Effect of Erodent on Erosion Wear of Fly Ash-Illmenite Coating

S. C. Mishra*, S. Das[1], H. K. Nayak*, P.V.Ananthapadmanabhan[2]

Abstract

In the present piece of research work, plasma sprayed coatings of fly ash-illmenite is deposited on mild steel substrate using a 40 kW atmospheric plasma spray system. Solid particle erosion tests are conducted at three different impact angles (i.e. at 30°, 60°and at 90°) using dry silica sand and silicon carbide as erodent. It is observed that, erosion rate is mainly dependant on angle of attack. The rate of erosion is also affected by the type of erodent. Microstructural observations reveal that the coating removal is mainly by chipping/plowing type mechanism at low impact angles. At higher impact angles (i.e. at 60° & 90°) the erosion wear behavior is as of the brittle material.

Keywords: plasma spray coating, erosion wear, fly ash, illmenite

* National Institute of Technology, Rourkela, India, 1. Metallurgical Eng Dept., IIT, Kharagpur. 2. Laser & Plasma Technology Division, B. A. R. C., Mumbai, India.
*Corresponding author: subash.mishra@gmail.com

Introduction

Thermal spraying allows the production of overlay protective coatings of a great variety of materials, almost without limitations as to its components, phases and constituents on a range of substrates. Wear and corrosion resistant coatings account for significant utilization of thermal spray processes; however, erosion resistance is the less studied part of thermal sprayed ceramic coatings. Nevertheless, the relationship between the erosion behavior of thermal sprayed coatings and its microstructural features is not satisfactorily understood yet. Owing to the high hardness and high temperature performance plasma-sprayed ceramic coatings have been widely employed to provide an improved wear resistance to various industrial parts [1-5]. The applications of plasma-sprayed ceramic coatings on machine components/structural components/structures etc. operating in a dusty/sandy/desert type environment, erosion wear behavior of the surface is of particular interests [6-9]. This is because the erosion by impact of solid particles entrained is a major life-limiting constraint in many industrial environments. Solid particle erosion is a wear process where particles strike against a surface and promote material loss. During flight, a particle carries momentum and kinetic energy, which can be 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 their erosion behavior has been mostly based on experimental data's [10]. The erosion of the ceramic coating may be influenced by both coating properties and impacting particle conditions including its size and morphology, velocity, incident angle and materials properties in a similar way to that of bulk materials [11]. In this paper erosion tests were carried out, on plasma sprayed of fly ash-illmenite coatings with a stream of dry silica sand with an average particle size range of ~400 μm and with silicon carbide particles of average size of ~ 200 μm; at different impact angles (30^0, 60^0& 90^0), with stand of distance of 150mm (i.e. exit point of the erodent form the nozzle to the specimen/substrate) and at a velocity of 58m/sec.

Experimental

Plasma sprayed coatings of fly ash-illmenite are deposited on metal substrate (i.e. mild steel) using a 40 kW atmospheric plasma spray system, at various power levels of the plasma torch. The coatings are eroded at different impact angles (i.e. at 30^0, 60^0& 90^0) at stand of distance of 150mm; and at a pressure of 6.5kgf/cm^2 (i.e. at a velocity of 58m/sec) with dry silica sand of 400 µm sizes and silicon carbide erodent of 200 µm sizes. Amount of wear is determined on 'mass loss' basis [12, 13]. It is done by measuring the weight change of the samples at regular time intervals during the test duration.

Results and Discussion

Erosion rate, defined as the coating mass loss per unit erodent mass (gm/gm) is calculated. The variation of cumulative mass loss with time, in case of the coating eroded by sand is illustrated in **Fig.1** and in case of the coating eroded by SiC is illustrated in **Fig.2**.

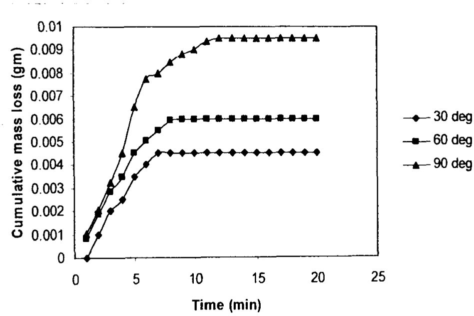


Fig.1. Variation of Coating mass loss with time, for 400 µm size (dry silica sand) erodent.

