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ANALYSIS OF WORN SURFACES OF PALM SHELL ACTIVATED CARBON (PSAC) REINFORCED ALUMINIUM MATRIX COMPOSITE

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ABSTRACT

Qualitative analysis of sliding wear behaviour of aluminium reinforced with 5wt% to 20wt% palm shell activated carbon (PSAC) was investigated using pin-on-disc wear testing machine. The composite specimens were fabricated by powder metallurgy technique. Wear testing was conducted at a load of 11N and a fixed sliding velocity of 150RPM. The characterization of the worn surface was conducted using OM, SEM with facility for EDX analysis. The wear rate was optimized at less than 5E10-5gmm^{-1} in the aluminu composite reinforced with 10wt% PSAC. The analysis of the surfaces indicate that the PSAC particles deformed, by sliding acting of the mating surfaces, as rigid asperity and squeezed out towards the surface *film forming a soft interfacial film*. The presence of this film was believed to be responsible for the low wear rate obtained at 10wt% PSAC reinforcement. Platic deformation of the matrix induces delamination in both the surface and sub-surface cracks resulting in large flaky debris.

Keywords: Sliding Wear, Al-PSAC P/M composite, reinforcement weight percent, Pin-on-Disc, debris

1. INTRODUCTION

Metal matrix composites (MMCs) are currently being developed as possible structural materials, offering improved elastic modulus, strength, elevated temperature properties and control over the coefficient of thermal expansion (Ref?). MMCs are fabricated by powder metallurgy, liquid metal and spray deposition techniques. Each fabrication technique has its own limitations in the size and shape of MMCs which may be produced and also the reinforcement chosen. Fabrication of MMCs is more difficult than the fabrication of the matrix alloy because during the fabrication process (e.g. the liquid metal technique) an interface reaction takes place between matrix and reinforcement to form intermetallics. Each processing routes taken to overcome the problems have resulted in high material costs, leading to extremely limited use (Yeh et al., 1997). Several fabrication routes such as e vortex route under vacuum (Skibo and Schuster, 1988), compocasting (Balasubramaniam et al., 1990), infiltration process (Cappleman and Hubbert, 1985), spray process (Gupta et al., 1991), powder metallurgy (Brindley, 1987), Lanxide's process (Xiao and Perby, 1991) and XD^{TM} process (Chirstodoulou et al., 1986) have been developed. These routes have their own advantages and limitations, and can be adopted for different product characteristics. Powder metallurgy has many merits such as: being a simple process, consumes low energy, , quite good for particulate reinforcements; but sintered part have high porosity resulting in the dynamic mechanical properties being affected (Chengchang et al., 2006). In aluminium matrix composites, the main particulate reinforcements used are boron, graphite, silicon carbide, alumina and fly ash. These reinforcements are expected to improve wear resistance in different mechanisms. Several researchers have focused on the wear behaviour of aluminum composites reinforced with particulates such as such as silicon carbide (Pramila-bai et al., 1992; Alpas and Zhang, 1992; Venkatamaran and Sundarajan, 1996a-b; Chen et al., 1997)., alumina (Hosking et al., 1982, Surrapa et al., 1982, Wang and Hutching 1989, Prasad et al. 1994, How and Baker 1997)., graphite, carbon char (Muralli et al., 1982) and Ejiofor and Reddy, 1997), fly ash (Ramachandran and

Radhakrishna, 2005), hematite and bauxite particles. Singh et al. (2007) investigated wear behaviour of spinel reinforced aluminum composites. They observed that wear resistance was improved by the addition of the reinforcement.

Based on previous works, 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 (Ejifor and Reddy, 1997). Palm shell activated carbon (PSAC) and Slag have potential to be used as reinforcement in aluminium matrix composite. PSAC and Slag are biomass by-products from palm oil factory and can be obtained locally. So, this idea shall reduce cost of starting material in fabrication of novel aluminium composite reinforced with local waste materials. Malaysia is currently moving towards a bio-technology industry as indicated in Ninth Malaysian Plan (RMK9).

Under this plan, one of the government's agenda is focusing on the generation of huge amounts of agriculture product. One the main commodity industries being targeted is the palm oil industry. It is expected that the growth of palm oil productions will increase tremendously.

