COMPARATIVE STUDY OF WEAR BEHAVIOUR ON AL-2014 ALLOY COATED WITH THERMAL SPRAY HVOF (HIGH VELOCITY OXYGEN FUEL) AND PLASMA SPRAY METHODS – A REVIEW

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ABSTRACT

In this present review, wear are common problems encountered in the piston. In this research, Aluminium 2014 alloy with specific properties against wear was selected, and it was sprayed with high velocity oxygen fuel (HVOF), plasma spraycoating methods. The coatings have same different thickness were coated with equal percentage. The mechanical and structural characterizations were carried out with the help of Scanning Electron Microscope, Image Analyser, X-ray Diffractometer, Energy Dispersive Spectroscopy and Pin-on-disc wear testing machine. Their wear behaviour was inspected by applying 5, 10, 15 and 20N loads by pin-on-disk machine, after which the results of both methods were compared.

***Keywords**: Thermal Spray Coatings, Anodizing Coating, Pin-On-Disc, aluminum alloys, Piston.*

I. INTRODUCTION

Coating is a thin film of material bonded to metals in order to add specific surface properties, such as corrosion or oxidation resistance, colour, attractive appearance, wear resistance, electrical resistance, or thermal protection. There are many thermal spray processes currently available for depositing coatings in order to improve several surface properties of the metallic part. Out of these, the HVOF thermal spray and plasma spray process is widely used to produce wear resistant coatings and Anodizing is an electrochemical process that converts the metal surface into a decorative, durable, increases resistance to corrosion and wear, anodic oxide finish. It is the process in which finely divided metallic or non-metallic materials are deposited in a molten or semi-molten condition to form a coating. The coating material may be in the form of powder, ceramic-rod, wire, or molten materials. It is advantageous due to its ability to create a cermet-based coating having a lower level of porosity than other traditionally used thermal spray processes such as arc spraying or conventional plasma spraying.

Aluminum silicon (AlSi) matrix is a chemical composite material that can be used in many abradable coating systems due to its good combination of erosion resistance and abrdability against wear. The silicon present in the material is virtually pure, acting to increase the hardness of coatings produced from hard materials and improving abrasion resistance. Aluminum with silicon is a simple eutectic system with a low melting temperature. Dry sliding conditions are used to investigate the wear properties of these ceramics. Previous research works have investigated the effect of silicon content in ceramics on mild wear. The output has shown that adding silicon can reduce the melting temperature to 577°C (1071°F) while increasing the fluidity, specific gravity and coefficient of thermal expansion. It also decreases the contraction associated with solidification. AlSi coatings have a lower melting temperature (577°C/1071°F) than pure aluminum coatings (660°C/1220°F); therefore, AlSi is more suitable for co-spraying with temperature-sensitive materials. Such materials are thus suitable for critical applications, such as aircraft landing gear, engines, turbine blades and valves to enhance the wear and abrasion resistance of these types of components and the wear property of AlSi is very good.

II. EXPERIMENTAL SETUP AND PROCESS

Experiments are carried out to examine metallurgical, topological, and wear properties of HVOF, Plasma spray and Anodizing coating.

Materials

The substrate was made of Aluminium 2014 alloy with the following element proportions.

Table 1: Composition of Aluminium 2014 alloy

Si	**Fe**	**Cu**	**Mn**	**Cr**	**Mg**	**Ni**	**Zn**	**Ti+Zr**	**Ti**	**Other Each**	**Other Total**	**Al**
0.50-0.90	0.50 max	0.50 max	3.9-5.0	0.4-1.2	0.10 max	0.2-0.8	0.1 max	0.25 max	0.20 max	0.15 max	0.05 max	Rem

Coating methods

HVOF thermal spray coating was achieved in this study using a Sulzer-MetcoDJ 2700 hybrid with a 3-inch nozzle and propylene as fuel gas. The propylene flow rate was 198 L/min and the O2 flow rate was 347 L/min. To prevent specimen overheating during coating, compressed air with a flow rate of 758 L/min was used to cool down the specimen holder while the traverse speed of the spraying gun was maintained constant. The particles were injected in axial and central directions, the spraying distance was fixed at 230 mm and the spray rate was 38 g/min.

In this study, plasma spray coating was achieved using a plasma gun (F4) made by Sulzer Metco. The plasma parameters used to spray Al8Si20BN powder were: 250 Amp current, 63 V voltage and 123.5 and 32 L/min flow rates for Argon (Ar) as a primary gas and hydrogen (H2) as a secondary gas respectively. The spraying distance was 120 ± 3 mm (4.75 ± 0.125”) while the splash rate was 33 g/min. (4.3lb/hr). Ar gas with a flow rate of 11.4 L/min served as a carrier to inject the coating material into the plasma jet.

