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Development of Ceramic Coating on Metal Substrate using Industrial Waste and Ore Minerals

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Abstract
The technological advancement in modern era has a boon for enlightening human life; but also is a bane to produce a huge amount of (industrial) wastes, which is of great concern for utilization and not to create environmental threats viz. polution etc. In the present piece of research work, attempts have been made to utilize fly ash (wastes of thermal power plants) and along with alumina bearing ore i.e. bauxite, for developing plasma spray ceramic coatings on metals. Fly ash and with 10 and 20% bauxite addition is used to deposit plasma spray coatings on a metal substrate. The surface morphology of the coatings deposited at different power levels of plasma spraying investigated through SEM and EDS analysis. The coating thickness is measured. The porosity levels of the coatings are evaluated. The coating hardness isalso measured. This piece of research work will be beneficial for future development and use of industrial waste and ore minerals for high-valued applications.

Keywords: Plasma Spraying; Industrial Wastes; Ceramic Coating

1. Introduction
Coal-fired thermal power stations generate vast quantities of fly ash as a by-product [1].In present years, fly ash is utilized for manufacture of cement, bricks, concrete, and tiles along with road embankment, mine filling and so forth [2]. Since last two decades, industrial wastes have been investigated for making high valued utilization [3, 4]. In this context fly ash; the waste of captive power plant and red mud, the waste of alumina companies are a subject for creating environmental threat and pollution. Some studies have already been made to use these wastes to develop plasma spray coatings [5,6]. It has been observed that, these coatings can be useful for wear resistant purpose of machine tool components and for thermal barrier applications [7-11].The present piece of research work is aimed at, not only to use an industrial waste but also addition of an ore mineral with the industrial waste and to evaluate its functionality and usefulness. Fly ash with 10% and 20% bauxite additions are plasma sprayed on metals to develop overlay coatings.

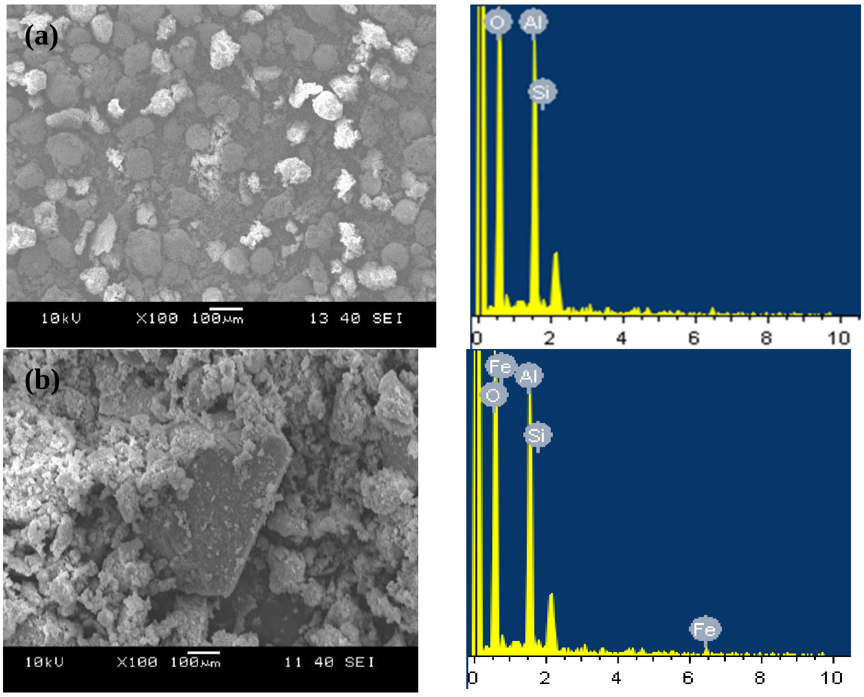
The use of Plasma spray coating is limited due to high cost of plasma spray grade powders. The objective of the present work is to develop a plasma spray ceramic coating on metal substrate using an industrial waste.

