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DRY SLIDING WEAR BEHAVIOUR OF NiCrBSiCFe PLASMA COATING ON AUSTENITIC STAINLESS STEEL

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ABSTRACT

In this work, the tribological characteristics of NiCrBSiCFe plasma sprayed on AISI 316 austenitic stainless steel (ASS) at room temperature are studied. En-8 medium carbon steel pin is used as a counterface material. The load is 20 N and sliding velocity is 1 m/s for a sliding distance of 2000 m. The experiment was carried out at room temperature (35°C). The NiCrBSiCFe powder consists of gas atomised spherically shaped particles of average size 63 µm. The coatings obtained are defect-free and are metallurgically bonded to the substrate. The mass loss due to wear in the AISI 316 ASS is measured in every cycle of experiment using an electronic balance. The microstructure of the coatings was analysed by optical and scanning electron microscopy (SEM). The higher hardness of the NiCrBSiCFe coating (823$HV_{0.3}$) was responsible for the superior wear resistance than the uncoated steel substrate in room temperature. The better wear properties of the coated steel are supported by the metallographic microstructure and the SEM pictures. The SEM pictures of the worn surfaces of the coated and uncoated substrate are also in good agreement with the wear characterisation.

Keywords: *AISI 316, NiCrBSiCFe, Plasma Spraying, Dry Sliding Wear, SEM*

1. Introduction

Austenitic stainless steels have frequent applications in engineering environments and have been widely used in various sectors of industries, but they exhibit poor friction and wear characteristics [1]. A detailed study on sliding-wear evaluation of nitride austenitic alloys was also carried out [2]. The wear of AISI 316 ASS has been studied in a variety of gaseous atmospheres at constant load and sliding speed under reciprocating conditions. The environments taken for study are air, CO_2, argon and partial vacuum. The wear debris in all cases was essentially metallic and its rate of production per unit length was constant with sliding distance [3]. The tribological behaviour of Al-Si composite was studied. The hardness, wear resistance, co-efficient of friction and wear rate for the composites were found to depend mainly on the distribution of the primary silicon particle along the radial direction [4]. Wear tests have been performed at room temperature on AISI 304L stainless steel claddings. The test duration has no effect on the wear behavior of material [5]. A great deal of research has been conducted to clarify the role of oxide films in the wear of metals. Oxides formed during dry sliding of steels at high temperatures determine their tribological behaviour [6]. Study of AISI 304 ASS worn surfaces indicated that depending on wear condition and applied load, different features of wear were involved, and during wear, austenite transformed to martensite. The intensity of martensite peaks in X-ray pattern depends on the magnitude of the applied load [7]. Intermetallic compounds find extensive use in high temperature structural applications. The Fe3Al based intermetallic alloys offer unique benefits of excellent oxidation and sulfidation resistance at a potential cost lower than many stainless steels. Plasma spraying is considered as a non-linear problem with respect to its variables: either materials or operating conditions. A mathematical technique was proposed on neural computations to study the effects of process variables on the wear behavior of iron-aluminide coatings made by plasma spraying [8]. The dry sliding behaviour of an ASS and a duplex 2205 austenitic-ferritic stainless steel was investigated. The evolution of wear was characterized by the existence of a sliding distance transition. In particular, wear passed from delamination to tribo-oxidation, with a reduction in wear rate [9]. The effects of normal load and sliding speed on tribological properties of the metal matrix composite (MMC) pin on sliding with En 36 steel disc was evaluated. The wear rate increases with normal load and sliding speed. The wear and friction coefficient of the aluminum alloy–silicon carbide MMC is lower than the plain aluminum alloy [10]. Wear properties of the as-plasma nitrided and untreated 316 ASS have been investigated using a pin-on-disc tribometer with cemented tungsten carbide ball as the counterface. Experimental results have shown that the plasma nitriding can improve the wear resistance of 316 ASS by more than two orders of magnitude [11]. A low