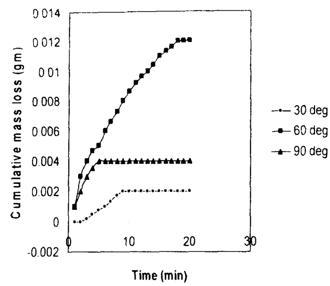


Fig.2. Variation of Coating mass loss with time; for 200 μm size (SiC) erodent.

From the figures it is seen that, the coating mass loss increases with increasing the time of attack. The cumulative increment in material loss due to erosion wear of plasma sprayed coatings with time and erodent dose has been studied by Levy [14]. In the present work such a trend is also found in case of all coatings, subjected to erosion test irrespective of angle of impact. This can be attributed to the fact that, the fine protrusions on the top layer of the coatings may be relatively loose and removed with less energy than what would be necessary to remove a similar portion/layer from the bulk of the coating at further time length. Consequently, the initial wear rate is high. With increasing exposure time the rate of wear starts decreasing and in the transient regime, a steady state in the wear rate is obtained.

The variation of erosion rate with time at impact angles of 30^0, 60^0 and 90^0, eroded with 400 μm size silica sand is shown in **Fig.3** and for the sample eroded with 200 μm size silicon carbide erodent is shown in **Fig.4**.

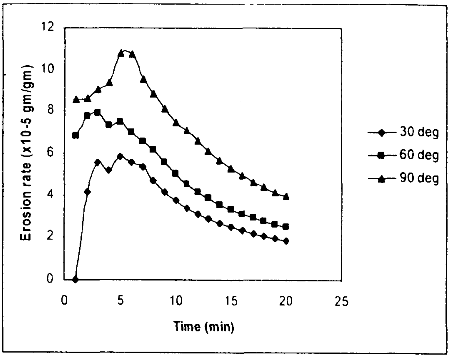


Fig.3. Variation of Erosion rate with time for the sample eroded with sand.

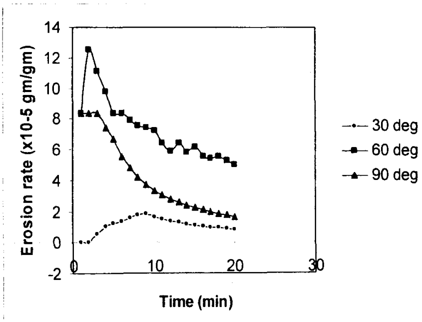


Fig.4. Variation of Erosion rate with time for the sample eroded with silicon carbide.

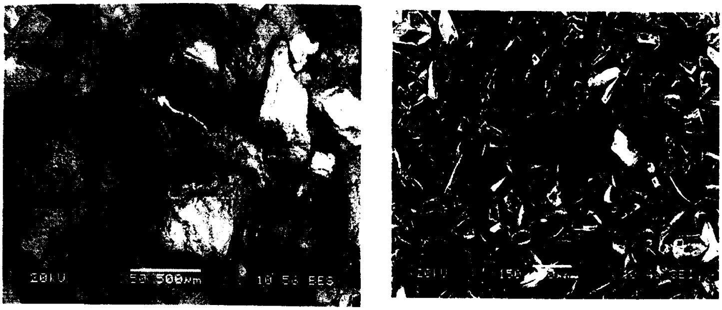
From the above figures it is observed that, the erosion rate increases with increasing the angle of impact and maximum erosion takes place at $\alpha = 90^0$, when eroded by sand; and $\alpha = 60^0$ when eroded by SiC. Similar to this, a difference in maximum erosion rate was observed in glass [16]. They have also observed the maximum erosion rate at 90° when eroded by sand and 30° when eroded by silicon carbide. Studies on the effect of the incidence angle on the erosion rate on brittle materials show that, the maximum erosion takes place at normal impact angle where as in case of ductile materials; the material removal is by plastic deformation and reaches its maximum rate at shallow impact angles [17]. According to the common rule of the erosion rate with the change of impact angle α, the erosion wear can be divided into plastic material wear and brittle material wear. The relationship [15] between erosion rate and impact angle is

$$E = A\cos^2 \alpha \sin (m\alpha) + B \sin^2 \alpha$$

Where m, A and B are constants.

