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Microstructure and Thermal Wear behaviour of Plasma Sprayed Fly Ash Coating on AISI 304 Stainless Steel

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Abstract -- **In this present study, thermal wear resistant fly ash coating was applied on AISI 304 stainless steel substrate by the plasma spray technique. Experiments were conducted under various time intervals (5 to 30 min) with temperature kept constant at 1500 ºC. The coating was characterized for coating thickness, surface hardness, SEM morphology and surface roughness. The worn surfaces and cross section surfaces of the coating were examined using SEM. The wear rates of the coating were measured and the results showed that the wear rates were related to the punching time. AISI 304 stainless steel with the fly ash coating not only reduced the surface roughness from 1.31 to 0.76 µm, but also remarkable improved the thermal wear resistance. The fly ash coated specimen was found to be very effective in increasing the thermal wear resistance of the given AISI 304 stainless steel at 1500 ºC.**

Keywords: Fly ash coatings, thermal wear, AISI 304 stainless steel, flame punching experiment

I. INTRODUCTION

Fly ash is a most divided powder generated as a solid waste in quantities during power generation in coal – based power plants [1]. It can be a cost effective substitute for conventional extenders in high performance industrial protective coatings. Surface degradation of metal containment walls and heat exchanger tubing by a thermal wear mechanism has been experienced in some boilers, gas turbines engines and turbine engines etc [2].

Austenitic stainless steels are the widely used because of their excellent corrosion, specific mechanical properties, cold formability and wear resistance in various aggressive environments. Among austenitic stainless steels, AISI 304 stainless steel due to some specific properties, i.e. better corrosion resistance and good machinability is extensively used in structural applications such as hydraulic machinery and in liquid-handling systems. However, low surface hardness and poor wear resistance limits their application under the thermal wear conditions [3–5]. AISI 304 stainless steel have shown the lowest wear resistance in both the dry sliding and under lubricated conditions and has severe thermal wear with significant mass losses [5]. Therefore, researchers have long reverie of developing new technologies to improve the wear resistance of stainless steel surfaces.

It is well known that fly ash coatings are used extensively for the protection of metallic substrates in various wear environments [6]. It is evident from literature that the fly ash coating (Al_2O_3, SiO_2, TiO_2, Cr_2O_3 etc.,) plays a vital role in wear protection [1, 2, 6–10].

Considering the broad applications of AISI 304 stainless steel and the need for identifying a suitable coating to enhance its thermal wear properties, the present work is aimed to investigate the microstructure and thermal wear characteristics of plasma sprayed fly ash coatings on AISI 304 stainless steel. The thermal wear behavior of the coating is assessed by using flame punching experiment at various time intervals of 5, 10, 15, 20, 25, 30 min with temperature kept constant at 1500 ºC.

II. EXPERIMENTATION

A. Formulation of coatings

The AISI 304 stainless steel with chemical composition weight percentage 0.053 C, 1.68 Mn, 0.43 Si, 0.04 P, 0.007 S, 0.06 Cu, 18.08 Cr, 0.05 Mo, 8.18 Ni, 0.05 N and remaining Fe was used as substrate steel. The AISI 304 stainless steel was cut to form approximately 150 X 75 X 8 mm^3 size specimens. The specimens were polished and grit blasted before coating. From Fig. 2(a) shows that fly ash powder chemical composition weight percentage and fly ash powder average particle size distribution is 8 – 112 µm (Fig. 4) was sprayed on these steel samples.

A 40 kW Atmospheric Plasma Spray Apparatus available at Spraymet Surface Technology Pvt Ltd., Bangalore (India) was used to apply the coatings. Nitrogen gas was used as powder carrying. All the process parameters including the spray distance were varied throughout coating process until a coating of around 100 µm thick was obtained. The process conditions were as tabulated in Table 1.

B. Characterization

Fly ash powder samples before coating were subjected to EDX/SEM and Particle size analysis. The coated samples and cross section morphologies were evaluated using a SEM at high magnifications. The samples were cut across the cross section subjected to mirror polishing to identify the cross sectional layers. The coating thickness was measured by scanning electron

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microscope. The micro hardness of coated specimen was also measured with the help of Vickers Hardness Tester made in India. Surface roughness analysis was carried out using a mechanical devices based on the profilometer principle (Time Group Inc, PRSR200). A total R_a measurement of 5 points was performed on the coated and thermal worn surface samples.