Anodization is the chemical change brought about by the passage of a direct current through and electrolyte via an aluminum anode and a suitable metal as cathode. Anodization of aluminum is formed by exothermic reaction on the external surface of aluminum or aluminum alloys with the nascent atomic oxygen produced by the electrolysis of an aqueous electrolyte. The electrolyte can be a solution of sulphuric acid, chromic acid, phosphoric acid and oxalic acid. The excellent corrosion resistance of pure aluminum is largely due to its affinity for oxygen. Anodization can find its use in protection application against corrosion and abrasion; and since it is an extremely versatile process capable of giving coating of great thickness, durability and highly corrosion resistance, it is therefore used for naval equipment. It is also used in interior decoration, in the design work and more also in architectural design in making of sliding door, sliding window and cotton rail. It is also use in decorating motor vehicle.

Pin on disc wear test

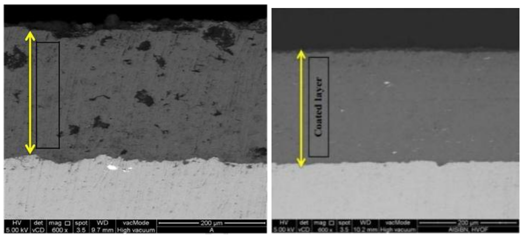
In this section, various types of physical testing were conducted, including density, porosity, micro hardness, roughness and bond strength, followed by wear testing under different loads. The coated surface was standardized by ASTM 633 and it was always a flat circle with 1” + 0/-0.005” diameter [7]. ASTM C633 was utilized to calculate the coating/substrate bond strength. The ASTM C633 Standard Test for the cohesion or adhesion power of coatings is a fundamental procedure required during tensile testing of the bond strength of thermal spray coatings and Anodizing coating.

Finally, wear testing was carried out with a pin-on-disc tester model TR-20LE. The wear tests for the uncoated and coated specimens were carried out using four loads of 5, 10, 15 and 20 N. The samples were polished with SiC sheets at 200 rpm disc speed in dry condition. The sliding speed (v=1 m/s) and track diameter (D=40 mm) were steady in all examinations. Wear testing was carried out for 60 minutes until the wear ratio of the coated specimens changed and the wear rate stabilized for each individual specimen at a sliding distance of about 9048.96 m. To enhance result reliability, each test was repeated at the same load and condition for five samples. After wear testing, the specimens were cleaned ultrasonically using ethanol and then dried. The net mass excluding debris was calculated by a high-sensitivity microbalance with accuracy of 0.0001 gm. Subsequent to wear testing, FESEM was used to observe the wear debris, worn surfaces and coating volume loss. Then a standard technique in accordance with ASTM G99-95 was applied to measure the specimens’ weight loss.

III. EXPERIMENTAL RESULT AND DISCUSSION

Morphological characterization

As seen in Fig. 1, the cross sections of the coated samples demonstrate that the deposited layer covered the substrate uniformly and adhered well. Fig. 1(a) displays a cross section of a plasma-coated sample. Here, the plasma-sprayed coating contained many pores of different sizes, and this porosity directly affected the wear and especially corrosion behaviour with this method. Unlike the HVOF spray coating in Fig. 1(b), the splat boundaries are not clear. The HVOF-coated sample had a very dense surface.

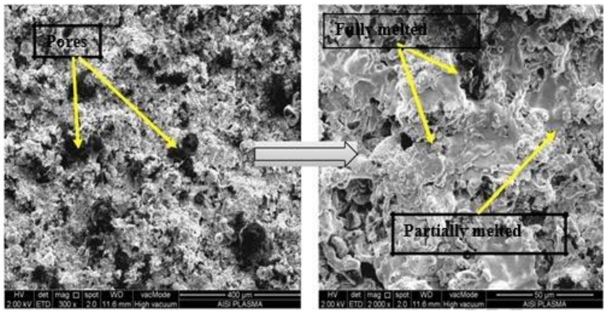


(a) Plasma *(b) HVOF*

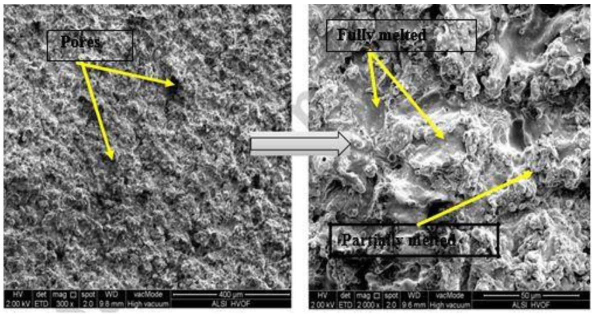
Fig. 1 Cross-section of Al-2014 coated samples for (a) Plasma (b) HVOF coating method techniques

In Fig. 2, the micrograph of this coating displays a dense microstructure with high cohesion and no surface cracks. A fully melted region is represented by the Al matrix, where Si and BN dispersed. However, during spraying, the temperature of the powder was not sufficient, so a partially melted region formed at the top of the Al matrix [7, 11]. Moreover, Fig. 2 displays a few porous areas in both coating types. Wang et al. reported platelet-like shaped BN distributed in the Al matrix and nearly interconnected pores in the Al–BN layer [8]. As reported by Bobzin et al. (2012) [5], the removed silicon particles leave pores as dark spots in the morphology. According to Figs. 2(a, b), the porosity extent and pore size in the plasma-coated samples were significantly higher than in the HVOF-coated samples.