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temperature plasma carburising technique was developed to engineer the surfaces of austenitic stainless steels to achieve combined improvement in wear and corrosion resistance. The resultant carburised layer is free from carbide precipitates and contains a single austenite phase supersaturated with carbon. The results showed that the hard and corrosion resistant carburised layers are effective in preventing surface plastic deformation, eliminating adhesive and severe abrasive wear [12]. The sliding wear behaviour of plasma nitrided layers produced in AISI 316 ASS at temperatures between 450°C and 550°C has been investigated. Dry sliding test with bearing steel and alumina as the counterface and sliding test in a corrosive solution have been conducted. The results show that the sliding wear behaviour of plasma nitrided 316 steel depends on the nitriding temperature, counterface material and testing conditions [13]. The sliding wear of AISI 304 and AISI 316 ASS was studied as a function of applied load (from 6 to 20N) and tangential velocity (from 0.07 to 0.81ms^{-1}). Wear experiments were conducted in a commercial pin-on-disc equipment and were designed with response surface methodology. The change in the wear mechanism was associated with the subsurface plastic deformation and surface temperature, which were strongly affected by sliding speed. In addition, strain-induced martensitic transformation was observed on the sliding surface of the austenitic stainless steels [14]. The Wear behaviour of laser clad and plasma sprayed WC-Co coatings was studied. The tests showed that wear rate in laser deposited coatings are approximately 34% lower than in plasma sprayed coatings. [15]. Scuffing resistance of plasma and high velocity oxy fuel (HVOF) sprayed WC12Co and Cr_3C_2-25(Ni20Cr) coatings were studied. The properties like hardness, coefficient of friction, method of spraying and coatings influence the scuffing process [16]. The characteristics and the phase composition of WC–Co/Cr_3C_2–NiCr coatings sprayed by HVOF with LPG as fuel gas used in boiler tube steel substrates have been studied. The microstructure, porosity, surface roughness and microhardness of HVOF sprayed WC–Co, Cr_3C_2–NiCr coatings deposited on boiler steels was compared [17]. A study was conducted to characterise the critical normal loads and sliding speed on the wear behaviour of a NiCrBSiRE alloy. SEM and XPS (X-ray photoelectron spectroscopy) were used for characterisation [18]. In this work the sliding wear experiment is carried out for uncoated and NiCrBSiCFe plasma sprayed AISI 316 ASS in pin on disc tribometer. The worn surfaces were analysed by SEM and the results were reported.

2. Experimental Procedure

The chemical composition of the AISI 316 stainless steel disc was 0.08% C, 18% Cr, 1% Si, 0.03%S, 14% Ni, 2% Mn, 3% Mo, 0.045%P, remaining Fe. The initial Vickers hardness of uncoated AISI 316 steel discs and EN-8 medium carbon steel pin was 223 $HV_{0.3}$ and 302 $HV_{0.3}$ respectively. These hardness values were determined using a load of 300 g with a Zwick MHT micro hardness tester for 20 seconds. Coating microhardness values were found to be in the range of 750–930 $HV_{0.3}$. The average coating hardness is 823 $HV_{0.3}$. AISI 316 contains Molybdenum in greater quantities. The dimension of the substrate plate was 100 mm diameter and 4 mm thickness. The powder composition is 13.3%Cr, 3.1%B, 3.9% Si, 0.5%C, 3.7%Fe, remaining Ni. The powder consists gas atomised spherically shaped particles of average size 63 µm. The morphology of the powder was analysed by SEM. The microstructure of AISI 316 ASS was analysed using optical microscope using standard metallographic procedure. Nital was used as an etchant. The standard parameters used for plasma spraying are shown in Table 1. AISI 316 ASS Substrates are sand blasted before coating. The coating was performed up to 500 µm thickness. Experiments were conducted using DUCOM pin-on-disc equipment under dry sliding test conditions at room temperature (35°C) (Fig. 1). The equipment consists of a rotating spindle fixed with the disc.

Fig. 1 Experimental Setup for Wear Testing

A pivoted lever arm with balancing weight and provision for fixing the pin along with the collet holder were to be brought to the desired track diameter. The LVDT (linear variable displacement transducer) probe was positioned on the weights to measure displacement and the load cell to sense the tangential force. The normal load was 20 N. The tangential velocity was 1m/s and with a wear track radius of 40 mm. Before and after tests, the discs were ultrasonically cleaned, dried and weighed using an electronic analytical weighing balance of 0.1 mg accuracy. Using the mass loss, the volume loss and wear resistance was calculated by standard formula. Using the data acquisition system, the depth of wear in micron and coefficient of friction were recorded automatically with respect to time. The worn surfaces were analysed and characterised by SEM.