2. Materials and Methods
The raw material used are, fly ash from captive power plant of Rourkela Steel Plant (CPP-2) and bauxite ore obtained from National Aluminium Company (NALCO). Particle size analyses of both the materials

are done by sieve analysis. In case of fly ash, the particle size was ranging from 20 to 110 micron and most of the particle are in the range of 40-80 micron, where as in case of bauxite powder, although the particle are in the range of 20-90 micron but majority of particles are below 60 micron.
Apart from raw fly ash, the other two compositions are made by adding 10 and 20 wt. % of bauxite ore to the fly ash. Prior to plasma spraying the raw materials are mixed thoroughly. Compositional analysis of fly ash and bauxite ore fines were done by wet chemical analysis and given in the table 2.1.Loss on ignition values were calculated by heating the raw materials at 1000^0C for 1 hour.

Table 2.1Weight Chemical analysis of raw materials.

Raw materials	Constituents (Oxides) in Wt. %					LOI
	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO/K_2O etc.	
Fly ash	61.2	31.5	2.6	1.25	2.75	0.7
Bauxite	4.0	43.0	23.0	3.0	5.0	22.0



Element	Wt. %	At. %
O K	56.45	69.16
Al K	15.48	11.24
Si K	28.07	19.59

Element	Wt. %	At. %
O K	52.84	68.95
Al K	32.30	24.99
Si K	1.37	1.02
Fe L	13.50	5.05

Figure. 2.1 Scanning electron micrographs with EDS spectra of a) Fly ash and b) bauxite.

The substrate chosen for the spraying is copper plates having 3mm thickness and a cross sectional area of 25.4mm x 25.4 mm. The substrates were cleaned properly and were sand blasted to get a surface roughness of ~4.0 Ra. A non-transferred arc plasma torch was used for plasma spraying. The power levels maintained are 10, 12, 16 and 20 kW DC. Argon is used as the plasma forming gas, with a flow rate of 30 L/min and with nitrogen at a flow rate of 2 L/min. Argon was also used as carrier gas with a flow rate of 6 L/min. The powder feed rate was maintained at 10gm/min. Torch to substrate distance 70mm is maintained. The surface morphology was studied using JEOL (JSM-6480LV) scanning electron microscope. The coating thickness was measured on the polished cross section of the specimen with an optical microscope. The porosity of the coatings was evaluated using AXIO vision software. The micro hardness of the coatings was measured with Vickers hardness tester with a load of 50 gf and dwell time of 20 sec. (as per machine specifications).

3. Results and discussion

The fly ash coatings without bauxite addition made at different operating power levels of plasma gun i.e. 10 kW to 20 kW are shown in figure 3.1.

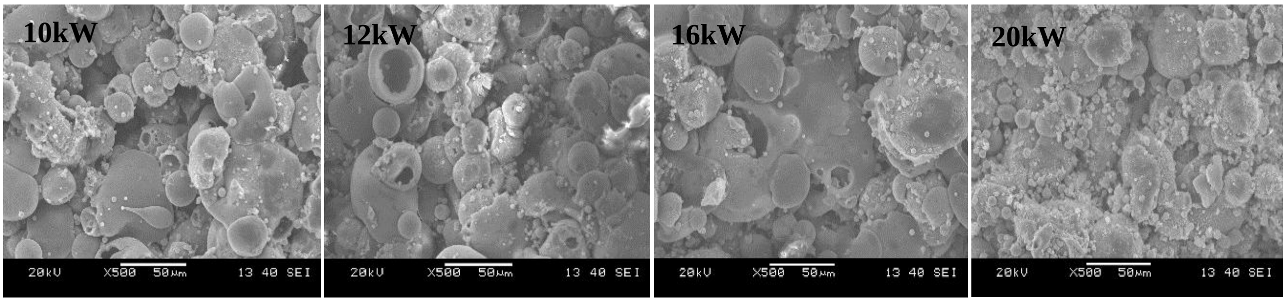


Figure 3.1 Scanning electron micrographs of fly ash coated samples

10, 12, 16 & 20 kW power level.