C. Thermal wear testing (Flame punching experiment)

For application to certain area, fly coatings are exposed to flame. In this area, some deformation is observed and higher working temperature is required. Thermal wear experiment is applied to measure the weight loss of coated specimen to hot flame. This experiment setup is shown in Fig. 1. Heat is directly applied to sample surface and punching times were measured. The weight loss measurements were taken after the time intervals of 5, 10, 15, 20, 25, 30 min. Wear rates calculated in terms of g/min with respect to time.

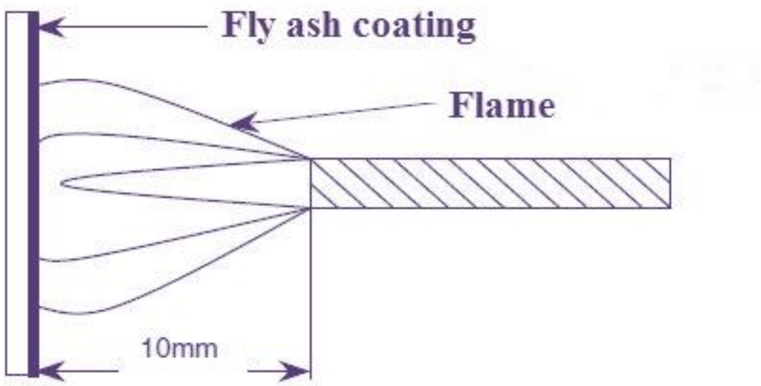

Fig.1. The schematic view of thermal wear testing

TABLE I Atmospheric plasma spraying parameters for preparation of the coatings

Parameters	Coatings	
	NiCr Bond Coat	Fly ash Top Coat
Primary gas, flow rate (LPM)	Ar, 45	Ar, 80-90
Secondary gas, flow rate (LPM)	H_2, 6	H_2, 15-18
Powder carrier gas, flow rate (LPM)	N_2, 37-39	N_2, 37-39
Powder feed rate (g)	30-35	40-45
Current (A)	500	500
Voltage (V)	60	60
Spray distance (mm)	120	75-100
Coating thickness (µm)	30	70

III. RESULTS AND DISCUSSION

A. Characterization of fly ash powder

1) EDX Analysis

The Elements analysis for the fly ash powder was using the Energy dispersive X-ray spectroscopy. “Fig. 2(a)” shows the chemical composition (wt%) of fly ash powder and Fig. 2(b) shows the elements present in fly ash powder of O, Al, Si, S, Ca, Ti, Fe and Mg elements has been indicated by EDX peaks.

2) Microstructure Analysis

The microstructure of fly ash powder SEM images at different magnifications is shown in Fig 3 which shows the presence of solid large particles (Fig. 3b) and near spherical particles (Fig. 3c). The average size of fly ash particles observed to the SEM image (Fig. 3a)

3) Particle Size Analysis

Particle size analysis of the fly ash powder with a Laser Particle Size Analyzer (make: PARTICA) revealed that the particle size varies between 8-112 microns is shown in Fig. 4. In general particle size varies between 20-140 microns of Air plasma spray process. However the larger fraction of particles average size of 100 microns.

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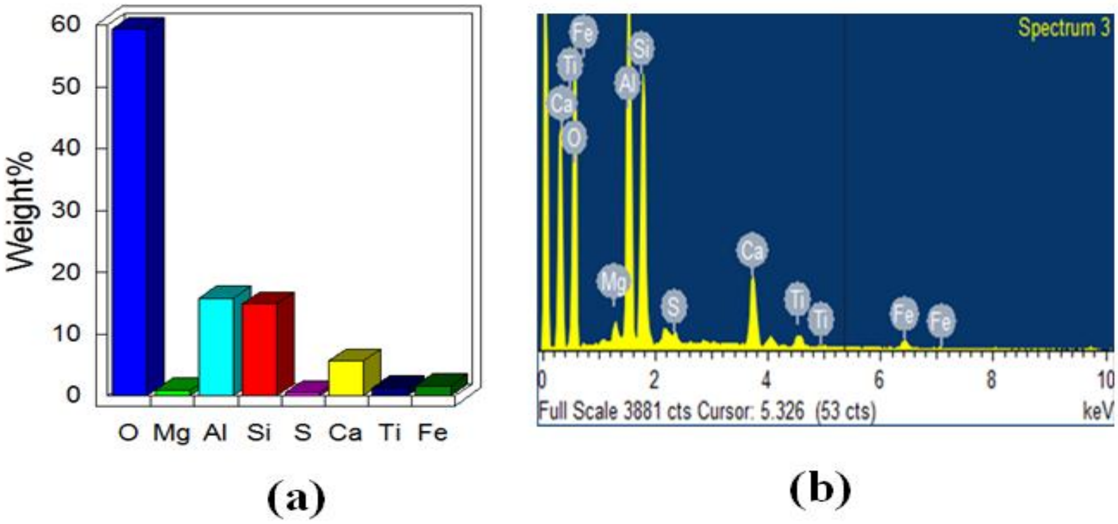