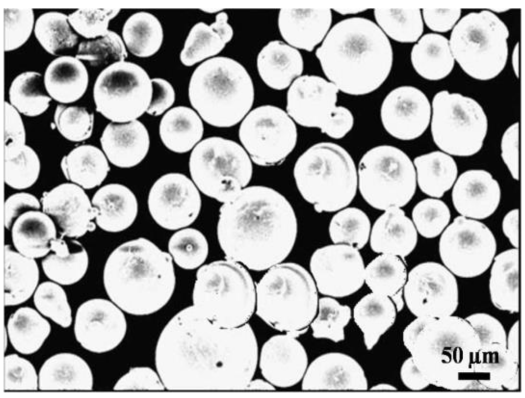


Fig. 2 SEM Morphology of NiCrBSiCFe Powder

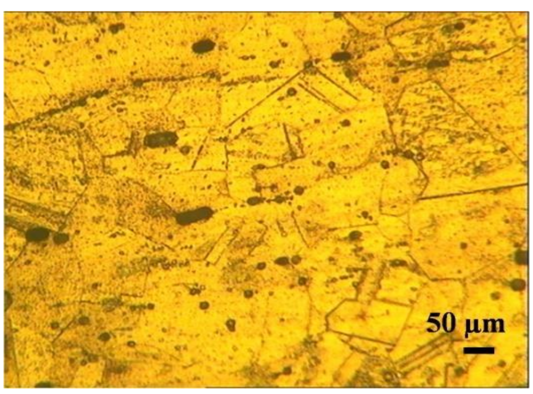


Fig. 3 Microstructure of AISI 316 ASS

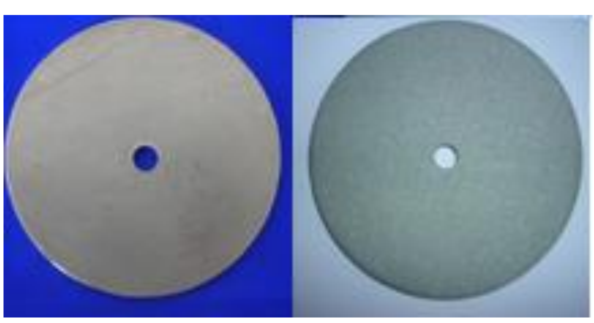


Fig. 4 Uncoated and NiCrBSiCFe Coated AISI 316 ASS

Table 1: Parameters for Plasma Spraying Process

S.No.	Parameter	Value
1	Argon pressure (psi)	100
2	Argon Flow rate (SLPM)	150
3	Hydrogen pressure (psi)	60
4	Hydrogen flow (SLPM)	15
5	D.C. Current (A)	480
6	Volts (v)	70
7	Carrier Gas flow (SLPM)	37
8	Powder feed rate (g/min)	120
9	Stand- off distance (mm)	125
10	Coating thickness (µm)	500

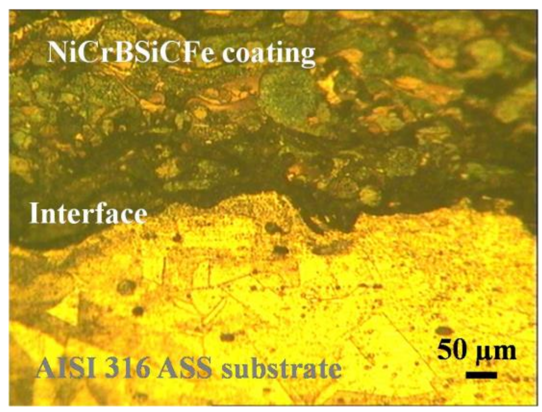


Fig. 5 Microstructure of NiCrBSiCFe Coating

3. Results and Discussion

3.1 Microstructural characterisation

Spherical morphology of the NiCrBSiCFe powder, which is best suited for plasma spraying, is clearly observed from the microstructure and is shown in Fig. 2. The powder consists gas atomised spherically shaped particles of average size of 63 µm. The Fig. 3 shows the microstructure of the AISI 316 austenitic stainless steel. Austenite structure with lesser amount of carbides was visible in the microstructure. In Fig. 5, the cross sectional microstructure NiCrBSiCFe coating shows sparsely distributed unmelted particles. The coatings obtained are defect-free and are metallurgically bonded to the substrate. Pores are situated between the unmelted particles. Elongated splats of molten powder, forming a lamellar structure, with oxide layers in between, is a typical structure of thermal spray coatings. This lamellar structure is responsible for the superior wear resistance of the coated substrates.

