Malaysian Journal of Microscopy 10: 118-124 (2014) ISSN: 1823-7010

MECHANICAL AND WEAR PROPERTIES OF ALUMINIUM COATING PREPARED BY COLD SPRAYING

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In this study, aluminum (Al) powders were deposited onto Al substrates using cold spray to form a coating. The main objective is to investigate and compare the microstructure, mechanical and wear properties of Al coating to that of the Al substrate. The microstructure of the coating and substrate were observed using Scanning Electron Microscope (SEM). Hardness was evaluated using the Vickers Hardness test and wear properties were investigated using a pin-on-disk wear test machine. The elemental composition of the coating and substrate was determined using Energy-dispersive X-ray spectroscopy (EDX). Results showed that the friction coefficient and specific wear rate decreased while wear rate increased linearly with increasing load. It was found that the coating exhibit slightly better mechanical and wear properties compared to the substrate.

Keywords: Al, wear, friction coefficient, specific wear rate

INTRODUCTION

Aluminium (Al) alloys are becoming increasingly important in various types of industries. It plays an important role in aerospace and automotive applications because of the low density and high strength-to-weight ratios with high corrosion resistant properties [1]. However, damage might occur in lightweight components and Al is highly susceptible to severe wear [2] and cracks [3]. In order to protect Al alloys from wear risks and structural damage, a metal protective coating must be applied [4]. Numerous studies have been conducted in the past to investigate the wear behavior of metal coating produced by traditional thermal spray process such as flame, plasma, HVOF, and HVAF. The disadvantages of these processes are the highly sensitive microstructure of the coatings and their mechanical properties that could be easily altered by the heat treatment process thus affecting its corrosion behavior [5]. Thus, to overcome these problems cold spray can be used as an alternative coating technique. Cold spray is the process that produces coating with a very low oxygen and porosity content [6-7]. Powder particles are accelerated to a velocity ranging from 200 m/s to 1200 m/s through a de Laval nozzle (or convergent-divergent nozzle) by a supersonic compressed gas jet at a temperature below the melting point of the powder material [8]. The velocity is approximately 200 – 1200 m/s depending on the particle size and shape, type of process gas and process conditions such as pressure

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and temperature [8]. Bonding in cold spray occurs when the powder particles impact on to the substrate. This process depends on elemental composition, hardness, wear rate, specific wear rate and friction of coefficient of the Al coating were studied and compared to Al substrate.

MATERIALS AND METHODS

Cold Spray Deposition

The coating samples were fabricated using the high-pressure type cold spray system, PCS-203(Plasma Giken Kogyo Co. Ltd, Japan). Feedstock powder of pure aluminium (AL G-AT, Fukuda Metal Foil & Powder Corporation) was used. Fig. 1 shows the schematic diagram of the cold spray system. Aluminium 1050 was used as the substrate. The particle diameter of the powder is 25 µm. Helium was used as a working gas for cold spray process (2.0 MPa). The initial temperature particle and substrate were set at 300K. The nozzle-substrate standoff distance was fixed at 20 mm.

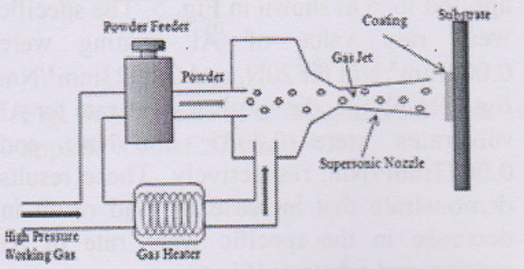

Fig. 1. *Schematic diagram of cold spray.*

Mechanical and Wear Tests

The micro hardness of coating and substrate was measured using Vickers hardness test machine. Friction and wear test was performed with a pin-on-disc type wear test machine according to the standard G99 ASTM standard test method. The samples were fixed on the handle bar of the pin-on-disc machine pressed on the rotating disk as shown in Fig. 2. The wear test parameters are given in Table 1.

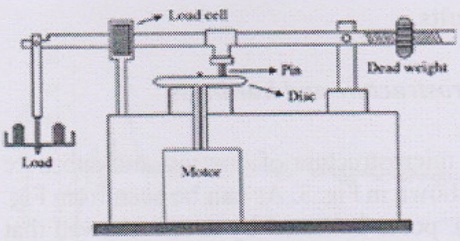

Fig. 2. **Fig. 2:** *Schematic diagram of pin-on-disc wear test machine.*

Table 1. *Wear test parameters.*

Parameters	Selected value
Applied load (N)	20, 30 and 40
Velocity (m/s)	0.1
Speed of motor (rpm)	200
Sliding distance (m)	1000
Track diameter (mm)	95
Time (s)	1005

