POTENTIAL OF PALM OIL CLINKER AS REINFORCEMENT IN ALUMINIUM MATRIX COMPOSITES FOR TRIBOLOGICAL APPLICATIONS

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ABSTRACT

This research studied the potential of palm oil clinker as reinforcement in composite based aluminium for tribological applications. Palm oil clinker particle (POCp) reinforced aluminium matrix composites at different weight % of POCp (0 – 20 %) were fabricated via powder metallurgy technique. Sliding wear behaviour of the composites was studied against mild steel mating surface using Pin-On-Disc configuration at different applied load (3 – 51 N), sliding distances (0 – 500 m) and sliding velocities (0.55 m/s). The analysis of worn surface and subsurface was studied using a scanning electron microscope (SEM). The results indicate that the composites exhibited better wear resistance at applied load below than 11 N. From surface morphology (SEM study), the presence of POCp in the composite enhance the wear resistance performance of aluminium matrix. From the practical perspective, POCp has highly potential to be utilised as reinforcement in order to improve wear resistance of aluminium in tribological applications.

Keywords: Palm oil clinker, Aluminium composite, Reinforcement, Sliding wear

1. INTRODUCTION

Since the half decade, materials design has shifted emphasis to pursue light weight, environment friendliness, low cost, quality and performance. Parallel to this trend, aluminium matrix composites have been attracting growing interest due to several factors such as reduced material and fabrication costs, can be forming into near net shape component and offered good mechanical as well as tribological properties. Another significant factor is that aluminium matrix composite can be greatly enhanced by incorporating reinforcing of variety reinforcement (usually ceramic). Aluminium alloy especially Al-Si alloys have been used for tribological application as reported Anasyida et al., (2009). Recently, aluminium matrix composites have been successfully used in tribological applications (Chawla and Chawla, 2006). Based on previous works, the main reinforcements material used in aluminium matrix composite are silicon carbide (Lin and Liu, 1988; Cao et al., 1990; Wang et al., 1995; Iwai et al., 1995; Martin et al., 1996; Wilson and Alpas, 1997; Venkatamaran and Sundarajan, 2000; Shorowordi et al., 2004; Miyajima and Iwai, 2003; Ramesh and Safiulla, 2007; Das et al., 2008; Saidur et al., 2008; Jahirul et al., 2007). alumina (Surappa et al., 1982; Narayan et al., 1995; Jiang and Tan, 1996; Zhang et al., 1997; Zhang et al., 1998; How and Baker, 1999; Modi, 2001; Rosenberger et al., 2005; Hamid et al., 2006; Yang, 2007), graphite (Pai et al., 1974; Krishan et al., 1980; Biswas and Pramila-Bai, 1981; Gibson et al., 1984; Das et al., 1989; Liu et al., 1992; Lin et al., 1998; Goto and Uchijo, 2005; Yang et al., 2004) and fly ash (Ramachandran and Radhakrishna, 2005, 2007). Many other possible reinforcements are readily available or naturally renewable at affordable cost such as coconut shell char, mica, palm-kernel shell char and zircon (Ejiofor and Reddy, 1997).

Currently, the interest of researchers in using natural material as reinforcement for metal matrix composite is increased (Murali et al., 1982; Ejiofor and Reddy, 1997; Ramachandran and Radhakrishna, 2005, 2007). Biomass waste materials likes palm oil clinker particles (POCp) also natural materials believed possible to be used as reinforcement in metal composite. POCp are biomass waste materials from palm oil factory and can be obtained in Malaysia. To date, research and development activities had been undertaken to further develop downstream products related to biomass. The focus is on promoting the utilization of biomass materials in products such as bio plastic and metal composite. One of five strategic thrusts in Industrial Master Plan 3 (IMP3) have been set to strengthen Malaysia’s position as a competitive, reliable and technologically capable producer and exporter of palm oil products is to expanding and diversifying product. Biomass products is one of targeted growth area will be promoted (IMP3, 2006). Biomass products included panel product, such as fibreboards, particle boards derived from empty fruit bunches and ‘green plywood’, moulded automotive
components and food grade packaging, pulp and paper, and composite materials. Although the research and development activities in palm oil industry had been undertaken to further develop downstream products related to biomass in Malaysia, there is still a lack of systematic research on that, especially in metal reinforcing composite. Information obtained from the past study would be able to a baseline understanding on the fabrication of metal composite especially aluminium matrix composite reinforced with biomass materials such as waste material from palm oil factory likes POCp. So, in order to utilize the biomass materials especially POCp, in metal composite fabrication, this work attempts to fabricate new metal composite via powder metallurgy route using POCp as reinforcement in matrix aluminium followed with wear behaviour studies.