Fig.2. Energy dispersive X-ray (EDX) analysis (a) Fly ash Chemcial composition (wt%) (b) Fly ash elements showing peaks

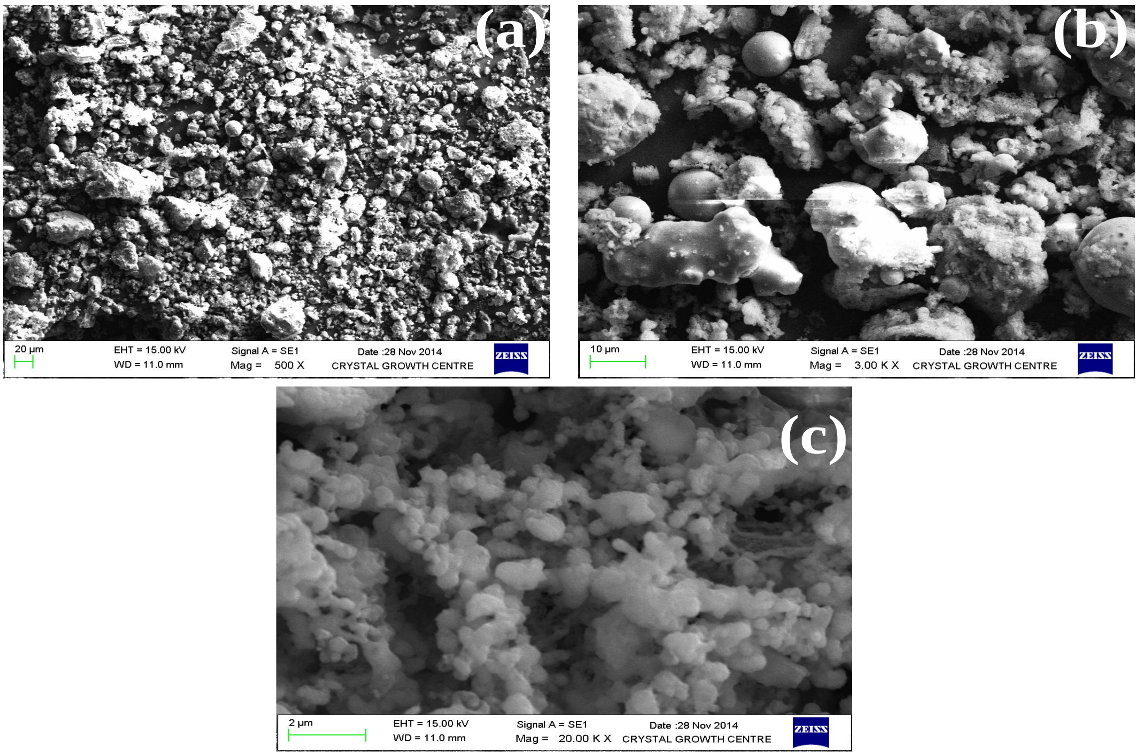

Fig.3. SEM images of fly ash powder at different magnifacations (a) 0.5 KX (b) 3 KX (c) 20 KX