Characterization

The samples were cut using Buehler Isomet Precision Saw. The cutter speed was set to low speed setting which are 100 rpm. Then, the samples were mounted using cold mounting technique. The mounting materials used are resin from Struers Epoxy kit that includes epoxy resin and epoxy hardener. In order to obtain a highly reflective surface that is free from scratches and deformation, the samples must be carefully grinded and polished before they can be examined under the microscope. The samples were grinded using Silicon Carbide papers of 800 and 1000 grit sizes. Then, in the polishing process, a diamond solution was used as the polisher. The cross-sectional microstructures, surface morphologies and wear tracks were examined using SEM (Hitachi SU1510). The elemental composition of coating and substrate were determined by EDX.

Results

Microstructure and hardness

The microstructure of coating and substrate are shown in Fig. 3. As can be seen from Fig. 3 (a), pores indicated by arrow showed that Al coating exhibit smaller pores formed between particles compared to substrate in Fig. 3(b). This is because the powder particles were fully deformed and have a good bonding between particles in coating. Therefore, size of pores formed between particles can be reduced. Micro hardness of Al coating and Al substrate are shown in Table 2. Al coating has higher hardness of 56.3 HV compared with Al substrate hardness of 44.8 HV. This is due to the lower porosity value as shown in Fig. 3 which is only 1.18% compared to 4.07% of Al substrate. It can be seen that lower porosity can contribute to higher hardness.

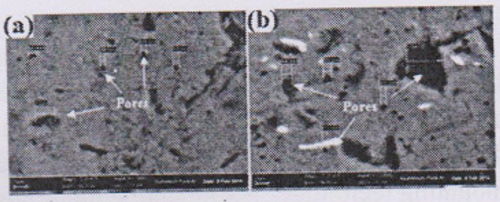

Fig. 2: *SEM images of (a) Al coating, and (b) Al substrate with pores before wear test.*

Table 2. *Micro-hardness test and porosity results.*

Category	Micro-hardness (HV)	Porosity (%)
Coating	56.3	1.18
Substrate	44.8	4.07

Wear

Wear and friction tests were performed on a pin-on-disc wear test machine. Fig. 4 (a) and (b) show wear load and frictional force of Al coating and Al substrate as a function of time under 20N which are used to calculate the wear rate and the specific wear

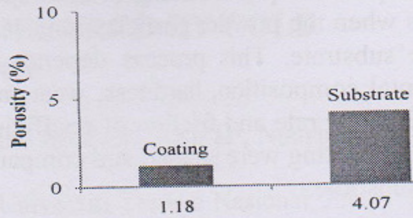

Fig. 3.*Porosity of the coating and substrate.*

rate. The wear rate and specific wear rate are given as;

$$\dot{W} = \frac{V}{F_n d} = mm^3/Nm. \quad (1)$$

$$\dot{V} = K\dot{W} \quad (2)$$

Where $\dot{W}$ is a specific wear rate, which is simply the wear volume, v divided by the product of the normal load, F_n and sliding distance, d. $\dot{V}$ is the wear rate and K is the wear constant.

The wear rate of Al coating and Al substrate ranged from 0.05mm³/m, and 0.09mm³/m, directly proportional to the applied load as shown in Fig. 5. The specific wear rate value of Al coating were 0.004mm³/Nm for 20N, and 0.0023mm³/Nm for 40N. While, the specific wear rate for Al substrates were 0.0025 mm³/Nm, and 0.0023mm³/Nm, respectively. These results demonstrate that increase in load result in decrease in the specific wear rate of Al coating and substrate (Fig.6).

Figure 7 shows the variation of friction coefficient of Al coating and Al substrate depending on applied load. The friction coefficient of Al coating changed from 0.4 for 20N to 0.3 for 40N. For Al substrate, the friction coefficient changed from 0.42 to 0.3 for 20 N and 40 N respectively. These results clearly showed that friction coefficient of Al coating exhibited lower friction coefficient than Al substrate.