Currently, one of major driving forces for the technological development of aluminium matrix composite (AMC) reinforced with ceramic particles is a result of these composite posses superior wear resistance and hence potential candidate materials for a number of tribological application. Application is in which are subjected to mechanical wear include pistons and cylinder liners in car engine and automotive disk brake in vehicles (Garcia-cordovilla et al., 1996). From the practical perspective, the finding of this study is also important for the development of palm oil industry in Malaysia. It can help the country to formulate the right and appropriate strategies to promote sustainable approaches in generating higher value-added natural and plant-based products and adopting of zero waste strategy.

Previously, researchers who studied the wear behaviour on AMC have been proposed some type of wear mechanisms such as delamination wear mechanism. (Alpas and Zhang, 1992; Wang et al., 1995; Venkatamaran and Sundarajan, 1996). Wang et al. (1995) studied the wear behaviour and microstructural changes of 20vol.%SiCp/Al composite under dry sliding using pin-on-ring configuration for a range of load (10 – 80N and sliding speed (1.34 – 5.00 m/s). Their composites were prepared by squeeze casting method followed by extrusion. They found that at heavy load, volume loss was high, the dominating wear mechanisms were adhesion and delamination wear. In SiC whiskers reinforced aluminium composites, the whiskers plays an important role. At depth of about 30µm below the surface, the shear strain was more than 1.3. The large plastic strain in the deformed layers gave rise to void nucleation and subsurface crack initiation and propagation.

The subsurface cracks initiated and propagated along whisker-matrix interfaces and resulted decohesion of whisker-matrix. Crack propagation by SiC-matrix decohesion process has been observed in SiC particulate reinforced aluminium-silicon alloys (Alpas and Zhang, 1992). The cracks will link to long cracks. With removal of surface material, the cracks become nearer to the surface and the shear strain is increased, this causes the removal of the surface layers by delamination. Delamination wear and the associated nucleation of voids at SiCp/matrix interface during the dry sliding of MMC pin against a steel counter face also reported by Venkatamaran and Sundarajan (1996).

Base on the previous literature, study the wear behaviour and mechanism on this new metal composite is one of the objectives of this work. Shortly, the objectives of this works are; (i) to develop a new metal composite via powder metallurgy route (ii) to utilize the POCp as reinforcement in aluminium matrix composite (iii) to study the wear behaviour of this composite.

2. MATERIALS AND METHOD

The materials used were pure Al and pure Al reinforced with 5-20 wt. % POC particles of 125 µm size. Pure Al particles supplied by “Sigma-Aldrich” German and the chemical composition of aluminium powder is 0.5 wt. % Fe, 0.03 wt.% Pb and 99.7 wt. % aluminium. Whereas, the POC particles supplied by “Palm Oil Factory, Felda Jerangau”, Malaysia and the chemical composition of POC particles based on EDX analysis is 4.8 wt. % Si, 5.48 wt. % O and 89.72 wt. % C. Depending on the reinforcements content, five different weight percents were prepared as shown in Table 1. Specimen of pure Al was used as reference.

<table>
<thead>
<tr>
<th>Material</th>
<th>Pure Al</th>
<th>POCp</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al</td>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>Al/5 wt.%POCp</td>
<td>95</td>
<td>5</td>
</tr>
<tr>
<td>Al/10 wt.%POCp</td>
<td>90</td>
<td>10</td>
</tr>
<tr>
<td>Al/15 wt.%POCp</td>
<td>85</td>
<td>15</td>
</tr>
<tr>
<td>Al/20 wt.%POCp</td>
<td>80</td>
<td>20</td>
</tr>
</tbody>
</table>

For the fabrication of composites, particles of POC in a form of irregular shape were used as reinforcement (Fig. 1a) and mixed with Al particles in a form of flaky shape (Fig. 1b) using rotational mixing at 95 RPM for 10 minutes and followed by compaction process using Universal Tensile Machine. The specimens were cold pressed in a steel die with 250 MPa applied pressure, then sintered for 2 hours at 500 °C in carbolite furnace. The pure Al and composites were pressed into a pin of length 15 mm with a flat surface of 8 mm in diameter at the both ends. Water displacement (Archimedes) method was used...
for bulk density measurement. A micro balancer with accuracy of 10^{-4} g was used. The specimens were weighed dry, immersed in water (after vacuumed for 1 hr) and right after the specimen removed from water. The density and porosity of each specimen were calculated.

