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Research Article

STUDIES ON DRY SLIDING WEAR CHARACTERISTICS OF HIGH VELOCITY OXY FUEL SPRAYED IRON BASED AMORPHOUS COATINGS

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ABSTRACT

This paper, the friction and wear behaviours of High Velocity Oxy – Fuel sprayed iron based amorphous metallic coatings and AISI 316 stainless steel sliding against a sintered tungsten carbide disc were studied in terms of mass loss and coefficient of friction under various operating conditions such as applied load, sliding velocity and distance by Pin on Disc tribometer. The surface morphology of the coated and uncoated materials was characterized by optical microscopy images. From these images, wear mechanisms of the worn surfaces of the test specimens were discussed adequately and it was found that the dry sliding wear behaviour of the HVOF sprayed iron based amorphous coated specimens exhibited superior wear resistance than the uncoated stainless steel specimens.

INTRODUCTION

Sliding wear is a material deterioration phenomenon that occurs when the two surfaces are rubbing each other. Many industries are trying to alleviate the sliding wear problem by selecting the appropriate design for the components and abrasion resistant materials. When the materials are subjected to continuous sliding environment, they may fail. The provision of surface modifying technique is essential requirement to protect materials from dry sliding wear and some unpredictable surface degradation. Stainless steels alloys are possess superior properties such as corrosion resistance, ductility, formability and ability to withstand different loads which are caused by fatigue and creep conditions. These significant properties of stainless steels makes them suitable for many engineering applications ranging from chemical and pulp handling equipment, shafts, bolts, aircraft fittings, rivets and studs[1]. On the other hand, stainless steels are limited its longer period applications because of its poor tribological properties.

High Velocity Oxy – Fuel (HVOF) spraying technique has been identified as the best one from other thermal spraying processes. This technique is the most suitable for the materials which are melting point less than 3000^{0}C.

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Out of all other coating techniques, HVOF sprayed coating exhibits high density, high bonding strength between coating and working substrate, since it is broadly using for many abrasion and corrosion wear resistance fields [2-4]. HVOF spraying has been utilized globally in innumerable engineering components for preventing the abrasive, corrosive and erosive wear environments. Particularly, it is applied for deposit hard coatings to resist sliding wear which are observed in nozzles of water jet cutting tools, foil producing industries, sliding areas of pressing irons, valves and pumps in petrochemical applications, and mechanical seals, etc. [5]. Amorphous materials are the short range order between the atoms and they are non-crystalline. Unlike the crystalline materials, the disordered structure and the absence of dislocations in the amorphous structure which combats the plastic deformation in the amorphous coating. Since the amorphous materials are very high strength, high hardness and better sliding wear resistance [6]. Very few powders are only used in HVOF spraying process such as WC-Co, CrC, alumina, iron based amorphous, etc. Out of all these, Iron based amorphous metallic powder is most preferable to use in HVOF spraying technique [7]. Due to the high velocity and low flame temperature of coating materials, the liquid atoms are frozen suddenly in a disordered random structure. The past research works were carried out on wear characteristics of WC based, Ni based and Co based powders. Although it has provided higher resistances to corrosion, erosion and abrasion, they are very expensive and having the potential to cause cancer disease [8]. Thus the utilization of these coating materials are should be avoided to prevent the health issues and formation of toxic agents through wear debris. The solution for these problems is iron based amorphous metallic coating, because it is free from carcinogenic issues and less expensive [9]. Nowadays many researchers are concentrating on iron based amorphous coatings in the thermal spraying field , but still there is lot of contradictions between the researchers to discover the wear resistance characteristics such as erosion, corrosion, erosion-corrosion, cavitation erosion and abrasion conditions [10]. In addition, the effect of the dry sliding wear characteristics of the iron based amorphous coatings has not been found properly. Hence an attempt has been made to evaluate the dry sliding wear behavior of HVOF sprayed iron based amorphous metallic coating in this research work.