From the coatings it can be seen that, at lower power level there is a lot of porosity, though some semi-molten globular particles are observed. With increase in power level, the flatness on coating (surface) is observed i.e. the semi-molten particle adhere to each other. That's why showing flatten regions. With further increase in power level, although the globular particles are seen, the porosity level of the coating is reduced; but there are some small fragmentations of particles, observed on the spheroids bigger particles/masses. Whereas, further increase in power level i.e. at 20kW, although very small amount of fragmented particles are seen but there is an increase in porosity (as evidenced from figure 3.3). From the EDS analysis it is observed that, there is a variation in silicon, aluminum and oxygen content with varying the power levels.

Scanning electron micrographs of fly ash+10%Buxite coated samples 10, 12, 16 & 20 kW power levels are shown in figure.3.2.

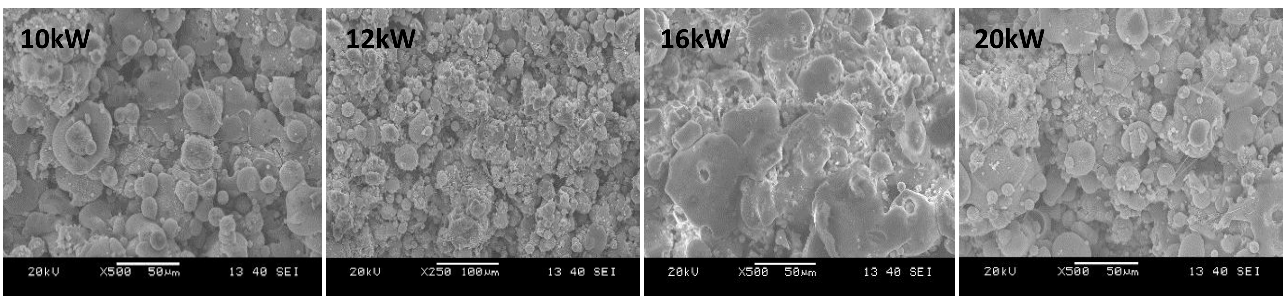


Figure 3.2 Scanning electron micrographs of fly ash coated samples

10, 12, 16 & 20 kW power level.

The surface morphology of coating is developed with 10% bauxite addition with fly ash as sheen in figure 3.2; similar type of observations is also made. Although the coating becomes denser with increase in power level, but flattening zone is more at 16kW than that of the coating deposited at 20kW. But at 20kW power level some small spherical particles are observed. It may be due to at high power level, fragmentations of particles have occurred and the small size particles are semi-molten and directly deposited. As because it a ceramic body, the temp zone at axial region of the plasma is in terms of few thousands of degree, whereas the flame end temp is of few hundred degrees. So quenching rate is very fast that's why small fragmented particles also got deposited at some regions. Also there is an increase in porosity level at 20kW power level. Similar types of observations are also noticed in case of coatings deposited with 20% Bauxite addition.

The porosity of the coatings was measured/evaluated using AXIO vision software is shown in Figure. 3.3.