3.2 Coefficient of friction and dry sliding wear loss

The wear versus time graph was recorded during the wear test at room temperature and is shown in Fig. 6. Sliding wear mechanisms were dominated by plastic deformation. From the graph it was inferred that the wear of the uncoated AISI 316 ASS discs are higher than that NiCrBSiCFe coated samples at 35ºC. The reason for better wear resistance of the coated samples is justified by the higher hardness of the coating (823$HV_{0.3}$). The lamellar structure resulted for the plasma spraying is also responsible for the superior wear resistance of the coated substrates. From the frictional load, the coefficient of friction was calculated (μ= F/N) with respect to time and is shown in Fig. 7. It was observed that μ varies between 0.6 to 0.7 in uncoated and 0.5 to 0.6 NiCrBSiCFe coated AISI 316 ASS discs.

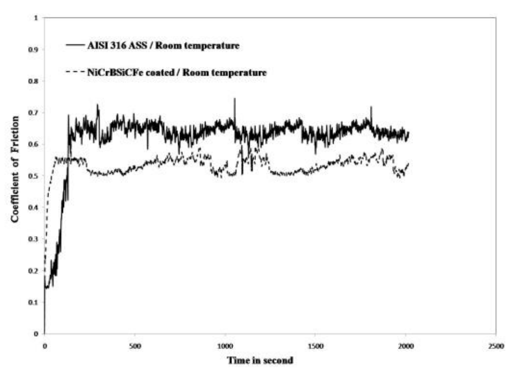


Fig. 6 Variation of Wear with Respect to Time

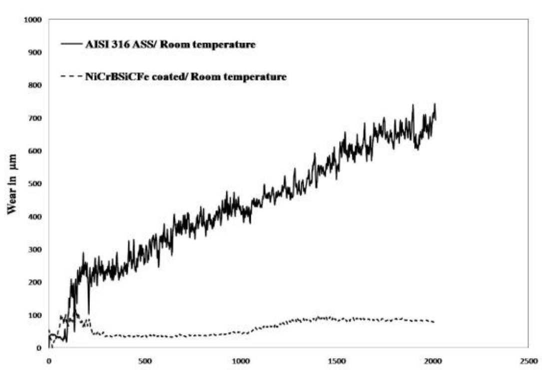


Fig. 7 Variation of Coefficient of Friction with Respect to Time

The plot shows the marginal decrement of the coefficient of friction in the coated discs, which is responsible for the superior wear resistance [19]. The wear of the disc in terms of mass loss of uncoated AISI 316 disc is more compared to the NiCrBSiCFe coated disc. The wear resistance (sliding distance/volume loss) of uncoated disc is 129.08 m /mm^3 and the coated disc is 540.62 m/mm^3 (Archard's law). It summarizes that the NiCrBSiCFe coating is four times more wear resistant than the uncoated discs (Fig. 8).

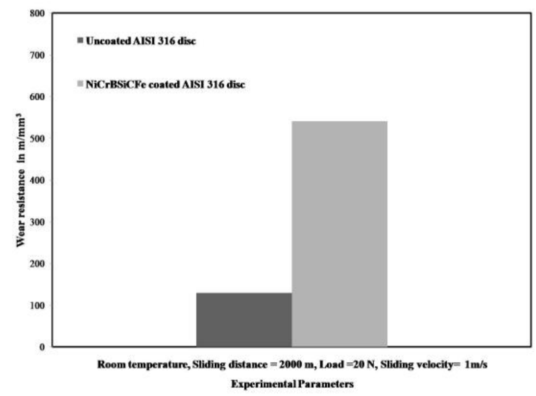
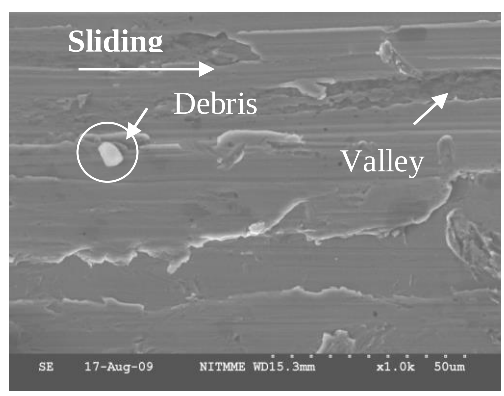
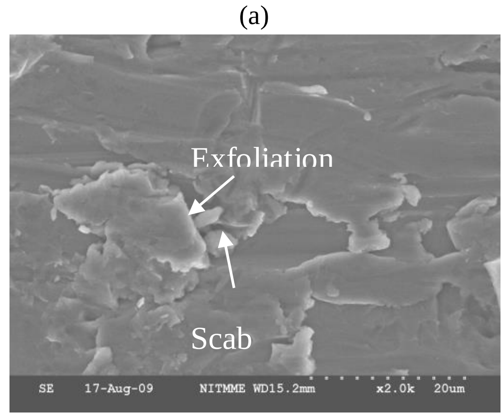