Experimental Work

Base Metal

The standard cylindrical test specimens with the dimensions of 20 mm length and 10 mm diameter were produced from AISI 316 stainless steel rods by conventional machining processes and then ground to remove the surface undulations. The chemical composition of the substrate material is given in Table 1.

Table 1 Chemical composition of the 316 stainless steel

	Chemical Composition (wt. %)										
Elements	C	Cr	Fe	Mn	Mo	N	P	S	Si	W	B
AISI 316L	0.08	18	62	2	3	14	0.045	.03	1	-	-

The micro hardness measurement was made using a Vickers digital micro hardness tester (Make: Shimadzu; Japan. Model: HMV-2T) with a load of 300 g and a dwell time of 15 s. Hardness values were measured at 10 random locations on the polished cross section of base metal and the average value was found to be 296 HV.

Amorphous Powder

The $Fe_{30}Cr_{25}Mn_5Mo_{20}W_{10}B_5C_3Si_2$ amorphous metallic powders with particle size in the range of -53 to + 15 µm were used to coat on the stainless steel specimen using HVOF spray process.The chemical composition of the substrate material is given in Table 2.

Table 2 Chemical composition of Iron based amorphous powder

	Chemical Composition (wt. %)										
Elements	C	Cr	Fe	Mn	Mo	N	P	S	Si	W	B
Fe based AMC	3	25	30	5	20	-	-	-	2	10	5

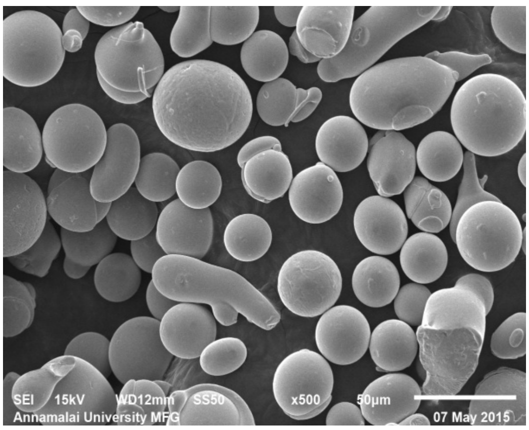


Fig 1 Scanning Electron Micrograph of Fe based Amorphous Metallic Coating

The powders were analyzed by scanning electronmicroscopy (Make: Jeol; Japan. Model: 6410-LV SEM) to reveal their morphology and is shown in Fig. 1.

HVOF Spray Parameters

From the literature review, it is understood that in HVOF spraying, there are several parameters that are affecting the coatings properties.

Table 3 Optimized process parameters of HVOF spraying

Factor	Notation	Unit	Levels
Oxygen flow rate	O	lpm	252
LPG flow rate	L	lpm	64
Powder feed rate	F	gpm	32
Spray distance	S	mm	230
Carrier gas flow rate	C	lpm	13

It is difficult to control all the process parameters. From the past work done at Centre for Materials Joining & Research (CEMAJOR) center, Annamalai University, Chidambaram, Tamilnadu, India, the optimized HVOF spray parameters were identified as given in Table 3 [11], and they are oxygen flow rate, fuel flow rate, powder feed rate, carrier gas flow rate, and spray distance. From these process parameters, it is understood that the oxygen flow rate is having greater effect on coating porosity and coating hardness and carrier gas flow rate is having lesser effect on coating porosity and coating hardness.

