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Tribological Behaviour of Plasma Sprayed Redmud-Flyash Coatings

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ABSTRACT

Plasma sprayed composite coatings are widely used as wear resistant coatings on a variety of metallic substrates. In spite of all advantages this process finds limited applications due to the high cost of the spray grade powders. The present investigation deals with wear behavior of a 300-micrometer thick coating deposited on Al substrate by Atmospheric Plasma Spraying (APS). The coating material employed are, two abundantly available industrial wastes, *redmud* and *flyash* mixed in a ratio of 2:1. Wear test were carried out under applied normal force of 15 N, with three different sliding speeds 0.5, 1.0 and 1.5 m/sec and at atmospheric condition (25^0 C, 60%RH) using a pin-on-disc tribometer.

Keywords: *Sliding Wear, Plasma Spraying, Coatings, Red mud, Fly ash, Pin on disc test*

INTRODUCTION

In industries, mechanical components have to operate under severe conditions such as high load, speed or temperature and hostile chemical environment. Thus their surface modification is necessary in order to protect them from various types of degradation. Ceramic coatings produced by thermal spray techniques are widely used for a range of industrial applications to confer wear and erosion resistance, corrosion protection and thermal insulation [1,2,3,4]. Thermal spraying belongs to a class of semi-molten state coating technique. Plasma spraying is one such route that involves projection of selected powder particles into the area of high thermal density, where they are melted, accelerated and directed on to the substrate surface [4]. Coatings are formed by the immediate solidification of the molten droplets on the substrate surface of lower temperature where they form splats. Oxide ceramics such as Alumina, Zirconia, Titinia, Chromia, Silica, Yittria have been used widely as surface coating materials to improve wear, erosion, cavitations, fretting and corrosion resistance [5,6]. Despite all the advantages plasma spraying has not been that much attractive, mostly because of the high cost of spray grade powders required for coating. This problem can be addressed to by exploring the use of some cheaper coating materials.

In the present work, *redmud* and *flyash*, two abundantly available industrial wastes were taken as the materials to be coated on metal substrates via Atmospheric Plasma Spraying (APS) technique and the influence of the torch operating power on the sliding characteristics of these coatings was examined. Literatures are available on coatability of red mud, fly ash and redmud-flyash mixture [7,8,9], but nothing so far has been reported on the tribological behaviour of these coatings. Operating power level is an important deposition parameter that essentially affects the microstructure of the plasma sprayed coatings and consequently their tribological characteristics. Plasma sprayed coatings are often used to restore dimensions of worn or damaged components. Hence a more detailed understanding of the effect of this deposition parameter on wear properties of plasma sprayed coatings is desirable.

EXPERIMENTAL

Plasma Spraying

Plasma sprayed coatings of redmud-flyash mixture in the ratio 2:1 (by weight) on aluminium substrates were prepared using a 40kW atmospheric plasma spray system at the Laser & Plasma Tech. Division, BARC, Mumbai. Red mud is the waste produced during alumina production following Bayer’s Process. Similarly fly ash is the waste produced in large quantity in all coal based thermal power plants. These powders were collected from National Aluminium Co. (NALCO) sites at Damanjori and Angul in Orissa state. The chemical analysis of both red mud and fly ash show Fe_2O_3, Al_2O_3, TiO_2 and SiO_2 as their major constituents. The set up used for coating deposition works in the non-transferred arc mode. A current regulated DC supply was used. A four stage centrifugal pump at a pressure of 10kg/cm^2 supplied cooling water for the system. Argon and Nitrogen taken from normal cylinders at an outlet pressure of 4kg/cm^2, were used as plasma gas and carrier gas respectively. Prior to coating,l the substrates were vapour greased, grit blasted to get the required surface roughness and subsequently cleaned with acetone. Surface roughness of these grit blasted substrates was measured to be 6.8 micron Ra. The powder feed rate was kept constant at about 10.0gm/min. The operating parameters used in the experiment are presented in Table 1.

Parameter	*Range*
Operating Power (kW)	6-16
Current (Amps)	150-400
Voltage (V)	30-40
Primary Plasma gas (Argon) flow rate (lpm)	20
Secondary gas (Nitrogen) flow rate (lpm)	2
Torch to base distance (mm)	100
Powder feed rate (g/min)	10
Powder carrier gas (Argon) flow rate (lpm)	6

Table 1: Operating parameters for plasma spraying of redmud-flyash composite powder

Tribological Testing

To evaluate the performance of redmud-flyash coatings under sliding wear conditions, they were subjected to pin-on-disc wear tests, as per ASTM G99. These tests were carried out on as-sprayed coated specimens (i.e., without any post treatment), using an EEE pin-on-disc wear monitor and the wear magnitude was assessed on a “mass loss” basis. In this particular setup the pin consisted of flat coated-specimens, which were slid against the counter body i.e. a disc of hardened ground steel (EN-32, hardness 65 HRC, surface roughness 0.5 micrometer Ra). Normal force was applied through a lever mechanism. Three series of tests were performed with sliding speeds of 0.5, 1.0 and 1.5 m/sec under atmospheric condition (25^{o}C, 60 % RH). The wear tests were continued up to a total sliding distance of 1 km. After the test, the weight loss suffered by the pins were measured using electronic weighing balance having an accuracy of ± 0.1 mg, and this loss was taken as the wear loss. During the wear tests, the tangential force was also continuously monitored and hence the coefficient of friction (μ) could also be measured.