For typical brittle material, A is equal to zero and the erosion rate is largest at 90^0 impact angle. For typical plastic material, B is equal to zero and the erosion rate is largest at $20–30^0$ impact angle. From the above, the erosion behavior of the fly ash-illmenite coating deposited at 15kW eroded by sand is like the behavior of brittle material. But, the coating eroded by SiC erodent shows some amount of plastically deformed regions and hence maximum amount of material removal occurred at 60^0 angle of impact. According to I.M. Hutchings, the transition in the erosion mechanism from plastic deformation to brittle fracture was explained by the necessary collision energy of the particle to reach a certain threshold [18]. He had proposed the dimensionless expression (K^2_{CT} /r.$H_T{}^2$), in which 'r' is the radius of the particle, can be used to determine the nature of the dominant erosion mechanism. A lower value of this expression is indicative of brittle fracture. To describe the nature and the mechanism of erosion of different materials, other authors have argued for a new parameter known as the erosion efficiency η, defined as: $\eta = 2Er.H/\rho V^2$,where Er is the erosion rate, H the hardness, ρ the density of the specimen and V be the velocity at impact [19].

The morphology of the erodent is shown in **Fig. 5**. It can be visualized that, the sand particles are mostly spherical or rounded/equiaxed in shape with cleavage/quasi-cleavage edges, as observed in **Fig.5 (a)**; while silicon carbide particles are having multiple angular facets and sharp edges, as seen in **Fig.5(b)**.

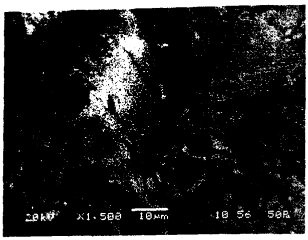


(a) **(b)**

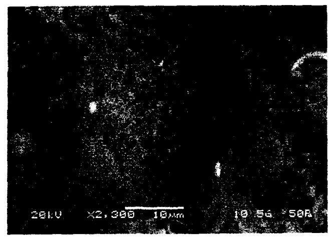
Fig.5. surface morphology of (a) dry silica sand and (b) silicon carbide erodent.

So there is no crack formation than minor chipping is observed. This might be the cause of fast rate of removal of material through chipping/plowing of the surface when silicon carbide is used as erodent there by leading to higher amount of material loss (i.e. cumulative mass loss). Hence erosion rate is higher when SiC is used.

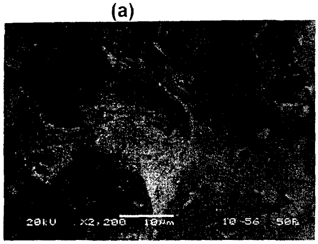
Surface morphology of fly ash-illmenite coating after being eroded at different impact angle is shown in fig.6. In **Fig.6 (a)** the worn surface morphology of fly ash-illmenite coating when the erodent is impacted at 90^0 and the erosion rate is higher in this condition. As described by Maozhong [20], during normal impacting of the erodent particles, the surface of the coating endures Hertz force, partial plastic deformation takes place and cracks initiate. The cracks propagate through the grain boundaries. And then the flattened grains on the coating surface loose and eventually fall off by repeated impact. **Fig.6 (b)** show the surface morphology of worn surface when the erodent is impacted at 30^0. Chipping away of layers/plowing caused by shear component of erodent particles play the principal role and hence more cavities are formed. Some cracks are observed and appears to have originated and spread along grains/splats boundaries. **Fig.6 (c)** exhibit the morphology of worn surface when erodent is impacted at 60^0. It is clearly seen that the traces of chipping/plowing are not as shallow and flat as is at 30^0 impact angle and the cracks are not as remarkable as those at 90^0. So, erosion at 60^0 is somewhere in between that at 30^0 and 90^0 impingement angle.



(a)



(b)



(c)

Fig.6. Micrographs of eroded surfaces of coatings for (a) 90^0 angle of impact; (b) 30^0 and (c) for 60^0 angle of impact.