Pin-on-Disc Experiment

Dry sliding wear test was carried out by Pin on disc tribometer under dry sliding conditions as per ASTM G99-04 (Make: DUCOM; India. Model: TR-20-PHM-M1) as shown in Fig. 2. Specimens (uncoated & coated pins) and the counter body sintered tungsten carbide disc (spark plasma sintered tungsten carbide disc manufactured by VBCC; India) were cleaned using acetone to avoid the presence of oil and other non-desirable films before the test. The spark plasma sintered tungsten carbide (WC) disc was preferred as the counter body as shown in Fig. 5, because it had a hardness of 2052 HV0.3, which is almost 2.5 times harder than the iron based amorphous metallic coating. After coating, all the specimens were ground to achieve 0.6 to 0.8 µm Ra surface finish and to maintain uniform thickness at 315 µm. By doing this, the nominal contact area was maintained constant during the tests in spite of the wear process. The surface roughness was measured using a diamond stylus surface roughness tester (Make: Mitutoyo, Japan; Model: SFTT301).The disc (WC counter body) rotates horizontally at a pre-set sliding speed, and hence, it was varied between 100 and 600 rpm. A dead weight loading system was used to perform the tests with nominal loads, which ranged between 10 and 60 N. The sliding distance was used between 200 and 1200 m. In order to analyze the worn surfaces and wear mechanisms were examined by the images of optical microscopy. Dry sliding wear behavior of the specimens was calculated on the basis of mass loss in milligrams (mg). The electronic micro balance weighing machine with 0.1 mg accuracy was used to measure the mass of the coated and uncoated test specimens before and after wear test. The mass loss is found that the difference between mass of the specimen before testing and mass of the specimen after testing. HVOF sprayed iron based amorphous metallic coating in this research work.

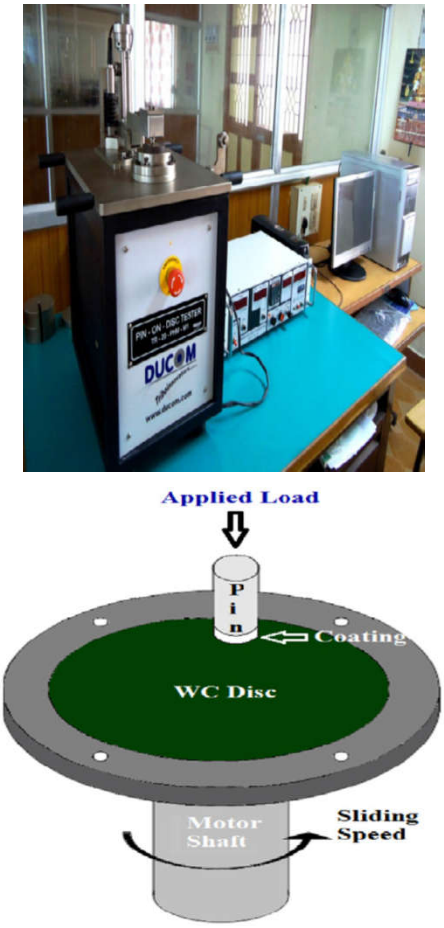


Fig 2 Pin on disc tribometer

RESULTS & DISCUSSION

Effect of Load

The effect of load on dry sliding wear characteristics of the uncoated and coated metal is shown in Fig. 3 and it is found thatthe mass loss values of specimens are increases with the increase in the applied loads. The coefficient of friction profiles and optical microscopy images of worn surfaces morphologies of uncoated and coated specimens are revealed by under various loading conditions are shown in Fig. 4 a-f& 5 a-f. The dry sliding wear of the uncoated and HVOF sprayed iron based amorphous metallic coatings against tungsten carbide disc takes place in three different loading conditions such as 20, 40, 60 N.