Fig. 8 Wear Resistance of Uncoated and NiCrBSiCFe Coated AISI 316 ASS

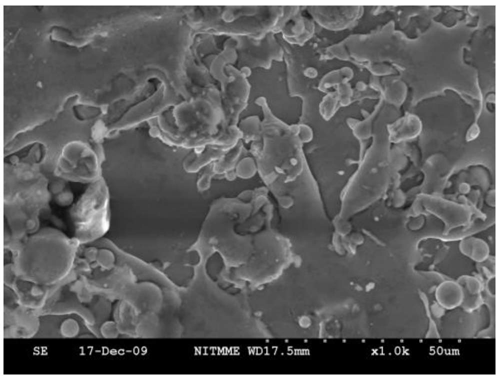


(a)

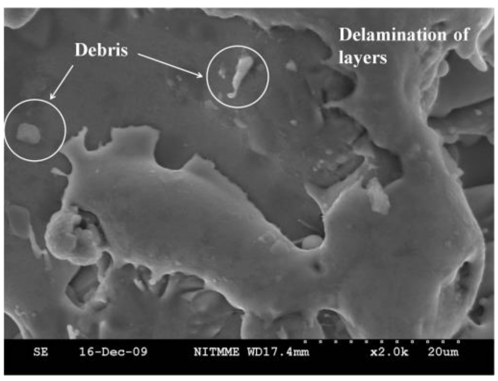


(b)

Fig. 9 (a) and (b) Worn Surfaces of Uncoated AISI 316 ASS at Room Temperature



(a)



(b)

Fig. 10 (a) and (b) Worn Surfaces of NiCrBSiCFe Coated AISI 316 ASS at Room Temperature

3.3 Characterisation of worn surfaces

Fig. 9(a) shows the worn surface of the uncoated AISI 316 ASS at room temperature. The sliding direction was well exposed by parallel grooves. A deeper valley was noticed and it was due to the excessive material removed by the sliding wear. Wear debris was also present in the worn surface. Thereby, abrasive wear has taken place in the uncoated disc to a greater extent. Fig. 9(b) shows the worn surface of uncoated AISI 316 ASS at room temperature at greater magnification. Dark non-reflecting regions are observed as "scabs" or crustations on the surface. The worn surface showed the remnants of a multilayered delaminated structure and appeared to be in various stages of breakup, in an exfoliative manner. Exfoliation is a severe mode of wear mechanism resulting in the delamination of the flakes, it promoted severe wear in terms of material loss in the uncoated AISI 316 discs..

The worn surface morphologies of the NiCrBSiCFe coating are shown in Fig. 10(a) and (b). After the dry sliding wear, the wear scars with the absence of grooves on the coating are shown in Fig. 10(a). In Fig. 10(b) with the higher magnification of the wear track, the debris and delamination of coating layers. There were interlamellar interfaces and relatively smooth patches on these worn surfaces. The minimal delamination of layers with absence of grooves, valley and plough markings justify the reason for minmal wear in terms of material loss for the coated discs.The wear mechanism of selective delamination of weak layers and removal of lamellae of the NiCrBSiCFe coating was visible. As the debris acted as lubricant, the coating promoted slipping of the counterface material excluding the chances of sevre wear.

4. Conclusion

From the dry sliding wear experiments conducted on uncoated and NiCrBSiCFe plasma sprayed AISI 316 ASS substrates at room temperature, the following conclusions can be drawn.

i. The NiCrBSiCFe coatings of 500 µm thickness obtained are defect-free and are metallurgically bonded to the substrate. The lamellar microstructure formed due the molten splat formed during spraying is responsible for the superior wear resistance.
ii. The hardness of AISI 316 ASS has been improved from 223 $HV_{0.3}$ to 823 $HV_{0.3}$ by NiCrBSiCFe plasma spraying, which attributed to the four fold improvement in the wear resistance than the uncoated disc.
iii. The coefficient of friction is marginally lesser in NiCrBSiCFe coated discs than the uncoated disc and thus justifies the reason for better wear resistance.
iv. In uncoated AISI 316 ASS, worn surfaces are characterised by dark non-reflecting regions observed as "scabs" or crustations on the surface leading to greater wear (abrasive wear).
v. The wear mechanisms of the NiCrBSiCFe coating are selective delamination of weak layers and removal of lamellae, which induces relatively lesser wear.

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