Dry sliding experiments were conducted in air at room temperature using a pin-on-disc technique. The disc which acted as the mating surface material was made of mild steel (120 HV) cut from commercial mild steel sheet (2 mm thickness) into 100 mm diameter. The influence of the applied load was investigated under a constant sliding velocity of 0.55 m/s (150 RPM on 70 mm diameter sliding track) with the applied loads at 3 N, 11 N and 51 N. The wear of the pins was recorded by measuring the weight loss of the material at 100 m, 200 m, 300 m and 500 m. The weight loss recorded was converted to a volume loss by dividing with density of materials. All specimens followed a single track of 70 mm diameter and the mild steel disc was changed for each surface of tested pin. The tests were repeated at least twice under the same operating conditions. Before each measurement, the pin was blown dry in air. Three readings were made for each weighing and the mean taken. In order to investigate the degree of influence of sliding distance, applied load and content of reinforcement to wear characteristic, the results have been treated based on quantitative approach.

The morphology of the raw materials was studied by scanning electron microscope (SEM JOEL 6460LA - Japan). The distribution of particles and porosity was determined by microstructure of the material studied. The microscopic examination of the pure Al and the composites after wear test was done by optical microscope. Worn surfaces and cross-section of worn surfaces were observed by optical microscope and scanning electron microscope (SEM). The debris collected during experiments was examined by SEM with EDX analysis.

3. RESULTS AND DISCUSSION

Figure 1 shows the SEM micrographs of monolithic pure Al particles and POC particles. Figure (1a and 1b) obviously shows the flaky shape particles of pure Al and irregular shape particles of POC respectively. The POC particles were used as reinforcement and mixed with pure Al particles to produce composite. Figure (2a and b) shows the optical micrograph of pure Al specimen and pure Al/20 wt. % POC composite respectively. It is seen that the reinforcement is homogeneously distributed in matrix pure Al as shown in figure 2a.

Figure 3 shows the wear curves of the Al/POCp composite specimens with various wt. % of POCp tested under different applied load of 3 N, 11 N and 51 N. Figure 3a clearly shows that the influence of wt. % POCp on volume loss. The pure Al specimen underwent large volume loss during the early stage of the test. For all Al/POCp composite specimens underwent small volume loss during early stage but after 200 m sliding distances, the Al/5 wt. % POCp specimen underwent volume loss increases drastically compare to others. It clearly shows Al/20 wt. % POCp maintains the lowest volume loss until 500 m sliding distance. This trend indicates significant role of POCp content in improving the wear resistance of pure Al matrix.

In order to clarify the influence of POCp content on wear rate of Al/POCp composites subjected under different applied load (3 N, 11 N and 51 N), the wear sliding testing results are plotted into cumulative wear rate at 500 m sliding distance versus POCp content (Fig. 4). It is seen that the cumulative wear rates of composite slightly decrease with increasing POCp content when tested under 3 N and 11 N, however cumulative wear rates tested under 51 N decrease at lower wt. % POCp but increases as the wt. % of POCp increases. The presence of POCp in the aluminium matrix enhanced the wear performance of the pure aluminium. This demonstrates that the POCp content has significant influence on the wear behaviour of Al/POCp composite at lower applied load. The results of SEM examination of the worn
surfaces of the composites with different amounts of POCp are shown in Fig. 5.

The micrograph of pure Al (Fig. 5a) clearly indicated that the worn surface is characterized by fairly long continuous grooves, where the material is removed from surface during wearing. Fig. 5b shows the worn surface of Al/5 wt. % POCp clearly revealed the presence of wide and long continuous grooves and plastic deformation. The wear tracks in the pure aluminium matrix and Al/5 wt. % POCp indicating plough-shape appearance material are displaced to the sides of wear tracks. Severe plastic ploughing can be observed in the pure aluminium matrix and Al/5 wt. % POCp, but they were reduced in the higher POCp content composites.