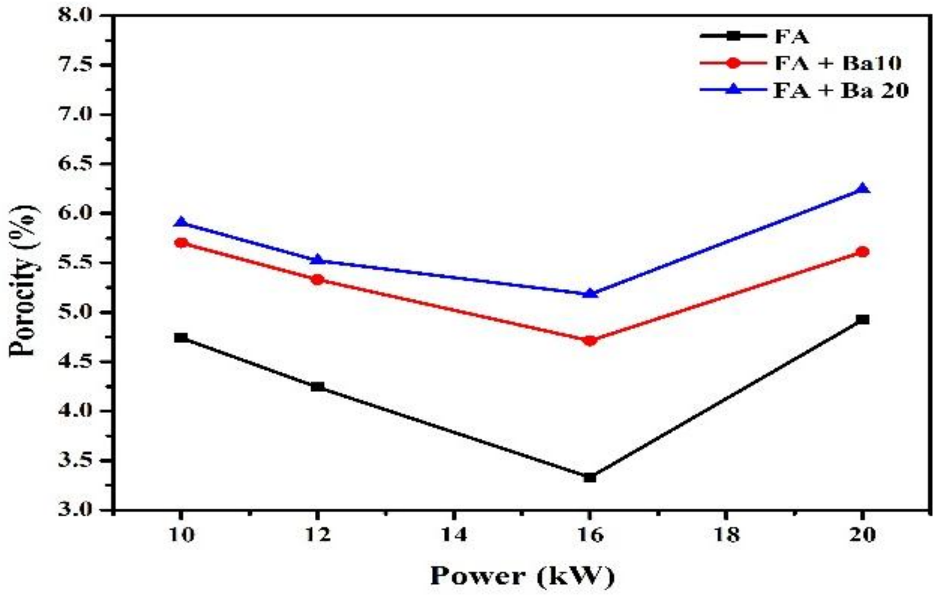


Figure.3.3 Porosity Comparison of Fly ash, Fly ash +Bauxite 10% and Fly ash + Bauxite 20% coatings made at different power levels.

From the figure, it is seen that the porosity level is minimum in case of fly ash coatings than that of bauxite added coatings. The minimum porosity is observed at 16 kW power level irrespective of compositions. With increase in bauxite content the porosity level is increasing. In all the coatings minimum porosity of about 3.4 % is observed, in case of fly ash coating and 4.75 % in case of 10% bauxite addition coatings. The addition of bauxite helps in in increasing the porosity level. It may be due to improper bonding between the particles during plasma spraying with addition of bauxite [5].

Coating is deposited for 30 seconds in all cases; the coating thicknesses of the substrates are measured and are shown in figure 3.4.

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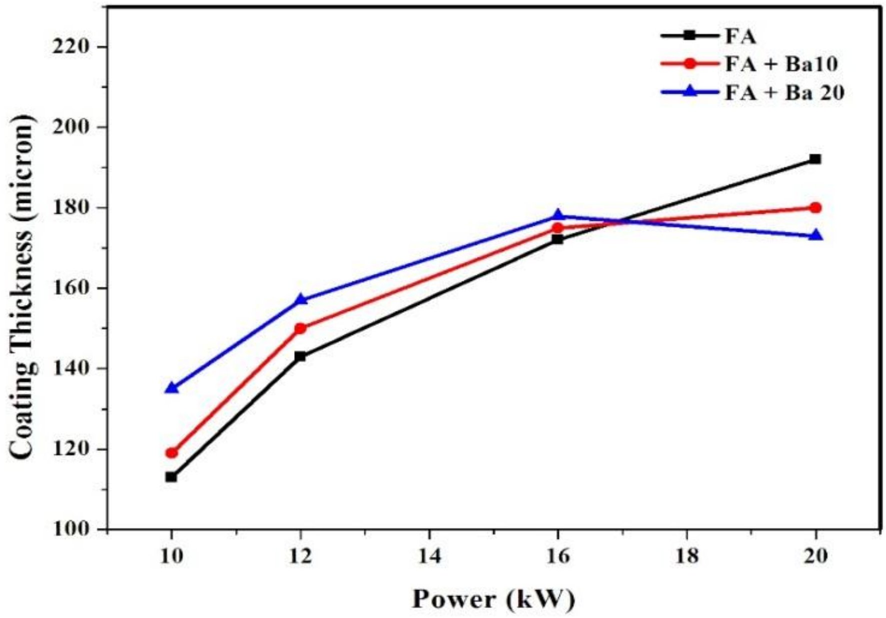

Figure. 3.4 Coating Thickness Comparison of Fly ash, Fly ash + Bauxite 10% and Fly ash + Bauxite 20% coatings made at different power levels.