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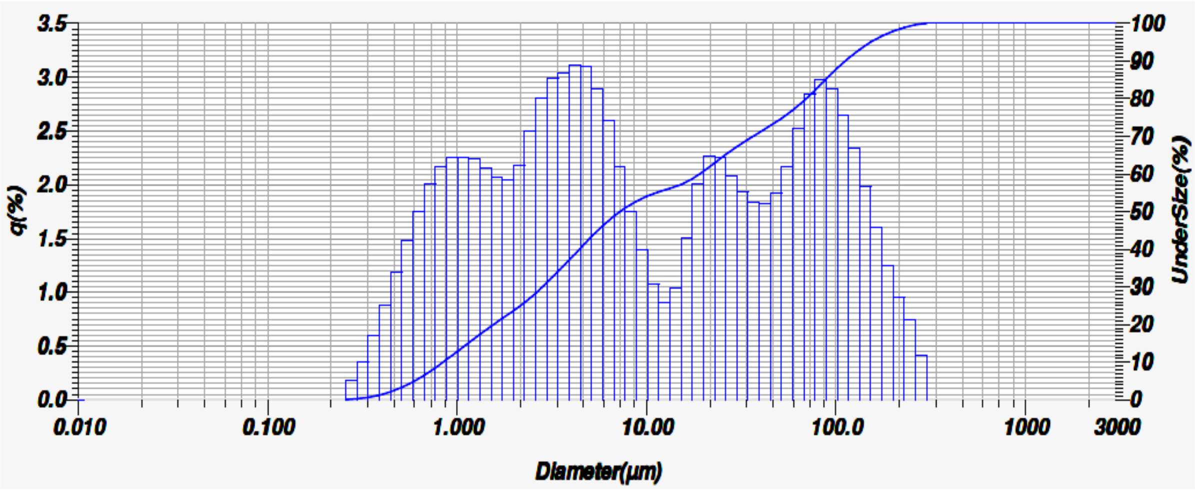

Fig.4. Fly ash particle size distribution curve

B. Characterization of coated fly ash specimen

1) Thickness analysis of coating

Fig. 6a shows the SEM micrograph along with the cross section layers of fly ash coated AISI 304 stainless steel, fly ash coated specimen layers can be seen clearly. The coating thickness was measured to be 100 µm.

2) Micro hardness

The micro hardness of fly ash coated specimen was measured across the cross section. The micro hardness values up to 1100 HV could be observed for the coated specimen layers, which is much more than the micro hardness of stainless steel that is only up to 230Hv at the coating substrate.

3) Surface roughness analysis

The surface roughness of fly ash coated specimen was measured the top-section. The surface roughness values up to 1.31 µm could be observed for the fly ash coated surface, which is more than the surface roughness of worn surface of fly ash coated specimen that is only up to 0.76 µm as shown in Fig. 5

4) Surface microstructure analysis

The top section of fly ash coated specimen micrographs as shown in Fig. 6b-6d. It is clear that plasma sprayed fly ash coated specimen homogeneous coating from the surface microstructure. The presence of a homogenous fly ash coating with uniform is a surface microstructure for improving the wear resistance of the AISI 304 stainless steel. "Fig. 6b" shows the some regions are partially melted and some regions melted completely.

C. Thermal wear behavior

Weight loss of the plasma sprayed fly ash coated specimen increased from 5 to 30 min from Fig. 7 due to frictional heat affecting coated specimen top surface. From the results it is clear that fly ash coated samples showed relatively lower weight loss when compared with the uncoated specimens. Variation of wear rate (g/min) with respect to increasing time is plotted in Fig. 8. Wear rate observed to be less in the initial stages of the time, which gradually increases to steady state in the latter stages of the fly ash coated specimens. There is increase in the wear rate with increase in punching time.