![Figure 3: Volume loss versus sliding distance of various POCp content tested.](image)

![Figure 4: Cumulative wear rate at 500 m sliding distance versus content of POCp at different applied load.](image)

Figure 3 Volume loss versus sliding distance of various POCp content tested; (a) at 3 N; (b) at 11 N; (c) at 51 N

The worn surfaces of the composites (Figures 5c to 5e) are different from that of the pure Al. The higher content of POCp in the aluminium matrix, produce shallower grooves on the worn surface, and consequently less plastic deformation are found during wear process. The presence of wear debris can be seen on the worn surfaces whereby the wear debris is increased with increasing POCp content in the Al matrix as shown in Fig. 5c to Fig. 5e. The debris was found fine particles may consist of POCp. The fine debris on the worn surfaces of composites may function as lubricant at sliding surface contact and contribute to reducing the wear rate of composites. The presence of wear debris indicates the probability of delamination during wear.

![Figure 6: Cross section of worn surfaces parallel to sliding direction of pure Al.](image)

Figure 6 shows the cross section of worn surfaces parallel to sliding direction of pure Al. Micrographs show the presence of delamination during wear. It’s clearly seen that surface plastic deformation causes subsurface cracks and defects. Base on SEM micrographs analysis, there are pronounced two different delamination process during sliding wear between monolithic pure Al and composites. In order to explain the delamination process during sliding wear on pure Al matrix (Fig. 6) the delamination theory proposed by Suh (1973) was refered. Suh stated that wear occurred firstly by the cyclic plastic deformation of surface layers by normal and tangential loads.
Figure 5 Scanning electron micrograph of worn surfaces of specimen tested under 11 N: (a) Al (b) Al/5 wt.% POCp (c) Al/10 wt.% POCp (d) Al/15 wt.% POCp (e) Al/20 wt.% POCp

Figure 6 Cross section of worn surfaces parallel to sliding direction of pure Al

Figure 7 Cross section of worn surfaces parallel to sliding direction shows the presence of Slag that confirmed by EDS result.

Consequently, the crack or porosity in the deformed layers at inclusions were increase the crack growth approximately parallel to the surface resulted from the
formation of thin, long wear debris particles and their removal by extension of cracks to the surface. Fig. 6 shows similar characteristics where the propagation of cracks parallel to the sliding direction and delamination leading to the formation of debris. Suh (1973) also stated that the rate-determining mechanism of wear showed dependence on the metallurgical structure. When sub-surface deformation controlled the wear rate, hardness and fracture toughness were both considered to be major influencing factors.

**Figure 8** High magnification micrograph of cross section of worn surface parallel to sliding direction shows the role of cavities at the surface and pore formation around the POC particles that reduce the crack propagation.

**Figure 9** Cross section microstructure of sintered Al/20 wt. % Slag shows the presence of pores and micro-pore around Slag particles.

In the present work, the wear resistance of POCp/Al composites were found to be better than to the wear resistance of pure Al due to the cavities at the surface and pores formation around the POC particles that reduce the crack propagation. Fig. 7 shows the presence of POC particles at the subsurface of the composites and was confirmed by EDS result. The cross section of worn surface parallel to sliding direction indicates the cavities and pores formation around the POC particle as clearly shown in Fig. 8. The presence of pores in the composite as well as micro-pores around the POC particles may due to fabrication history. Fig. 9 shows the cross section microstructure of sintered composite Al/20 wt. % Slag reveals the presence of pores and micro-pore around Slag particles. Fig. 10 shows the delamination process during sliding wear of Al/10 wt. % POCp composites reveals the crack propagation parallel to sliding direction. It found that the plastic deformation occur during sliding distance resulted crack nucleation at pores and propagates to the worn surface. With removal of surface material, the cracks become nearer to the surface and the shear strain is increased, this causes the removal of the surface layers by delamination.

**Fig. 10** Cross section of worn surfaces parallel to sliding direction of Al/10 wt. % POCp

**4. CONCLUSION**

Based on the results obtained and analysis made on the worn surfaces and sub-surfaces, few points can be deduced as follows:

1. Presence of POCp enhanced the wear resistance performance of the aluminium.

2. The wt. % of POCp and applied load had insignificant effect on the cumulative wear rates of Al/POCp composite. Even though, cumulative wear rate pronounced slightly increases with increasing the wt. % of POCp at applied load 51 N.
3. The wear mechanisms of the composite were predominated by subsurface crack and micro-crack formation around the POCp which cause the wear.

4. The POCp acts as solid lubricant at the contact surface and reduces the crack propagation.

5. REFERENCES


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