Unfortunately, there is still a lack of systematic research on utilisation of the biomass by-products into composite materials especially metal composite. Information obtained from the previous studies provide a baseline understanding on the fabrication of aluminium matrix composite reinforced with biomass by-product such as PSAC and waste material from palm oil factory such as Slag. So, studies on utilization of palm oil-biomass by-product as reinforcement in fabrication of new aluminium matrix composite should be carried out. In addition, the literatures show that the aluminium matrix composite provides enhance wear resistance and presently used in tribological application (Chawla and Chawla, 2006). So, it is believed that this new aluminium composite reinforced with biomass by-products also have a potential to be used in tribological application. In order to make aluminium matrix composite based component become a useful component for industrial applications especially tribological applications, so, tribology supposed to be done for reliable prediction of wear behaviour and wear mechanism of this new aluminium composite.

This study focuses on palm shell activated carbon (PSAC) as reinforcement in aluminium (Al) matrix composite fabricated by powder metallurgy technique. The objective of the present study was to evaluate the dry sliding wear of PM Al/PSAC composites and to analyse the worn surfaces and sub surfaces by using qualitative approach in order to understand the wear behaviour.

2. METHODOLOGY

2.1 Starting Materials

The materials used were pure Al and pure Al reinforced with 5-20 wt. % PSAC particles of 125 μm size. Depending on the reinforcement content, four different weight percents were prepared. Specimen of pure Al was used as reference. Composite specimens were reinforced with 5wt. %, 10 wt. % 15wt% and 20wt.%, respectively. For the fabrication of composite specimens, particles of PSAC in a form of irregular shape were used as reinforcement (Figure 1a) and mixed with Al particles in the form of flaky shape (Figure 1b).

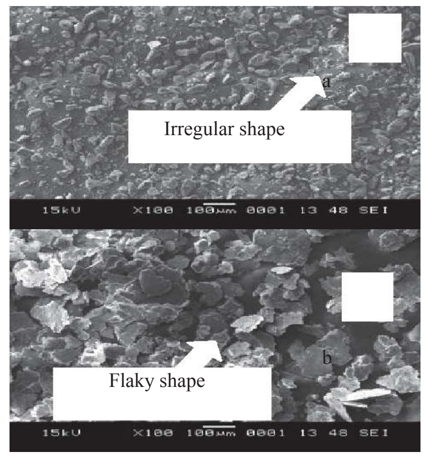


Figure 1 SEM micrograph of: (a) PSAC particles; (b) Aluminium particles

2.2 Powder Metallurgy Route

The specimens were cold pressed in a steel die at a pressure of 200 MPa, then sintered for 4 hours at 600 ^{0}C in a carbolite furnace. The pure Al and composites were pressed into a pin of 15 mm length with a flat surface of 10 mm in diameter at the both ends.

2.3 Pin-on-Disc Wear Tester

The pin-on-disc configuration was used for the dry sliding wear testing at room temperature in air under dry conditions. The pin was mounted vertically on the tester arm at one end and the other pin surface held against the rotating mill steel disc. The pure Al and composites were used as the pin, and the mild steel disc was used as the mating surface. Tested specimens were coded as given in Table 1. All tests were performed under a constant sliding speed at load of 11 N. The Al and composites were tested at sliding speed of 150rpm RPM. Prior to the test, the flat surface of the pin was polished by sliding against 600grit SiC paper. The mild steel disc specimens were ground to a constant roughness of about 0.40 micron Ra (arithmetic roughness), and measured using a roughness tester. The wear of the pins was recorded by measuring the mass loss of the pins using a micro balance of accuracy 10^{-5}g. Each measurement was made by interrupting the test every 100 m of sliding distance. The wear rate was calculated by dividing the mass loss by the sliding distance according to ASTM G99-95a (2000). All specimens followed a single track of 50 mm in diameter and mild steel disc was changed for each surface of the pin tested.