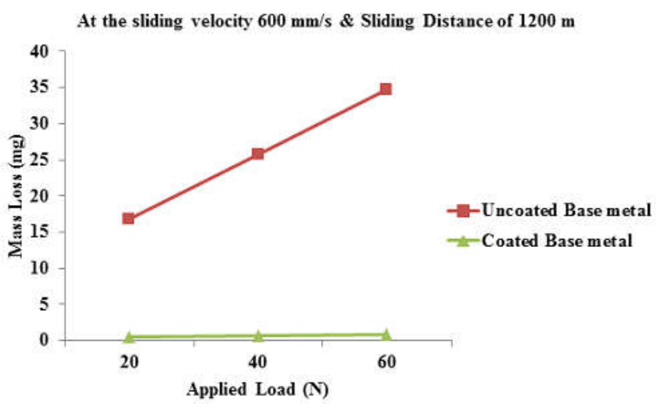


Fig 3 Effect of load on dry sliding wear characteristics

During the applied load 20N (Fig.s 5 b), in the coated specimen, Due to high hardness of amorphous coating, the tungsten carbide disc is in elastic contact with the specimens. Small scratching actions only occurred and it is found that the applied load was not responsible for mass loss as shown Fig. 3. In case of uncoated base metal, combined scratching and abrasion wear mechanism as shown in Fig. 5 a. From this, the applied load is not influenced for HVOF sprayed metal and there is no metal removal at this loading condition. When the load of 40N, In the case of base metal, scratching and ploughing wear mechanisms were takes place as shown in Fig. 5 c. In HVOF coated metals, scratch marks are found and there is no change in the mass loss of the coated specimens with the previous loading conditions. In the applying load of 60N stage, in the uncoated specimens, the mass loss increases rapidly due to the ploughing and fatigue crack wear mechanisms are found as shown in Fig. 5e [12].Thus, the three body abrasion will takes place by wear debris which are entrapped between the specimen and tungsten carbide disc and it may leads to the material removal from base metal surface and forms undulated surface. In coated metals, the mass loss was slightly increased when compared with previous loading conditions. Scratching and polishing actions are dominant as shown Fig. 5 f [13]. From this discussion, it should be noted that the iron based amorphous metallic coatings are not affected by different loadings and it is observed the mass loss of the HVOF coated specimens are negligible quantity only. Thus, the dry sliding wear characteristics of coated metals are better wear sliding wear resistance than uncoated 316 stainless steel specimens under different loadings.

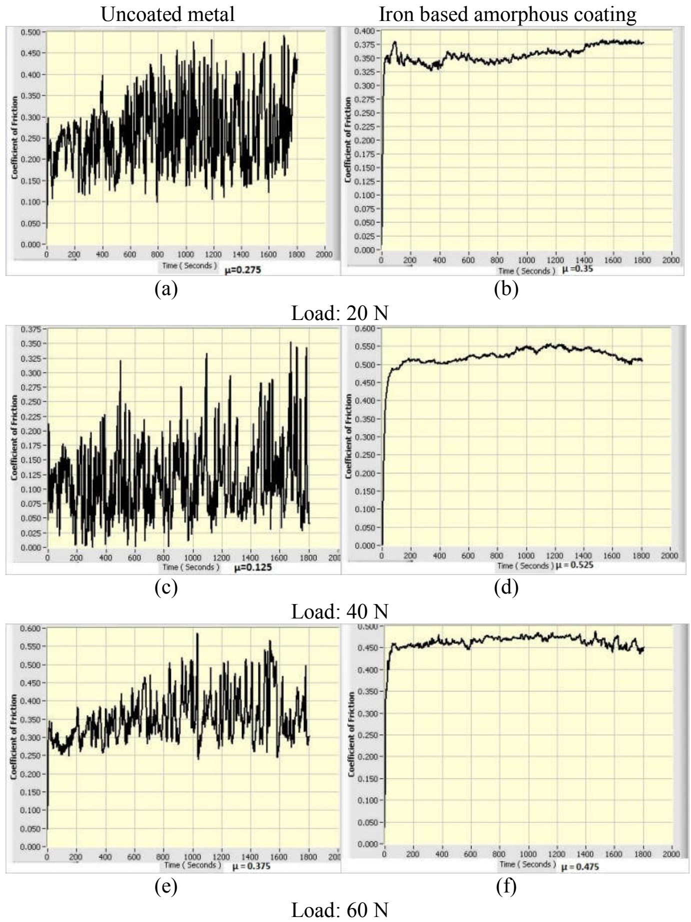
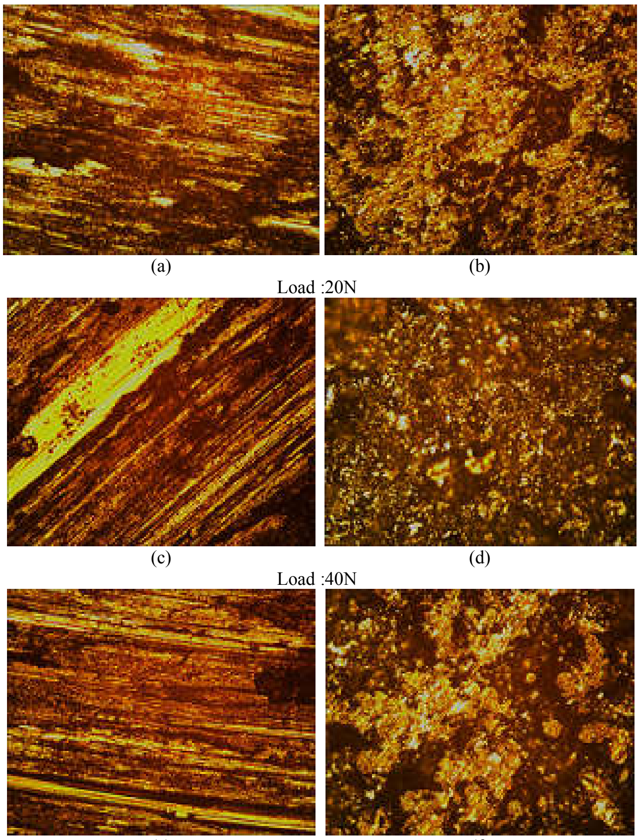