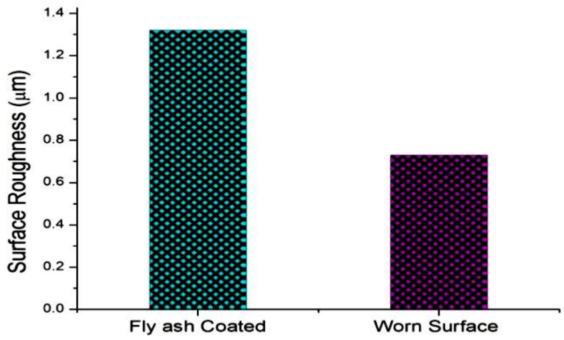

Fig.5. Surface roughness analysis of fly ash coated specimen and worn surface

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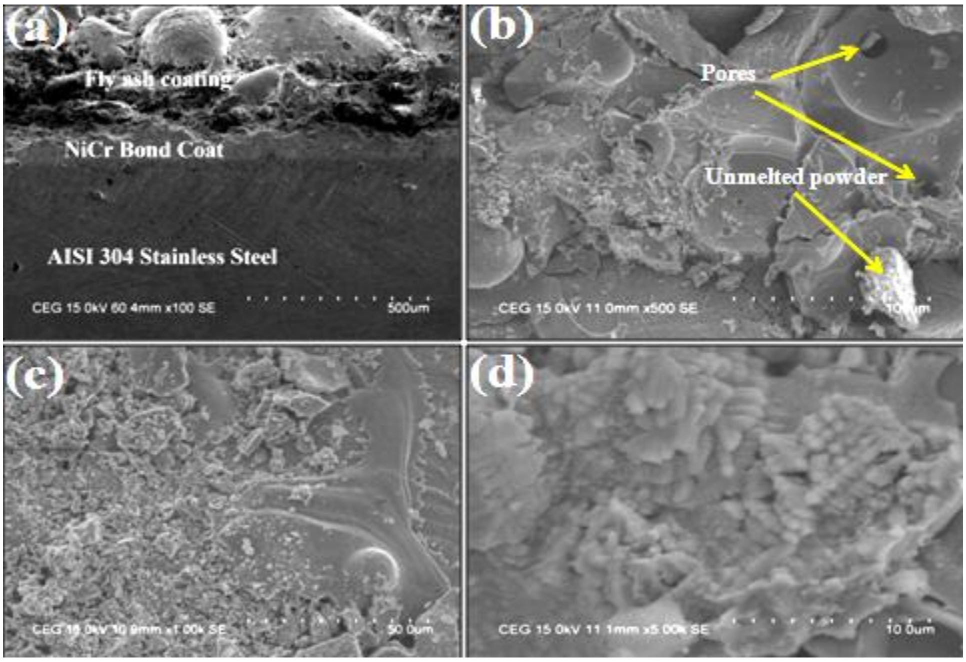

Fig. 6. SEM micrograph showing the surface morphology at different magnifications (a) Cross – Section, 100x (b) fly ash coated surface, 500x (c) fly ash coted surface, 1 kx (d) fly ash coated surface, 5kx