Table 1: Details of the specimens used in the present study

Specimen Code	Weight Percent (%)	Applied load (N)	Sliding velocity (RPM)	Sliding Distance(m)
Al	0	11	150	Up to 500
Al/5 wt. % PSAC	5	11	150	Up to 500
Al/10 wt. % PSAC	10	11	150	Up to 500
Al/15 wt. % PSAC	15	11	150	Up to 500
Al/20 wt. % PSAC	20	11	150	Up to 500

2.4 Microscopic Examination

2(b) shows SEM micrograph of Al/10 wt. % PSAC and its EDX indicated worn surface consists of grooves as well as the presence of

The morphology of the powders was studied by scanning electron microscope (JOEL 6460LA-Japan) with capacity for EDX analysis. The distribution of particles and porosity was determined by examining the SEM microstructure of the specimens in detail. . Furthermore, the microstructure of both the pure Al and composite was examined together with the testing debris with via EDX after wear testing.

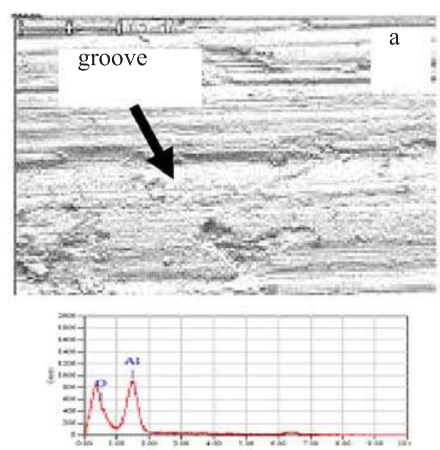
3. RESULT AND DISCUSSION

3.1 Worn surface analysis

Figure 2(a) shows SEM micrograph of pure Al and its EDX indicated worn surface consists of grooves without carbon film whereas, Figure

carbon film on the worn surface. The wear mechanism is a mixed mode of abrasive-adhesive wear. The black carbon film comes from smearing of PSAC particles on the composite worn surface during sliding (Ref). Combining this observation with the result given in Figure 3 clearly demonstrate that the reduction in cumulative wear rate of Al/10 wt. % PSAC tested at 11 N is directly linked to the formation of smeared PSAC (a lubricating film). The present study tried to describe the smearing process of the embedded PSAC particles during sliding in detail. The decreasing in cumulative wear rate when increasing content of PSAC up to Al/10 wt. % PSAC as shown in Figure 3 is directly linked to the formation of smeared PSAC (a lubricating film). On the other hand, the increasing of cumulative wear rate when content of PSAC more than 10 wt. % is directly linked to the poor bonding between matrix and PSAC particle.

Base on this observation, it was found that the weight percent of PSAC influences the wear behaviour of Al/PSAC composite. The presence of black film smeared on the worn surface of composite containing 10 wt. % PSAC can reduce wear rate. According to Chawla and Chawla (2006), the addition of ceramic particles to a metal matrix can improve wear resistance and they reported the fracture toughness of the composites reduces significantly with the amount of the reinforcements. If the fracture toughness is inadequate, the particles will fracture and contribute to the wear process.



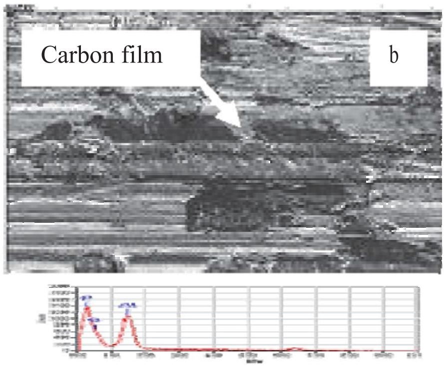


Figure 2 (a) SEM micrograph of Al/0 wt. % PSAC and its EDX showing the presence of Al and O elements. (b) SEM micrograph of Al/10 wt. % PSAC and its EDX showing the presence of carbon film on the worn surface.

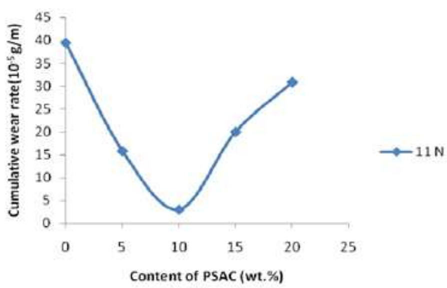


Figure 3: Cumulative wear rate versus content of PSAC at 400 m sliding distance under applied load of 11 N.