Based on various coating formation mechanisms and plastic deformation, HVOF coatings are denser than plasma coatings [12]. This is due to the effect of the coating particles' high speed that leads to high cohesive strength of individual splats and high density [9]. As a result of the stress produced at the time of rapid solidification, cracks and pores form vertically into splats. Relatively homogenous coatings without segregation are crucial for enhancing the corrosion and wear resistance of coatings [10, 11].



(a),(b) Plasma



(c),(d) HVOF

Fig. 2 illustrates the top FESEM surfaces of samples coated by HVOF and Plasma spray methods at different magnifications.

Al2O3 and Al2SiO5 phases formed from the Al and Si powders due to the spraying system distance and arc currents, but the amount of Al2O3 was higher with HVOF than with plasma. The higher amount of Al2O3 with the HVOF method helps prolong sample life against a corrosive environment, because it exhibits a sticky property that covers the top sample surface. Sarikaya et al. [12] reported that Al tends to form in the Al2O3 phase in the coating at a greater spray distance and higher arc currents in the atmospheric plasma spray. Furthermore, the EDX of the Al-2014 composite attained with the plasma spray, HVOF and Anodizing methods

Wear behaviour

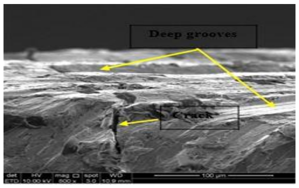
The densities of the plasma and HVOF-sprayed samples were 1.7 and 2.5 respectively. This was mainly due to the different coating formation mechanisms. In addition, the possibility of SiBN pull out from the aluminum matrix was minimal because the SiBN particles were held strongly in this matrix [14]. As shown in Table 2, the amounts of porosity in the plasma and HVOF-coated samples were 8-12% and 4-7% respectively. The plasma coatings were not as dense as the HVOF coatings, as reflected by the pull out following metallographic preparation. The higher density in the HVOF coatings prevented complete pull out from occurring.

Table 2:- illustrates the physical properties of the coated samples.

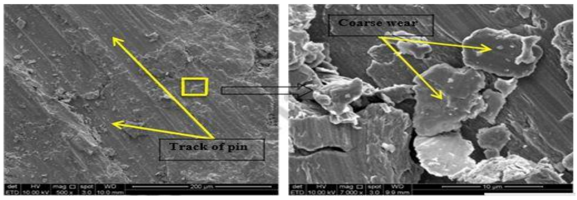
Samples	Density (g/cm3)	Porosity (Vol%)	Hardness (hV)	Bonding strength (Psi)	Roughness (μm)
HVOF-sprayed	2.5	4-7%	240	2000-2700	4.8
Plasma-sprayed	1.7	8-12%	175	1500-2000	4.0

The samples coated by plasma and HVOF methods attained average micro hardness of 175 and 220 HV respectively. The hardness in the aluminum region was lower and higher in the SiBN region. In addition, coating density directly affected coating hardness, which is why the HVOF sample hardness was higher than that of the plasma-coated sample. According to Bobzin et al. [5], the average micro hardness of this chemical composition coated using the plasma method is around 165 HV. Rolink et al. also indicated that the micro hardness of Al20Si is around 157 HV [15].

In terms of application, it is important for the bond strength between the coated layer and substrate to be high enough to increase the coating's service life [10, 14]. For this reason, all samples in this research work were coated to achieve high adhesion (bonding) strength. A comparison of the bonding strength of both coated samples indicates that the bond strength for plasma with 1500-2000 Psi was lower than HVOF-coated samples with 2000-2700 Psi. This finding is supported by Wu et al.'s results (2006) [16].