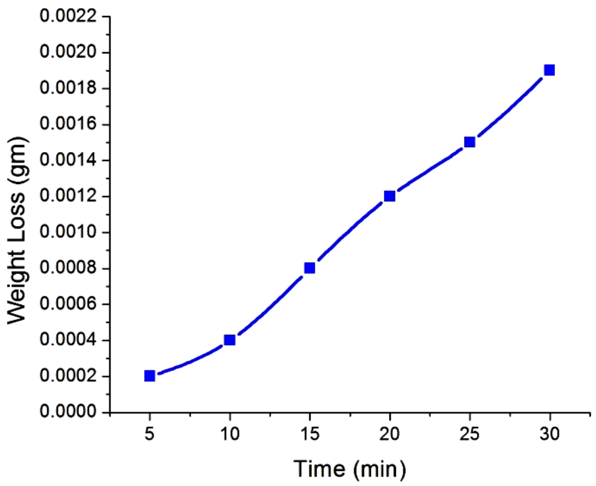

Fig.7. Weight loss (gm) Vs Time (min) of the fly ash coated specimen

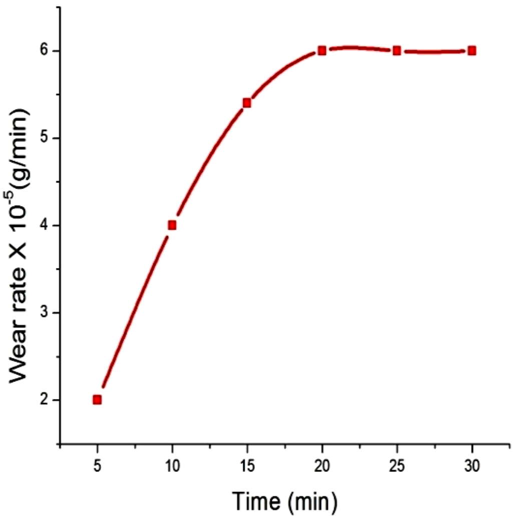

Fig.8. Wear rate (g/min) Vs Time (min) of the fly ash coated specimen

D. Thermal worn surfaces analysis using SEM

The thermal worn surface of the fly ash coated specimen after 30 min of time at 1500 ^{0}C temperature SEM micrographs is shown in Fig. 9 (a-d). The deformation of oxides on the surface of fly ash coated specimen during thermal wear can be revealed from the black and white faces present in the microstructure, which has adhered on the whole thermal wear surface. However, the morphologies of worn surface in case of fly ash coated specimen under similar conditions indicate porous structure, deformation of coated layer, delamination and small, large wear debris as is evident from Fig. 9 (d).

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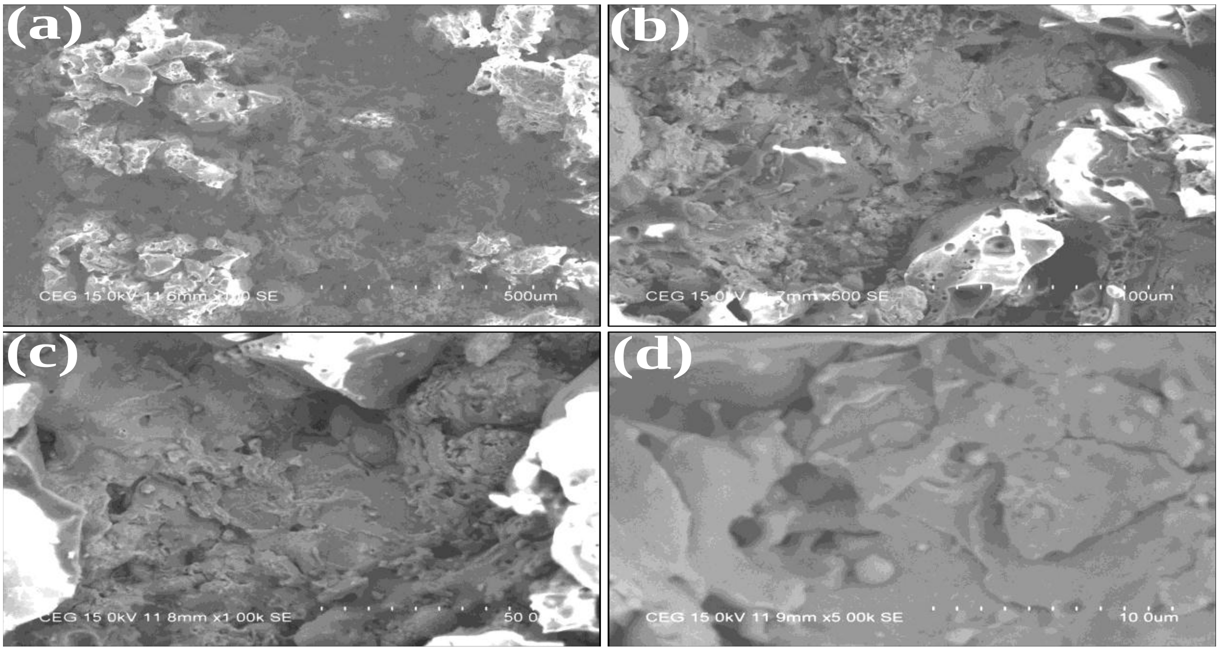

Figure 9. SEM micrographs of the worn surface of fly ash coated specimen at different magnifications (a) 100x (b) 500x (c) 1kx (d) 5kx

IV. CONCLUSIONS

Air plasma spray process could be used to deposit fly ash coating on the given AISI 304 stainless steel under the given parameters. The micro hardness value for fly ash coated specimen (1100 HV) was found to be higher than that of the uncoated specimen (230 HV). The wear rate of fly ash coated specimen was more than that of similar type of uncoated austenitic stainless steel. The fly ash coated specimen was found to be very effective in increasing the thermal wear resistance of the given AISI 304 stainless steel at 1500 ºC. The presence of SiO_2 and Al_2O_3 might have contributed to increase the thermal wear resistance of fly ash coated specimen. Wear resistance of the plasma sprayed fly ash coated specimen was relatively higher than the uncoated specimen at various testing punching time.

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