Fig 4 Effect of load on co-efficient of friction

Uncoated Iron based amorphous coating



(a) (b)
Load :20N

(c) (d)
Load :40N

(e) (f)
Load :60N

Fig 5 Effect of load on the worn surfaces morphology

Effect of Sliding Velocity

The effect of sliding velocity on the mass loss of the uncoated and the iron based amorphous metallic coated metal is shown in Fig. 6 and it is clear from that the mass loss increases with increase in sliding velocity. The tangential impact wear phenomenon which states that when the two moving surfaces are loaded, interlocking in the sliding direction may happen between the asperities of the two surfaces [14]. Actually the sliding of the two surfaces is not continuous process and the instant before the two asperities meet, two kinds of results found, depending on the rotational speed of WC disc: (1) When the speed is low, plastic deformation will produce and there is no brittle fracture occurring to the asperity and (2) when the speed is high, the tangential impact effect will cause a high stress inside the asperity and the asperity will be fractured as a wear debris.

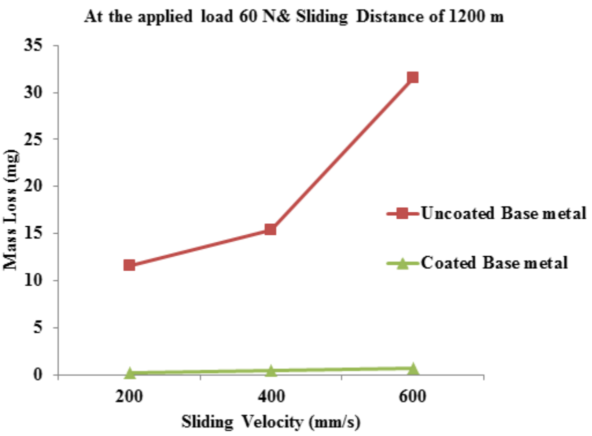
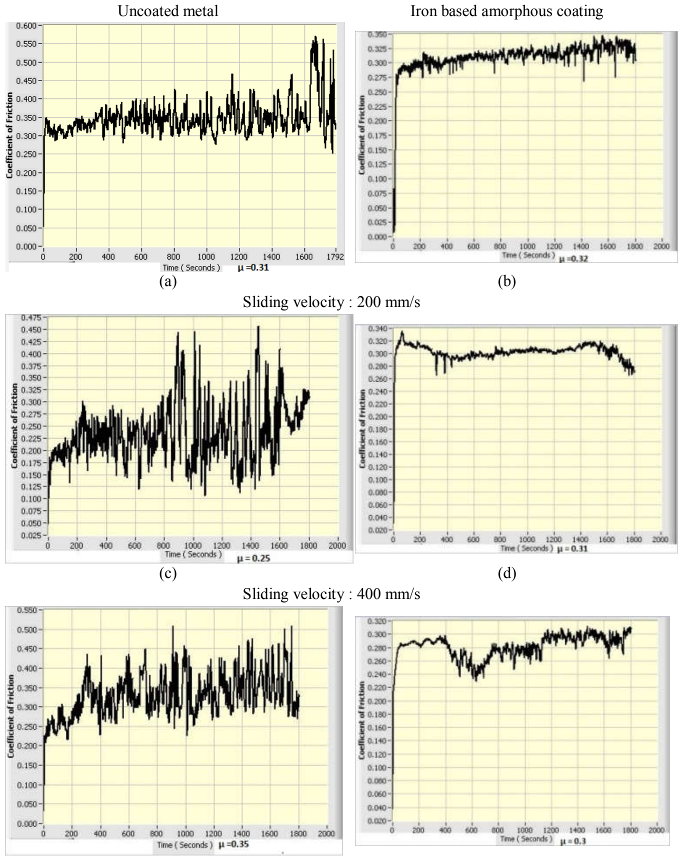