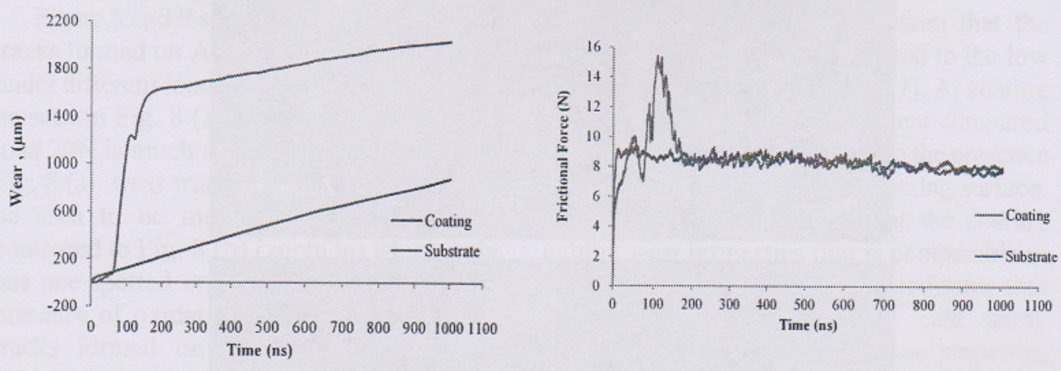

Fig. 4: (a) Wear load (b) frictional force of the Al coating and substrate as a function of time for 20N.

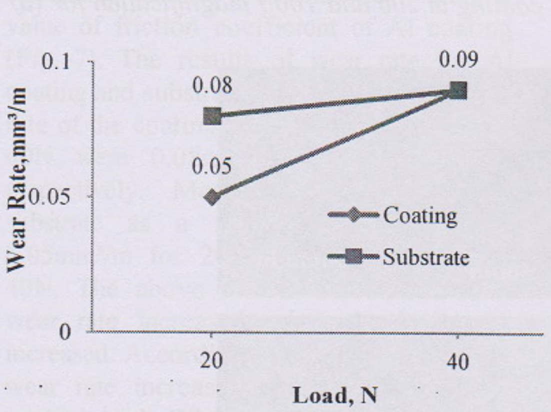

Fig. 5: Wear rate of coating and substrate as applied load of 20N and 40N.

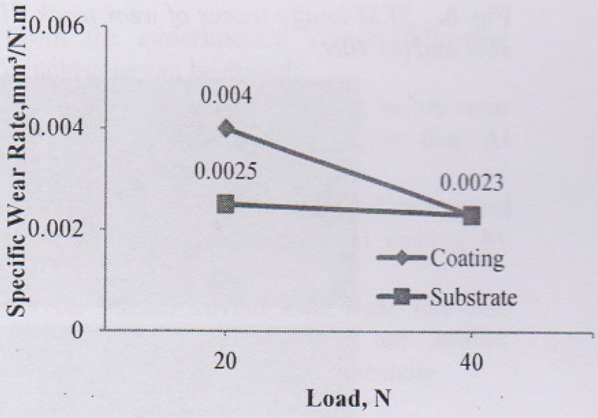

Fig. 6: Specific wear rate of coating and substrate as applied load of 20N and 40N.

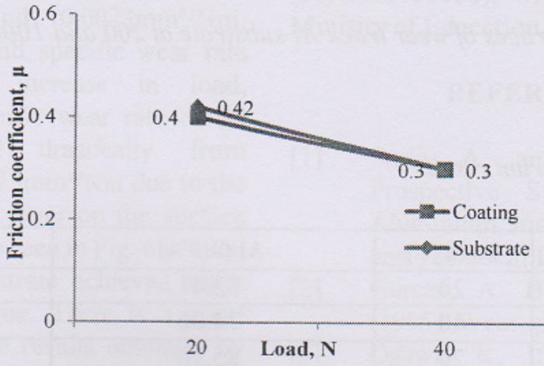

Fig. 7: Friction coefficient of coating and substrate under different loads of 20N and 40N.

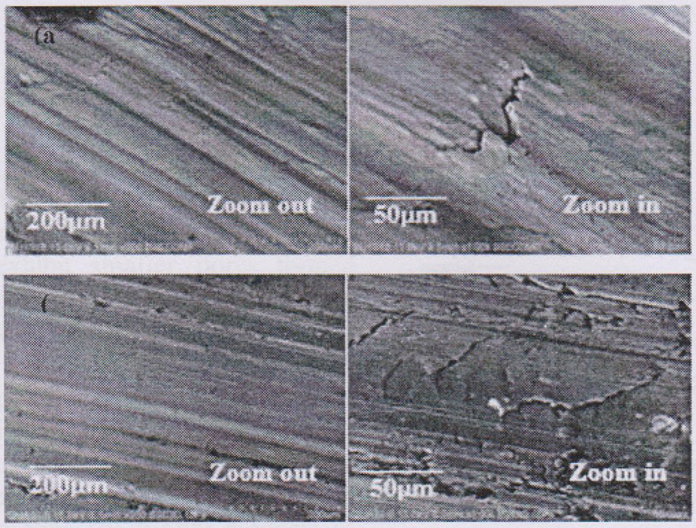

Fig. 8. *SEM image traces of wear track Al coating at 200 and 1000 magnification for (a) 20N and (b) 40N.*