However, PSAC particles acted as solid lubricant in this present composite. The PSAC particles deform by the sliding action of the mating surface and squeezed out toward the surface, forming a soft interfacial film. The presence of this film is believed to be responsible for the observed reduced wear. According to Alexeyev and Jahanmir (1993a-b), when the solid lubricant film is worn away, the resulting increase in friction accentuates plastic deformation of the surface layer, and force more material from the second-phase particles toward the surface, thus re-forming the worn film. Unfortunately, at the highest content of PSAC (20 wt. % PSAC), the presence of severe damage on the worn surface can be observed. This may probably be as a result of the poor bond of interface between matrix and reinforcement, consequently surface structure is unable to support the applied load and the wear resistance reduced. In addition, some of PSAC particles pull out from the worn surface and delamination of surface and subsurface occur due to plastic deformation. The presence of large flaky debris in the microstructure is postulated to have come from the delamination process.

In order to understand the basic mechanism of the formation of lubricating films, the worn surface of the Al/PSAC composite has been studied. Figure 4 shows the SEM micrograph of the worn surface of Al/10 wt. % PSAC indicating the black film on the worn surface with a pattern of "shear wedges" and magnified view of box is shown in next figure revealing a good adhesion of black film to the worn surfaces. Based on the above observation, smearing of the PSAC has occurred during sliding. When the Al/10 wt.% PSAC composite was subjected to wear, the PSAC reinforcement was preferentially removed layer by layer from the PSAC particles due to the layered structure and PSAC softening. As sliding continues, the deformation of the worn surface occurred because the plastic deformation of the matrix made the surface and subsurface crack to delaminate and produce the large flaky debris observed in the microstructure. The cavities containing PSAC particles deform owing to this subsurface deformation, thus squeezing the PSAC onto the worn surface; the same phenomenon has also been observed in the aluminium-graphite system (Liu et al., 1992) and iron- graphite system (Sugishita and Fujiyosha, 1982). Liu et al. (1992) have studied the wear behavior of aluminium alloy 2014-graphite particle composites. They found that the wear resistance can be improved by the addition of graphite, which causes a corresponding reduction in the coefficient of friction. The reduction in friction and wear of this group of aluminium-graphite composites is a result of the smearing of the embedded graphite particles during sliding, forming a lubricating film on both the tribosurface of the composite and the steel counterface. Whereas, Sugishita and Fujiyosha (1982) studied the formation of nodular cast iron graphite films and the factors affecting squeeze film formation during rolling-sliding contact. In this work, as the PSAC comes onto the surface, it is sheared by the asperities of the mating surface and consequently smeared between the mating surfaces, resulting in the formation of a lubricating film as shown in Figure 4. The formation of a large area of black film as lubricating film between contact surfaces is believed to reduce the wear rate of Al/10 wt. % PSAC composite. The areas covered with smeared PSAC after 400m sliding is shown in Figure 4.

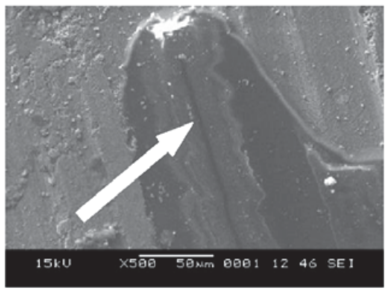


Figure 4: SEM micrographs showing the worn surface of Al/10 wt. % PSAC at applied load 11 N after 400m sliding distance indicating the black film on the worn surface with a pattern of "shear wedges" and magnified view of box is shown in figure revealing a good adhesion of black film to the worn surface

3.3 Wear Debris Analysis

SEM micrograph of collected wear debris particles of pure Al tested at 11 N and its EDS indicated the presence of Al, O and Fe elements. Figure 5 shows SEM micrograph of collected wear debris particles of Al/20 wt. % PSAC tested at 11 N and its EDX indicated the presence C, O and Fe elements. The debris consists of not only Al and C from the wearing composite materials but also Fe from the mating surface steel disc. These elements mixed together in wear debris and are found to influence the wear rate of the composite.(Ref)

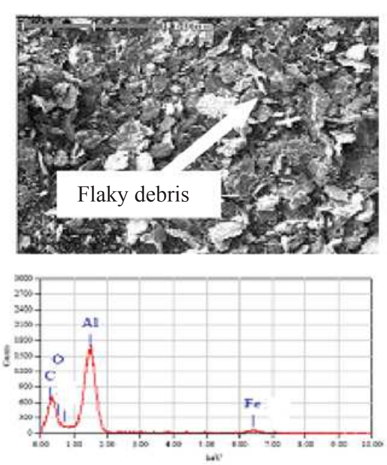


Figure 5 SEM micrograph of collected flaky debris particles of Al/20 wt. % PSAC and its EDX analysis showing C, Al, O, and Fe.

