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Coatability and Characterization of Fly Ash Deposited on Mild Steel by Detonation Spraying

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Recently, considerable emphasis has been placed on the processing of low-grade ore minerals through thermal spray techniques. In the present investigation, the suitability of detonation spray system for coating fly ash onto a mild steel substrate has been demonstrated. Resultant coatings are 2-3 times harder than the substrate material and also exhibit a 3-fold reduction in coefficient of friction under sliding wear conditions. However, these coatings exhibit poor sliding wear resistance.

Keywords detonation spraying, fly ash, friction coefficient, wear resistance

1. Introduction

Among the currently available coating processes, the thermal spray technique has gradually emerged as the most versatile method capable of depositing a wide range of materials on an equally wide range of substrate materials.[1-3] Among the thermal spray coating techniques available commercially, the detonation spray coating (DSC) technique has long retained a preeminent position as a process to produce hard, dense, and wear-resistant coatings.[4-6] Unlike many of the more recently developed high velocity oxygen fuel (HVOF) coating processes, the DSC process has the ability to deposit ceramic coatings as well.[7-9]

Fly ash, the waste generated by thermal (fossil fuel burning) power plants in ever-increasing quantities, is posing an environmental threat and also a disposal problem since adequate avenues for its utilization are not currently available. As a result, fly ash is available free of cost and presents itself as an attractive feed stock material for DSC coating, provided that spray performance and coating performance are acceptable. In this context, Mishra et al.[10] have recently used the plasma spray coating technique to obtain coatings of fly ash mixed with 5-15 wt.% Al powder on stainless steel substrates. Their results indicate that plasma sprayed fly ash + Al coatings had adhesion strength up to 50 MPa.

The main objective of the present work is to evaluate the feasibility of fly ash as the feed stock material for DSC on mild steel substrates.

2. Experimental Details

Fly ash collected from the thermal power plant of National Thermal Power Corporation located in Andhra Pradesh, India was used as the feed stock material. The scanning electron microscope (SEM) image of the fly ash particles is presented in Fig. 1 and the particle size distribution as determined using a laser diffraction particle size analyzer (CILAS 920) is shown in Table 1. It is clear that fly ash is composed of both very fine (a few micrometers in size) and coarse particles (10-20 μm size), with a mean size around 5.5 μm. An x-ray fluorescence (XRF) (Philips, 2400, Almelo, The Netherlands) analysis of the fly ash powder revealed the composition (wt.%) as 58.02% SiO_2, 27.77% Al_2O_3, 5.14% Fe_2O_3, 3.99% CaO, 1.76% TiO_2, 1.09% MgO, 1.29% K_2O, 0.56% Na_2O, and traces of Cr_2O_3, P_2O_5 and MnO_2.

Mild steel (≈0.25% C) samples were used as the substrate. Prior to coating with fly ash, the samples were vapor degreased, grit blasted (with alumina grits), and subsequently cleaned with acetone in an ultrasonic cleaner.

An Indian-made DSC system was used to deposit the fly ash coatings on mild steel substrates. Among the DSC process variables, the shot frequency and spray distance were kept constant during the present experiments at 3 shots per second and 150 mm, respectively. Experiments were carried out at two oxygen to acetylene ratios (called OF ratio) namely 1:1.73 and 1:1.54. At both the OF ratios, DSC coating was carried out till the fly ash coating thickness, as measured using an eddy current thickness gauge, reached a value of 275 μm (±10%).

3. Results and Discussion

An SEM micrograph of the fly ash coatings deposited on mild steel substrates using the DSC process is shown in Fig. 2. Figure 2(a) and (b) corresponds to the coatings obtained using OF ratios of 1:1.73 (referred to as coating I) and 1:1.54 (coating II), respectively. The first point to be noted is that DSC is capable of depositing fly ash particles to form a thick, dense, and adherent coating on the mild steel substrate. Both coatings I and II exhibit negligible porosity (the black regions in the coatings are probably pullouts generated during metallographic polishing), and their interface with the substrate is clean and free of cracks.