Micro structural Observation

A Jeol T-330 Scanning Electron Microscope was employed for the micro structural observations. The phase composition of the coating was identified by Phillips X-ray Diffractometer using Cu Kα radiation.

RESULTS AND DISCUSSION

Analysis of the raw material with a Laser Particle Size Analyzer (make: MALVERN) revealed that the particle size varies between 50-110 microns for red mud, 40-150 microns for flyash and between 50-130 microns in case of plasma processed material. However the larger fraction of particles are of average size of 100 microns.

XRD was done to identify the phases present in the raw material as well as in plasma sprayed samples. A Phillips X-ray Diffractometer with Ni filtered Cu Kα radiation was used for the purpose. It was seen that Fe_2O_3 (Hematite), SiO_2 (Cristobalite), TiO_2 (Rutile), Al_2O_3 (Alumina) are the major phases/constituents present in the raw material. Along with all these phases Fe_3O_4 (Magnetite) and $2Al_2O_3.SiO_2$ (Mullite) are found in the coatings. This envisages that during plasma spraying Fe_2O_3 has transformed to Fe_3O_4 and some amount of Al_2O_3 and SiO_2 have combined to form Mullite.

Hardness measurement at the polished crossection of the coated samples was done using Leitz Micro-hardness tester with a load of 0.49N on the coating. Different hardness values were recorded and that is due to the presence of different phases as identified from XRD. The maximum values of hardness for coatings deposited at different power levels are plotted in Fig.1. The coating hardness was found to vary significantly with the operating power level and the maximum value recorded was 930 HV for the coating deposited at 12kW power level.

The cumulative wear losses of the coatings with the sliding distance for three different sliding velocities are presented in Fig.2 (a) (b) and (c). Each of these figures illustrates two distinguished stages, characteristic for different wear mechanisms. In the initial stage the wear rate is rapid, which later becomes steadier after a certain sliding distance. This is a situation of “break in”. In the subsequent stage, the relatively steady wear rate can be attributed to the fact that contact area does not change much with the sliding distance. In case of the first stage, taking into account the stratified structure of the coating and the expected similarity of the topography between the top surface and the inter-lamellar interfaces, it can be concluded that wear takes place by the adhesion mechanism, due to shear stresses developed between the hard asperities of the two surfaces in contact. After the initial "break in" effect wear rate remains almost constant for the coatings deposited at all power levels. The duration of this stage extends till the end of the tests.