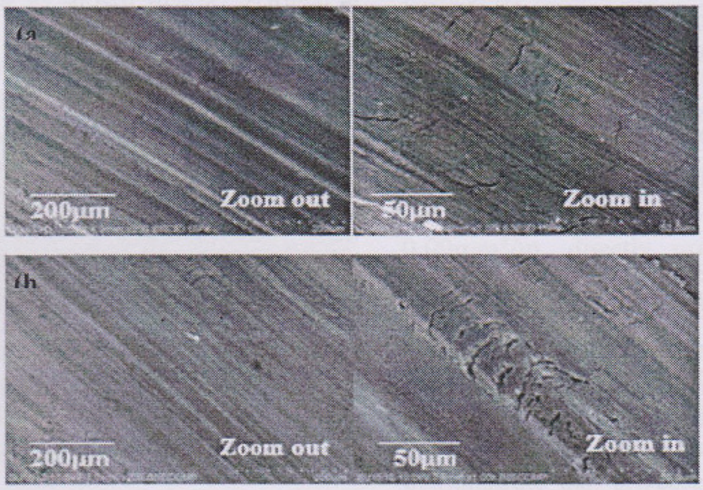

Fig. 9. *SEM image traces of wear track Al substrate at 200 and 1000 magnification for (a) 20N and (b) 40N.*

TABLE 3. *EDX spectrum results*

Layer	Load (N)	Al (at. %)	O (at. %)
Coating	20	82.41	17.59
	40	74.06	25.94
Substrate	20	85.96	14.36
	40	93.88	6.03

Figure 8 and 9 shows SEM image of wear tracks formed on Al coating and Al substrate under different loads, 20N and 40N. As it can be seen in Fig. 8 (zoom out), wear tracks of load 20N is much smoother than 40N. From Fig. 8 (a), wear tracks (zoom in) surface can be seen to be more coarse and ruptured compared to Fig. 8 (b) (zoom in) which only has one spotted crack surface owing to the presence of oxidation. SEM image of wear tracks formed on Fig. 9 shows that Al substrates have regular surface profile. The presence of oxidation was detected by EDX analysis are given in Table 3. The presence of oxidation of Al coating was higher resulting to the increase of oxide layer formation. Thus, it will contribute to the low value of friction coefficient of Al coating (Fig. 7). The results of wear rate for Al coating and substrate shown in Fig. 5. Wear rate of the coating at applied load 20N and 40N were $0.08 mm^3/m$ and $0.09 mm^3/m$, respectively. Meanwhile, wear rate of substrate as a function of load were $0.05 mm^3/m$ for 20N, and $0.09 mm^3/m$ for 40N. The above results demonstrate that wear rate increased when the load was increased. According to the Asuke et al., [9] wear rate increases with the increase in applied load. When applied load is small, wear loss is quite small. The specific wear rate of Al coating were $0.004 mm^3/Nm$ for 20N, and $0.0023 mm^3/Nm$ for 40N. Whereas, for Al substrates the specific wear rate were $0.0025 mm^3/Nm$, and $0.0023 mm^3/Nm$, respectively. As a result specific wear rate decreases with an increase in load, respectively. The specific wear rate of Al coating is reduced drastically from $0.004 mm^3/Nm$ to $0.0023 mm^3/Nm$ due to the effectiveness of oxide layer on the surface (Fig. 6). Also, as can be seen in Fig. 6 at 40N, both coating and substrate achieved same specific wear rate value. There is a good agreement between the results obtained by this study with Scot et al. [10]. A study performed by Scot et al. [10] claimed that the oxidation layer forming on the surface may contribute to the decrease in the specific wear rate. Also, it is possible to claim that the formation of oxide layer can lead to the low friction coefficient value (Fig. 7). Al coating exhibits lower friction coefficient compared to the substrate. This is owing to the presence of oxidation forming on the coating surface. These results demonstrate that the coating exhibit wear properties that is comparable to the substrate. Overall finding indicates that Al coating deposited using cold spray possess good mechanical and wear properties which makes it a potentially effective protective coating to prevent surface from wear.

CONCLUSION

From the experimental results following conclusions can be stated:

- Micro-hardness of Al coating before wear test reached to56.3HV, higher that Al substrate (44.8HV).
- Low friction coefficients indicate good tribological properties of Al coating by cold spray method.
- Wear studies reveal that wear rate and specific wear rate value are similar between Al coating and Al substrate.

ACKNOWLEDGMENTS

This study was supported by the Fundamental Research Grant Scheme (FRGS20130108), which is funded by the Ministry of Education.

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