X-ray diffraction (XRD) analysis of the coatings (I and II) indicate that the phases originally present in the fly ash powder

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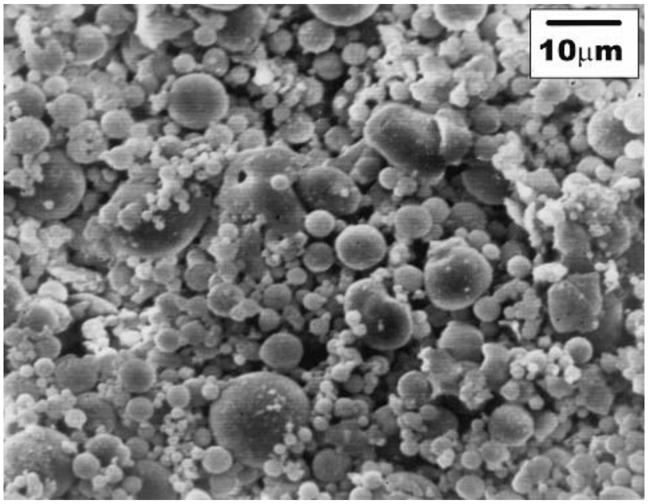

Fig. 1 SEM micrograph of fly ash particles

Table 1 Fly Ash Particle Size Distribution

Nomenclature	Size, μm
Median size	5.56
Diameter at 10%	0.88
Diameter at 90%	16.91

(i.e., SiO_2, Al_2O_3, Fe_2O_3, CaO, TiO_2, MgO) are no longer present, having transformed to complex phases that did not match with the known and documented phases.

The hardness values of the fly ash coatings (I and II), determined using a Vickers indentor and at a load of 100 gf, are compared with that of the mild steel substrate in Fig. 3. It is clear that fly ash coatings are substantially harder (HV 430-470) than mild steel (HV 170). However, the hardness values of fly ash coatings are substantially lower than the hardness of alumina coatings (around HV 1000) obtained using DSC. This is due to the fact that fly ash contains only 28% Al_2O_3.

To evaluate the performance of fly ash coatings under sliding wear conditions, they were subjected to pin-on-disk wear tests, as per ASTM G99. The mild steel pins (diameter: 6 mm; length: 30 mm) were coated with fly ash using DSC and then slid against a WC-10.5%Co coated steel disc having a hardness of around HV 1300. The nominal applied stress and the linear sliding velocities were kept constant at values of 0.7 MPa and 3.4 m/s, respectively, during the wear test. The wear tests were continued up to a total sliding distance of 3 km. After the test, the weight loss suffered by the pin was measured using an electronic weighing balance having an accuracy of ±0.1 mg, and this weight 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.

In Fig. 4, the wear loss and the μ data with respect to the two fly ash coatings and mild steel are presented. It is clear that μ is reduced dramatically (from 0.7-0.26) due to the presence of fly ash coating. In contrast, the wear loss exhibited by the fly ash coated mild steel is comparable to that of uncoated mild steel as can be noted from Fig. 4. In fact, if the wear loss is compared on a "volume basis," the fly ash coated steel has poorer wear resistance than uncoated steel since the density of fly ash is considerably lower than the density of steel.

The above results can be rationalized on the basis that fly ash on coating transforms to the mullite based (the inter oxide of silica and alumina) phase plus the glassy phase (as fly ash contains CaO, K_2O, and Na_2O phases). Such a glassy phase, usually brittle, can result in low friction coefficient in conjunction with poor wear resistance.