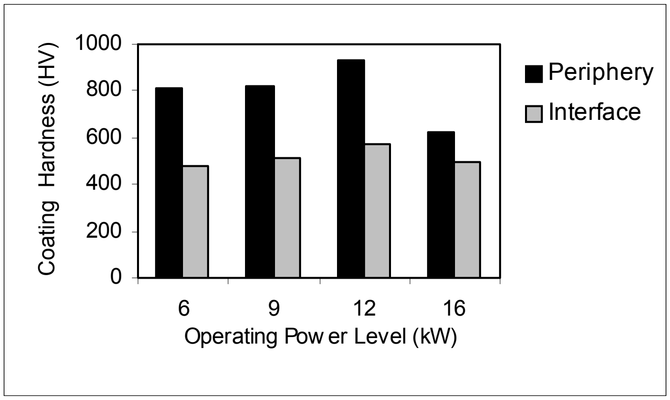

Fig. 1. Coating Hardness at Different Operating Power

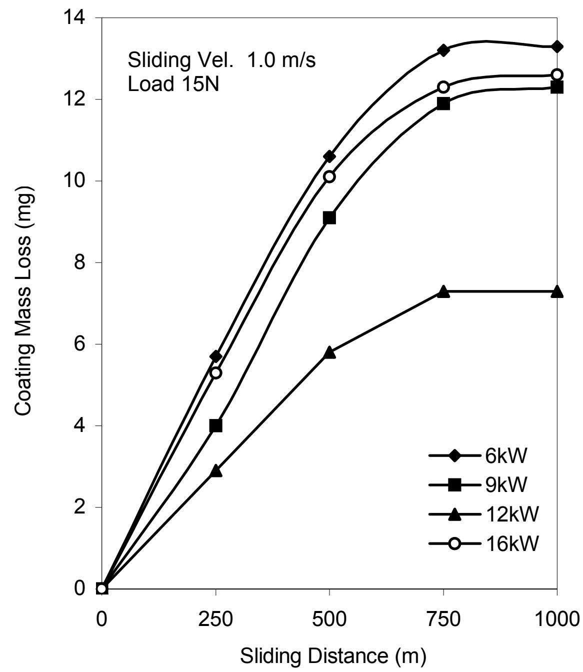

Fig. 2(b) Coating Wear (Mass Loss) Vs. Sliding Distance at velocity 1.0 m/s

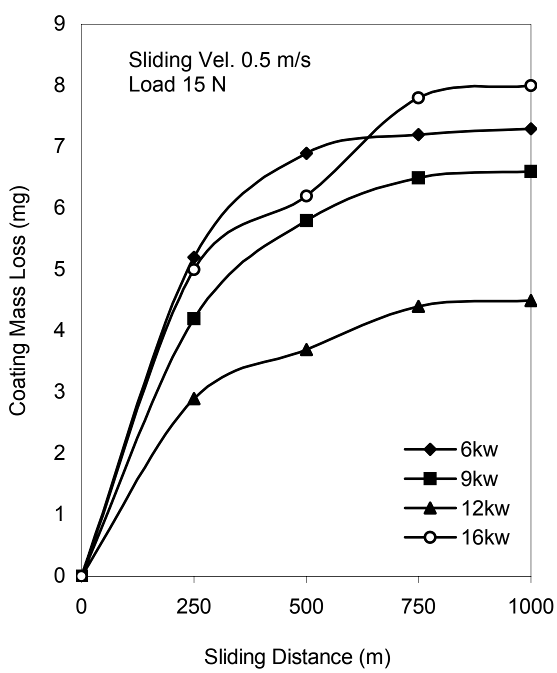

Fig.2 (a) Coating Wear (mass loss) Vs. Sliding Distance at velocity 0.5 m/s.

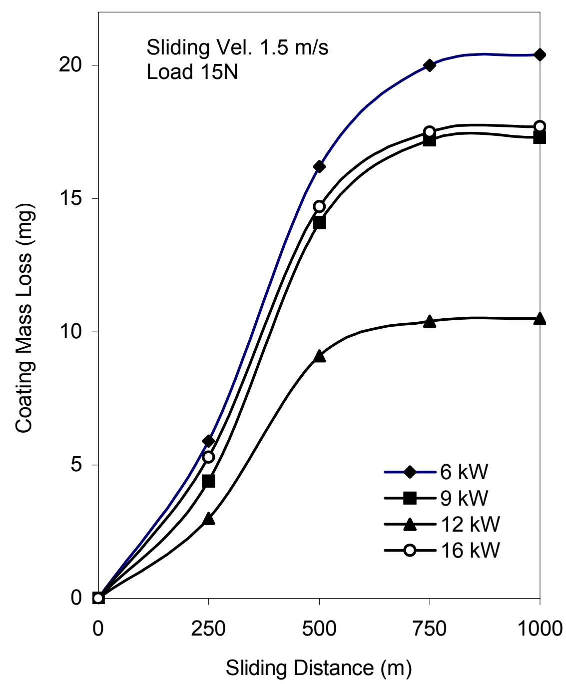

Fig. 2(c) Coating Wear (Mass Loss) Vs. Sliding Distance at velocity 1.5 m/s

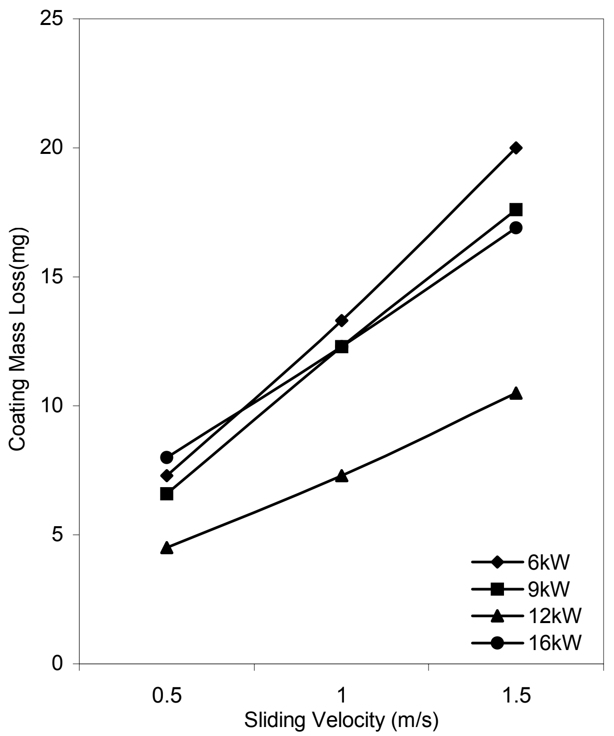

Fig.3 Variation in Wear Loss with Sliding Velocity

Fig. 3 presents the influence of sliding velocity on the wear loss of the coatings. It was seen that the mass loss increased significantly with the increment in the sliding velocity. The magnitude of wear was found to be minimum for the coating deposited at an operating power of 12 kW.