Fig 6 Effect of sliding velocity on wear characteristics



(a) (b)
Sliding velocity : 200 mm/s

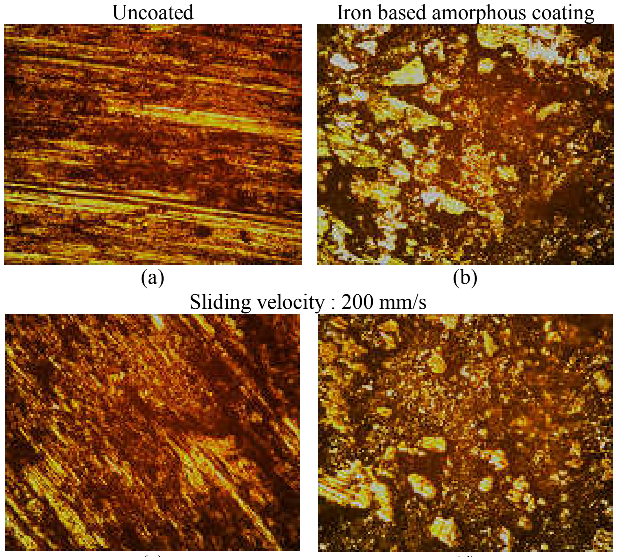
(c) (d)
Sliding velocity : 400 mm/s

(e) (f)
Sliding velocity : 600 mm/s

Fig 7 Effect of sliding velocity on co-efficient of friction

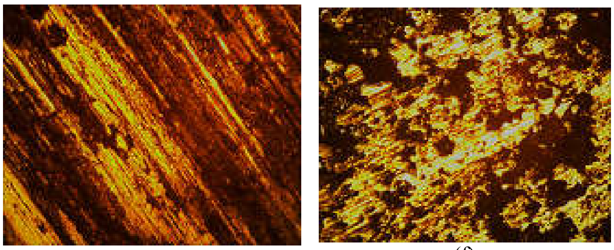
The friction coefficient profiles and optical microscopy images of the worn surfaces of the coated and the uncoated specimens are shown in Fig. 7 a-f& 8 a-f. From Fig.s 8 b, it is observed that scratching actions found on the iron based amorphous metallic coatings at 200 mm/s. In base metal (Fig.s 8 a), point contact is possible between the asperities of the specimen and tungsten carbide disc. Thus, the undulations are formed on the base metal surface by ploughing wear mechanism and it found that the contact regions of the base metal experienced plastic deformations [15].

