figures it can be visualized that the cumulative coating mass loss i.e. erosion wear rate increases rapidly with time and after some erosion time erosion rate becomes constant. This trend is observed in case of all the coatings even made with different particle sizes. Figure 2, shows the erosion wear rate of the coatings made at 30°, 60°, and 90° impact angles for the coating deposited at 16 kW and 20kW power level for different particle size of fly ash. It can be observed that the erosion wear rate is affected with impact angle of the erodent. With increase in the stand-off distance (SOD) i.e. distance between the coating and the nozzle (erodent outlet point) the erosion rate decreases (Fig.3). Initially, there is sharp rise and then it becomes linear after some time. Comparing with figure 1 (b) the magnitude of erosion wear rate is lower. This implies that with increase in stand-off distance the rate of erosion reduces. With increase in force of the erodent i.e. at 8 kgf pressure (40m/sec particle velocity) the wear rate is shown in figure 4, for SOD of 150 mm. Comparing with figure 1 (b) it can be well remarked that the wear rate follows the similar trend but with a difference in magnitude. It is evident from these figures that a transient regime in the erosion process exists, during which the incremental erosion rate decreases monotonically down to a constant value is referred to as the steady state erosion rate. The relationship between erosion rate (E) and impact angle (α) is suggested by Bayer [8] as

$$E = (K_d V^n \mathrm{Cos}^n \alpha + K_b V^m \mathrm{Sin}^m \alpha)\ M$$

For a particular test condition, velocity of impact V, erodent supply rate M are constant. The constants K, m and n are determined by fitting the equation to experimental data. For typical brittle materials Kd=0. For typical ductile material, Kb=0. This variation of erosion wear loss confirms that the angle at which the stream of solid particles impinges the coating surface influences the rate at which the material is removed. It further suggests that, this dependency is also influenced by the nature of the coating material. The angle of impact determines the relative magnitude of the two components of the impact velocity namely, the component normal to the surface and parallel to the surface. The normal component will determine how long the impact will last (i.e. contact time) and the load. The product of this contact time and the tangential velocity component determines the amount of sliding that takes place. The tangential velocity component also provides a shear loading to the surface which is in addition to the normal velocity component causes. Hence, as this angle changes the amount of sliding that takes place also changes as does the nature and magnitude of the stress system. Both the aspects influences the way a coating wears. These changes imply that different types of material would exhibit different angular dependency.

4. Conclusions

Fly ash can be utilised to develop ceramic coatings on metal substrate. Particle size range from +53 μm to -106 μm are well suited for plasma spray deposition. 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. Erosion wear rate varies with impact angle and stand off distance and is low for the coatings deposited at higher power level.

5. References

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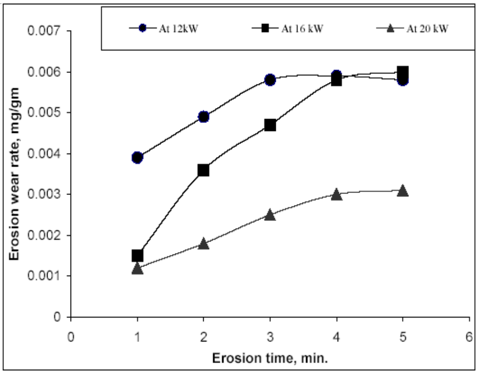

Fig. 1 (a). Time dependence erosion wear rate rate for coatings made at different power levels (for particle size +75-106 micron).

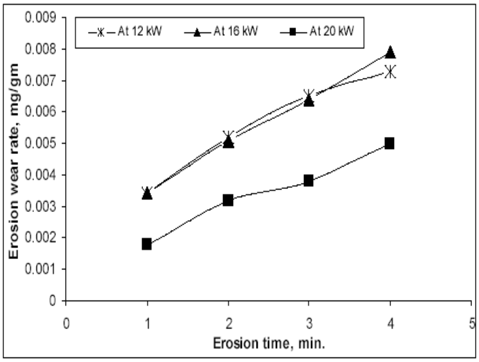

Fig. 1 (b). Time dependence erosion wear for coatings made at different power levels (for particle size +53-75 micron).

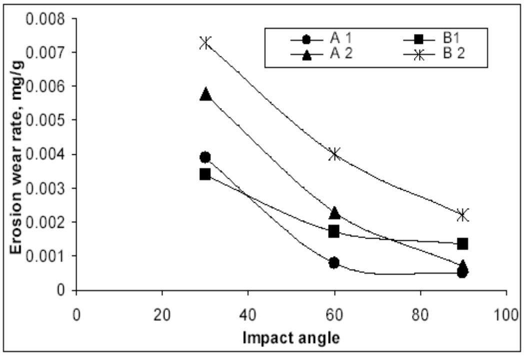

Fig. 2. Dependance of erosion wear rate for raw material particle size A=+75-106& B=+53-75micron; 1 & 2 for coatingsmade at 16 and 20 kW power level.

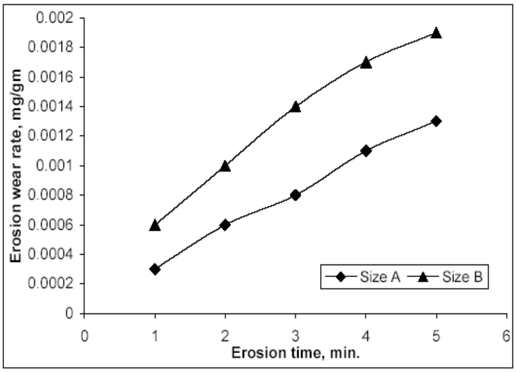

Fig. 3. Variation of erosion rate with time of impact, A = +75-106 and B = +53-75 particle size feed stock.

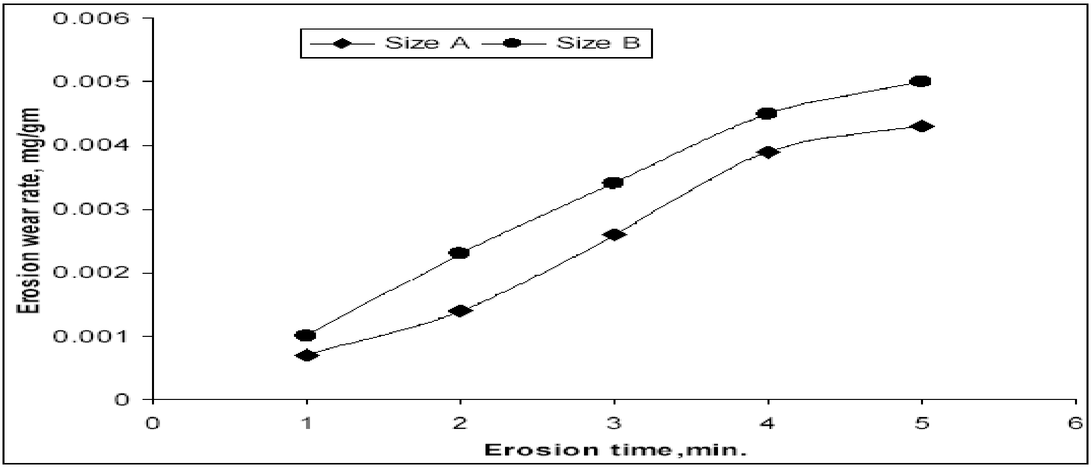

Fig. 4. Erosion wear rate for 150 SOD, 30º impact angle and at 40m/sec. impact velocity. A = +75-106 and B = +53-75 micron size raw material (fly ash).

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