Conclusions

The erosion rate is minimum at 30^0 angle of impact and is maximum at 90^0 when silica sand is used as erodent. Using silicon carbide as the erodent, the erosion wear is maximum at 60^0 impact angle the wear behavior of coating can be ascribed to that of a brittle material. The erosion wear rate of the coating is higher when eroded by SiC than that of by silica sand , which may be due not only to the morphology/structure but also to the hardness of the erodent material. The mechanism of erosion wear at 90^0 impact angle is that, the abrasive particles impact and extrude the surface of the coatings and produce indentations and extruded lips. The lips become work hardened by repeated impact of the particles and eventually fall-off. Whereas when erodents impact at acute angles erosion wear is dominated due to micro-cutting, plowing and tunneling via pores and inter particle/grain boundaries.

References

1. Tucker R.C., (2002), Thermal spray coatings: broad and growing applications, Int. J. Powder Metall. 38, 45–53.
2. Westergard R., Erickson L.C., Axen N., Hawthorne H.M. and Hogmark S., (1998), The erosion and abrasion characteristics of alumina coatings plasma sprayed under different spraying conditions, Tribol. Int., 31, 271–279.
3. Toma D., Brandl W. and Marginean G., (2001), Wear and corrosion resistance of thermally sprayed cermet coatings, Surf. Coat. Technol. ,138, 149–158.
4. Fu Y.Q., Batchelor A.W., Wang Y. and Khor K.A., (1998), Fretting wear behaviors of thermal sprayed hydroxyapatite (HA) coating under unlubricated conditions, Wear, 217,132–139.
5. Liao H., Normand B. and Coddet C., (2000), Influence of coating microstructure on the abrasive wear resistance of WC/Co cermet coatings, Surf. Coat. Technol., 124, 235–242.
6. Arata A., Ohmori A.and Li C.J., (1986),Basic study on properties of plasma sprayed ceramic coatings, Trans. Jpn. Weld. Res. Inst. ,15, 339–348.
7. Lathabai S., Ottmuller M. and Fernandez I., (1998),Solid particle erosion behaviour of thermal sprayed ceramic, metallic and polymer coatings, Wear, 221, 93–108.
8. Westergard R., Axen N., Wiklund U. and Hogmark S., (2000),An evaluation of plasma sprayed ceramic coatings by erosion, abrasion and bend testing, Wear,246, 12–19.
9. Clark H.Mcl., Hawthorne H.M. and Xie Y., (1999), Wear rates and specific energies of some ceramic, cermet and metallic coatings determined in the Coriolis erosion tester, Wear,233–235, 319–327.
10. Roberto Josė, Branco Tavares, Gansert Robert, Sampath Sanjay, Berndt Christopher C., Herman Herbert, (2004), Solid Particle Erosion of Plasma Sprayed Ceramic Coatings. Materials Research,7(1),147-153.
11. Engel P.A., (1976), Impact Wear of Materials. Elsevier Scientific Publishing Company, Amsterdam
12. Nicholls J.R., Deakin M.J. , Rickerby D . S., (1999), A comparison between the erosion behaviour of thermal spray and electron beam physical vapour deposition thermal barrier coatings, Wear, 233–235,352–361.

13 Mishra S.B., Chandra K. , Prakash S., Venkataraman B., (2005), Characterisation and erosion behaviour of a plasma sprayed Ni_3Al coating on a Fe-based superalloy. Materials Letters, 59, 3694 – 3698.

14 Levy A. V., (1988), The erosion corrosion behavior of protective coatings. Surf. and Coating Technology,36,387 – 406.

15 Lishizhou, Dong XiangLin, (1987), Erosion wear and Fretting Wear of Materials (in Chinese), Publisher of Mechanical Industry, Beijing,

16 Chabane Bousbaa, Abderrahim Madjoubi,Mohamed Hamidouche, Nourredine Bouaouadja,, (2003) ,Effect of annealing and chemical strengthening on soda lime glass erosion wear by sand blasting. journal of European ceramic society,23 ,331-343.

17. Bousid, S. and Bouaouadja, N., (2000) Effects of impact angles on glass surface eroded by sand blasting,. J.Eur. Cer. Soc., 20(4), 481-488.

18. Hutchings, I. M., (1992), Tribology: Friction and Wear of Engineering Materials. Metallurgy & Material Science Series.

19. Manish, R., Vishwanathan, B. and Sundarajan, G., (1994), The solid particle of polymer matrix composites. Wear, 171, 149–161.

20. Yi Maozhong, Huang Baiyun and He Jiawen, (2002), Erosion wear behavior and model of abradable seal coating, Wear, 252, 9-15.