Uncoated Iron based amorphous coating



(a) (b)
Sliding velocity : 200 mm/s

(c) (d)
Sliding velocity : 400 mm/s



(e) (f)

Sliding velocity : 600 mm/s

Fig 8 Effect of sliding velocity on the worn surfaces morphology

At sliding velocity 400 mm/s, from Fig. 8 d, the micro fracture on the surface was found to be the dominant wear mechanism. In Fig. 8 c, it is found that, surface fatigue crack may produce and mass loss increased high due to theadhesion between the surfaces of the counter body and the base metal surface.

At high sliding velocities 600 mm/s, the frictional heat is developed between tungsten carbide disc and specimen interfaces, it leads to the formation of crack initiation and crack propagations [16]. The surface fatigue crack produces with increasing speed. From Fig. 8 e, the surface fracture and cracks are increases abrupt manner and it is revealed that the propagation of the cracks is responsible for the rapid removal of the base metal from the surface and causing the heavy mass loss.

Effect of Sliding Distance

The effect of sliding distance on the dry sliding wear characteristics of the uncoated and coated metal is shown in Fig. 9. The mass loss of the material is directly proportional to the sliding distance.

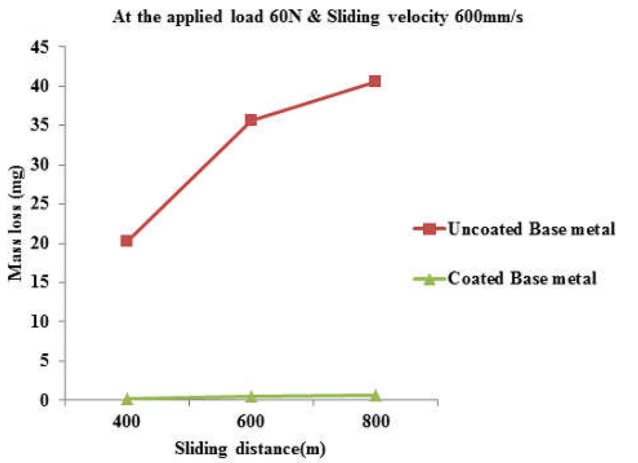
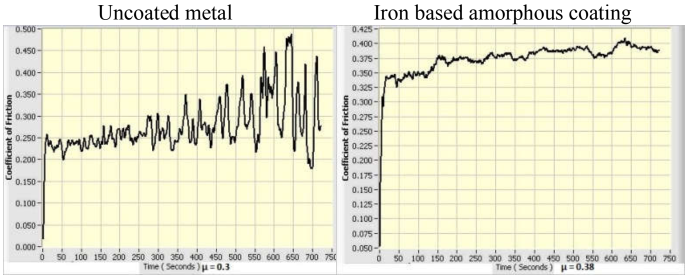


Fig 9 Effect of sliding distance on wear characteristics

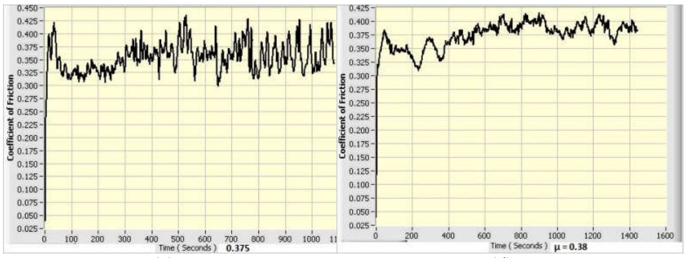
The coefficient of friction profiles and worn surfaces morphologies under different sliding distances (400, 800 &1200m) are shown in 10a-f &11 a-f.