Here, also similar things are observed that, addition of bauxite gives the higher/improved coating thickness. With 10% bauxite addition, the thickness is increased slightly and after 16 kW the rate of increase is less. When the bauxite addition is 20%, the thickness is further increased. It may be due to with higher amount of bauxite addition more alumino-silicate phase is forming which is helping in increasing the thickness where as in lower power level the particles are not able to form any complex phase. But after 16 kW power level the coating thickness is decreased. Whereas with only fly ash coating the coating thickness is increasing continuously with increase of power level and provides a maximum thickness of 192micron at 20 kW power level. It may be due to the fact that, at higher power level the high enthalpy plasma flame is favoring the melting of SiO_2/other oxides present, formed other/mixed compound phases which might give rise to a higher thickness [10].

Micro hardness of Fly ash, Fly ash + Bauxite 10% and Fly ash + Bauxite 20% at different power levels is shown in figure 3.5.

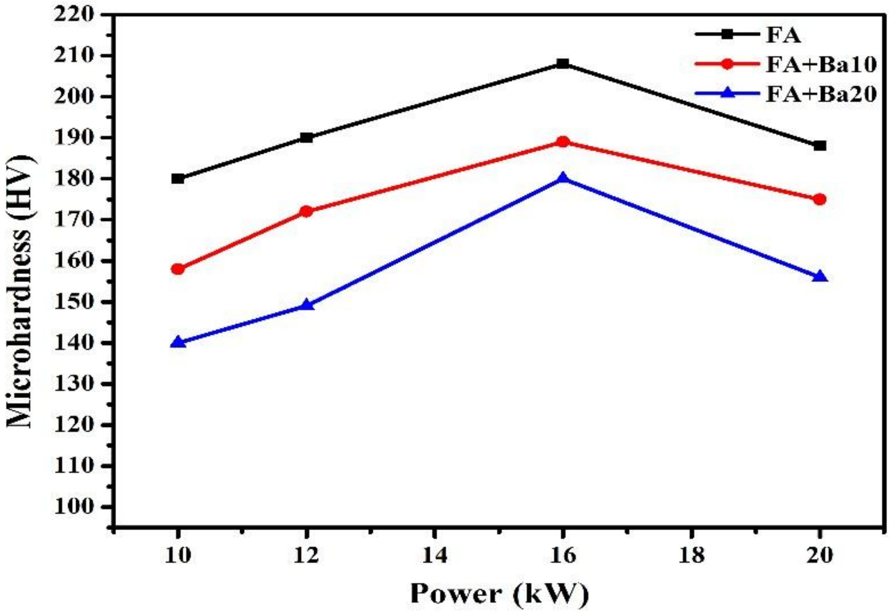

Figure. 3.5 Micro hardness of Fly ash, Fly ash + Bauxite 10% and Fly ash + Bauxite 20% coatings made at different power levels.

From the above figure it can be well visualized that, with only fly ash coating the micro hardness is highest among all other compositions, with a value of 208 HV at 16 kW power level. With increase in power level the micro hardness increases up to 16 kW and then decreases in all the cases. This may be due to, at 20kW power level the particle velocity is too high and it finds less time to melt/solidify and adhere to each other. The addition of bauxite is decreasing the micro hardness value. This may be because of, with increase in the porosity level with bauxite addition.

Conclusions

1. From the scanning electron micrograph we observed that the particles are melted efficiently at 16 kW operating power level and further increase in power level restricts the proper bonding/melting and deposition etc.
2. The porosity is always high at 20 kW power level in all cases.
3. Increase in power level favors the increase in coating thickness in all cases except fly ash with 20% bauxite addition at 20 kW. This may be due to reason that at 20 kW operating power and with this composition, the particles are not melted properly and some of the particles may be fragmented or/and fly off happened/favored for smaller particles.
4. The fly ash coating without bauxite addition gives the best micro hardness value at 16 kW power level. It is found that 16 kW operating power level is the optimum condition for deposition of best coatings using these raw materials.

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