It was observed invariably in all cases that the wear rate was minimum for the coating deposited at 12kW power level. The SEM microstructure of this coating (Fig.4) shows high degree of homogeneity. Incidentally the coating adhesion strength and hardness both were also found to be maximum at this power level.

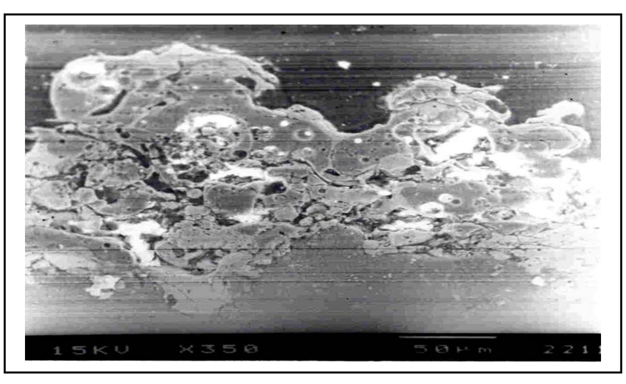

Fig.4 Interface morphology of Coating made at 12kW

The maximum value of coefficient of friction (μ = 0.47) is obtained with the coatings made at 12 KW power level and minimum (μ = 0.24) with 16 kW power level which may be due to coating homogeneity and amount of porosity in the respective coatings.

CONCLUSIONS

Redmud-flyash mixture was found to have fairly good coatabilty on metallic substrates. The coating quality is affected appreciably by a number of variables including the operating power of the plasma torch. Maximum hardness of these coatings was found to be as high as 930 HV. This value is quite encouraging for recommending its use in wear resistance applications. The trend of coating mass loss due to wear by sliding it against a hardened steel counter body was studied. At the initial stage, the wear rate was found to vary rapidly and the wear mechanism is predominantly adhesive. Once the "break in" was reached the wear loss happened to be steadier and subsequently in the later stage, wear rate remained almost constant, the nature of wear becoming abrasive. This led to formation of small sized debris. A maximum value of 0.47 recorded for the coefficient of friction implies that these coatings can be gainfully used in tribological applications.

REFERENCES

1. K.G.Budinski, Surface Engineering for Wear Resistance, Prentice Hall,NJ,1988.

2. M.K.Hobbs, H.reiter, Residual Stresses in ZrO_2 – 8%Y_2O_3 Plasma Sprayed Thermal Barrier Coatings,in: D.L . Houck (Ed.),Thermal Spray: Advances in CoatingsTechnology, ASM International,1989,pp.285-290.

3. H.Herman,C.C.Berndt,H.Wang, Plasma Sprayed Ceramic Coatings, in: J.B. Watchman , R.A. Haber (Eds.),Ceramic Films and Coatings, NJ, 1993.

4. Lech Pawlowski, *The Science and Engineering of Thermal Spray Coatings*, John Wiley and Sons. New York, (1995)

5. J. Knuuttila, S. Ahmaniemi, E. Leivo, P. Sorsa, P. Vuoristo, T. Mantylat, Wet abrasion and slurry

erosion resistance of sealed oxide coatings, Proceedings of the 15th International Thermal spray conference, Vol. 1, 25-29 May 1998, Nice, France, pp.145-150.

6. A.Giroud, C. Jouanny, J.L. Heuze, F. Gaillard, P. Guiraldenq, Friction and corrosion behavior of different ceramic coatings (oxides) obtained by thermal spray for qualification tests in seawater, Proceedings of the 15th International Thermal spray conference, Vol. 1, 25-29 May 1998, Nice, France, pp.211-216

7. S. C. Mishra and P. V. Ananthapadmanabhan "Use of Fly-Ash for Plasma Sprayed Ceramic Coatings"- Proceedings of The National Seminar on Fly Ash 1998, NML, CSIR, Jamshedpur .

8. S. C. Mishra, "Plasma Processing of Mineral and Industrial Wastes" - Proceedings of DAE – BRNS Symposium on Power Beams and Material Processing PBAMP 2002, BARC, Mumbai , pp-271-278.

9. S.C. Mishra, Alok Satapathy, K.P. Sreekumar, P.V.Ananthapadmanabhan "Plasma Spray Coating of Red mud on Metals" – proceedings of DAE-BRNS symposium on Power Beams and Material Processing, B.A.R.C. , Mumbai pp-369-372.