Uncoated metal Iron based amorphous coating



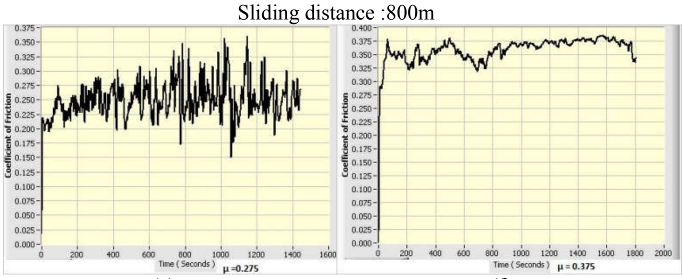
(a) (b)

Sliding distance :400m



(c) (d)

Sliding distance :800m



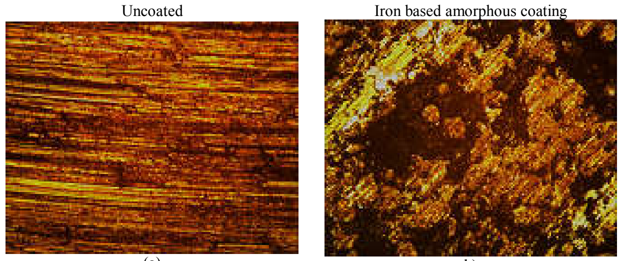
(e) (f)

Sliding distance :1200m

Fig 10 Effect of sliding distance on co-efficient of friction

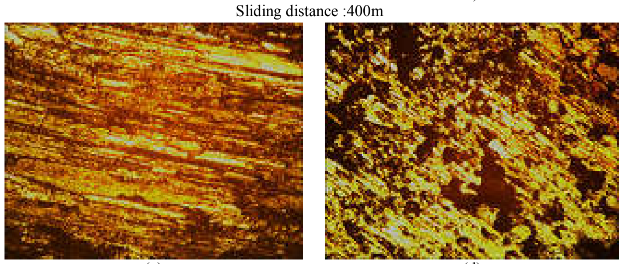
In sliding distance 400m (Fig. 11 b), Due to the thermal stability and high strength of the amorphous coating , serration marks are produced and it is revealed that the low range of sliding distance was not responsible for mass loss as shown Fig. 9. In base metal, frictional force developed between the specimen and disc interface, as the results of combination of scratching and ploughing wear mechanism takes place as shown in Fig. 11a [17]. In the sliding distance of 800m, there is no change in mass loss of coated specimens with the previous sliding distance condition (400m), whereas in the uncoated metal, the mass loss is increases in abrupt manner [18].

Uncoated Iron based amorphous coating



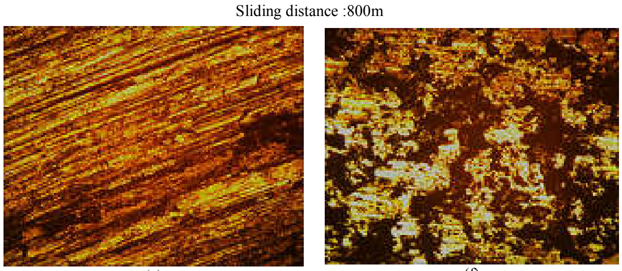
(a) b)

Sliding distance :400m



(c) (d)

Sliding distance :800m



(e) (f)

Sliding distance :1200m

Fig 11 Effect of sliding distance on the worn surfaces morphology

In base metal, the ploughing cum fatigue crack initiation wear mechanisms were occurred as shown in Fig. 11 c. During the sliding distance of 1200m, the mass loss increases rapidly due to the formation of fatigue crack and ploughing on the surface of the uncoated metal (Fig. 11 e), which produce the wear debris between the tungsten carbide disc and test specimen interface and then three body abrasion takes place instead of two body abrasion [19]. Since the heavy mass loss revealed in the base metal and produce waviness and surface irregularities on the base metal.

CONCLUSION

HVOF sprayed iron based amorphous metallic coating provides excellent dry sliding wear resistance in aggressive environments. A significant improvement was revealed in coefficient of friction of coating compared to that of uncoated AISI 316 stainless steel and the corresponding mass loss being less for coating under different operating conditions. In effect of load, the HVOF sprayed coating performs 40% better than uncoated stainless steel substrate under the applying load 60N.In effect of sliding velocity, the coating performs 45% better than uncoated metal under the maximum sliding velocity 600 mm/s. In effect of sliding distance, the coating performs 60% better than uncoated metal under the maximum sliding distance 1200 m.

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