(a) FESEM-800x



(b) FESEM-500x(c) FESEM-7000x

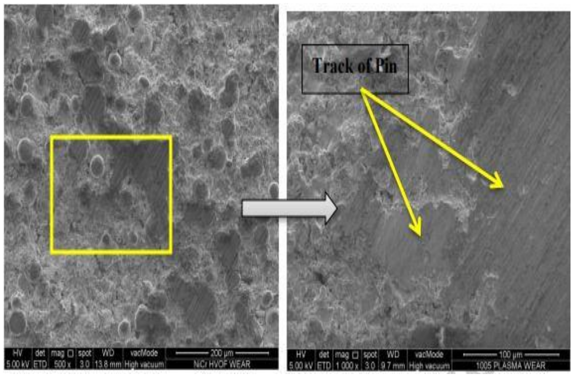
Fig 3 - FESEM images for carbon steel samples at maximum load (20 N)

Fig. 3(a) represents a remarkable crack that ended in deformation after load exertion at the edge of the substrate surface. In Fig. 4(b), it is evident that the carbon-steel model was worn. Deep and wide grooves formed on the surface at the end of wear testing and the wear tracks became visible on the entire surface. These wear tracks were made during the wear test with the pin-on-disc device. Conforming to Fig. 4(c), the higher magnification clearly shows the worn carbon steel sample surface and the wear debris. This investigation signifies that due to the remarkably high load on the substrate, the carbon steel surface lost a noticeable amount of components and the surface roughened on account of the wear debris.

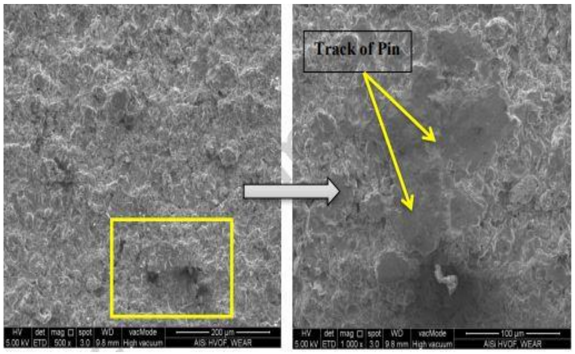
According to Figs. 4(a, b), the pin track on the plasma-coated sample is significantly clearer than with HVOF in Figs. 5(c, d). Besides, the rate of material removal from the plasma-coated sample surface was considerably higher than from the HVOF-coated sample. This observation indicates that this load was too high for the plasma-coated sample. The presence of voids in the plasma coating additionally increased coating loss [18]. As a result, the plasma-sprayed coating had lower wear resistance, because when maximum load was applied, the coated sample surface was more worn than that of the HVOF sample and the pin track was obvious. This happened mainly because of the abundant porosity on the coated sample surface [11, 15].

Furthermore, Lei et al. (2014) [5] reported that the soft aluminum-rich matrix wears off quickly, but the hard SiBN particles decelerate the wear process. This is associated with the elevated bonding strength between the splats and component as well as the significant role that bond strength may have in splat propagation and resistance to crack initiation [18]. According to the FESEMs of plasma-sprayed coatings in Figs. 4(a, b), depositions formed by molten or partially molten droplets and the coated samples possessed a certain amount of porosity. In Figs. 4(c, d), there was minimal possibility of SiBN in the aluminum matrix of the HVOF-sprayed coating because this matrix held the SiBN particles strongly and the deposited layer was very dense [4, 6, 7 and 18].

The average wear and weight loss rates for carbon steel and plasma- and HVOF-coated samples, respectively, under 5, 10, 15 and 20 N loads. According to Table 2, the average wear with the plasma method changed from 200 to 657 mg under different loads, while with HVOF, the average wear changed from 68 to 107 mg. This proves the greater average wear with the former method compared to the latter. The maximum wear values for plasma-coated samples were 80, 91, 103 and 120 mg for loads of 5, 10, 15 and 20 N respectively. It is observed that when loads were applied on the coated and carbon steel samples, the wear rate of the coated sample changed slightly. In contrast, the wear rate of the carbon steel sample changed significantly. The high wear rate on the carbon steel sample was a result of the rapidly increasing friction. The weight loss trends of the carbon steel, plasma and HVOF samples confirm the average wear results. The weight loss rate for carbon steel changed between 2.3121% and 8.2035%. It can be seen that when the load on the carbon steel sample increased from 15 to 20 N, the weight loss was twice greater, from 4.0926% to 8.2035%. For plasma-coated samples the weight loss changed from 0.0196% to 0.0501%, while for the HVOF-coated samples, the rate changed from 0.0163% to 0.0431%. Therefore, the HVOF-coated samples exhibited the highest wear resistance.



(a) FESEM-500X (b) FESEM-1000X



(c) FESEM-500X (d) FESEM-1000X

Fig.4 FESEM of wear debris of Al-2014 coated samples under maximum load (20 N) for (a), (b) plasma coating, and (c), (d) HVOF coating.

IV. CONCLUSION

According to the microstructural analysis as wear testing, the HVOF-sprayed specimens performed better than the plasma-sprayed specimens. The wear properties of HVOF-coated samples under different loads showed greater durability and the weight loss rate of these samples was limited, especially under 5 and 10 N loads. Therefore, for this chemical composition the HVOF method outperformed the plasma method in terms of wear and corrosion resistance.

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