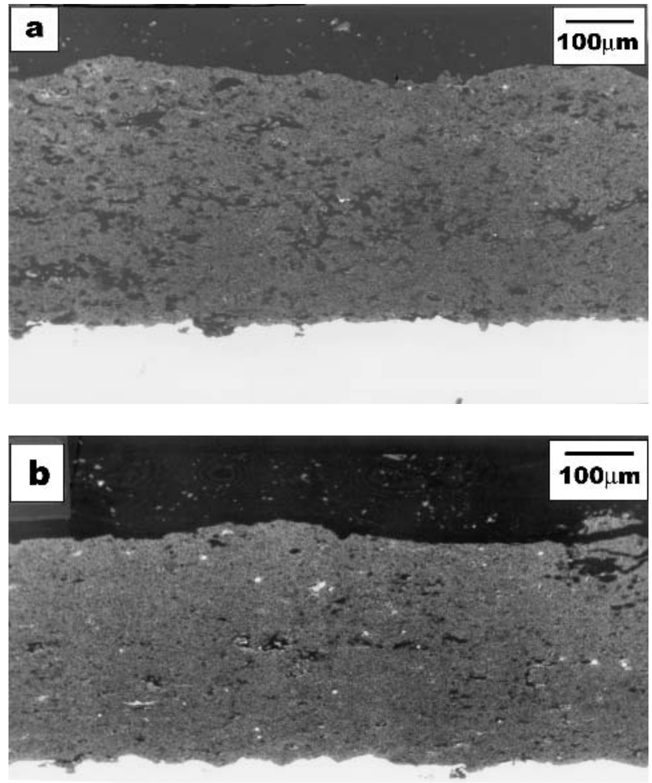

Fig. 2 SEM micrographs of **(a)** coating-I and **(b)** coating-II

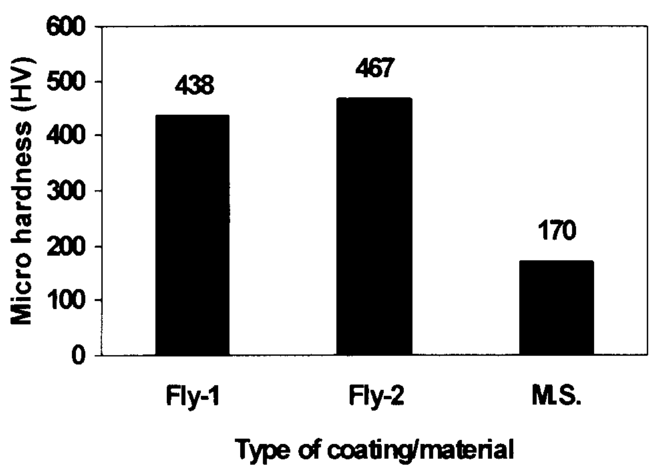

Fig. 3 Microhardness of fly ash coatings in comparison with mild steel

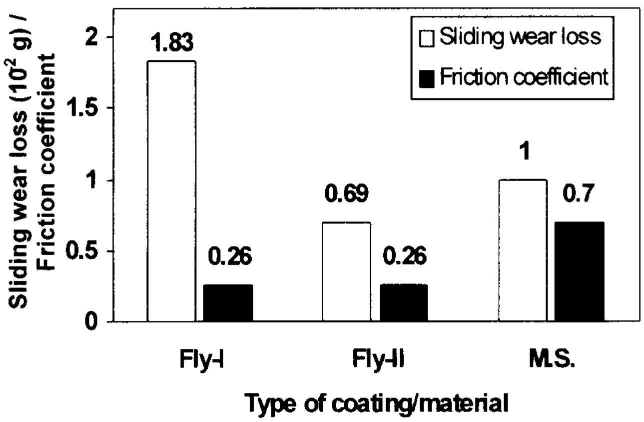

Fig. 4 Wear loss and friction coefficient of fly ash coatings in comparison with uncoated mild steel when slid against WC-Co coated discs

4. Conclusions

Though fly ash is eminently coatable utilizing the DSC process, the resulting coatings do not have adequate properties to be commercially attractive. In the future, the possibility of enhancing the wear resistance of fly ash coatings through additions of Al_2O_3, TiO_2, etc., will be explored.

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