Generally, the analysis of the worn surfaces of the specimens and the collected debris using optical microscopy, SEM and EDX analysis revealed various mechanisms involved in the wear of the material studied. The wear mechanisms identified in this analysis are abrasive wear, adhesive wear and delamination.

4. CONCLUSION

From the data obtained in this observation, it is possible to arrive at the following conclusions:

(a) The wear behaviour of PSAC reinforced aluminium matrix composites depends on the weight percent of embedded PSAC particles. Under dry sliding condition used in the present investigation, the wear resistance can be improved even with reinforcement with just 5 wt% PSAC.

(b) The wear rate decreases gradually with increasing weight percent of PSAC, reaching about 10 wt. % PSAC.

(c) The wear behaviour of the composites depends on the smeared PSAC films formed on the worn surface during sliding.

(d) The PSAC is squeezed out onto the worn surface by subsurface deformation and smearing onto the worn surfaces resulting in the formation of lubricating film.

(e) However, the wear rate of composite drastically increases when PSAC content is above 10 wt.% due to poor bonding between aluminium matrix and PSAC particles.

REFERENCES

Alexeyev, N. and Jahanmir, S. 1993a. Wear, 166, pp. 41-48.

Alexeyev, N. and Jahanmir, S. 1993b. Wear, 166, pp. 49-54.

Alpas, A. T. and Zhang, J. 1992. Wear, 155, pp. 83

ASTM G99-95a, Standard Test method for Wear Testing with a Pin-on-Disc Apparatus, ASTM INTERNATIONAL, 2000.

Balasubramaniam, P. K. , Rao, P. S. and Pai, B. C. 1990.Composites Sci and Techn., 39, pp. 241.

Brindley, P. K. 1987. Mat. Res. Soc. Symp. Proc., 81, pp. 419

Cappleman, P.A. and Hubbert, J. 1985. Mater. Sci., 10, pp. 85

Chan, K. C., Goh, S. H., & Ing, T. W. (1976). Utilisation of oil palm nut shells. Planter Kuala Lumpur;52:127-130.

Chawla, N. and Chawla, K. K. 2006. Metal Matrix Composites, Springer Science+Business Media, Inc, 2006.

Chen, R., Iwabuchi, A., Shimizu, T. , Shin, H.S. and Mifune, H. 1997. in: Vol. III Metal Matrix Composite and Physical Properties, Eleventh International Conference on Composite Materials, Woodhead Publishing Limited, U.K., 3, pp. 679.

Chengchang, J., Weihua, L. and Zhimeng, G. 2006. Journal of University of Science and Technology, Beijing, 13, pp. 29

Christodoulou, D. C., Nagle, T. M. and Brupbacher. 1986. International Patent No. W086/06366, November, 1986, pp. 6

Das, S., Prasad, S. V. and Ramachandran, T. R. 1989. wear, 133, pp. 173

Dubrujeud,B., Vardavoulis, M. and Jeandin,M. 1994. Wear, 174, pp. 155

Ejiofor, J. U. and Reddy, R. G. 1997. Automotive Alloys, Warrendle, PA: TMS, 1997.

Ejiofor, J. U. and Reddy, R. G. 1997. Journal JOM, 49, pp. 31

Gupta, M. I., Ibrahim, A., Mohamad R. A. and Laverniak, E. J. 1991. J. Mater. Sci., 26, pp. 6673

Hosking, F. M., Folgar-portillo, F. , Wundnerlin, R. and Mehrabian, R. 1982. J. Mater. Sci., 17, pp. 477

How, H. C. and Baker, T. N. 1997. in: Vol. III Metal Matrix Composite and Physical Properties, Eleventh International Conference on Composite Materials. Woodhead Publishing Limited,UK., 1997.

Liu, Y. B., Lim, S. C., Ray, S. and Rohatgi, P. K. 1992. Wear, 159, pp. 201-205

Murali, T. P. , Surappa, M. K. and Rohatgi, P. K. 1982. Metall. Trans., 13B, pp. 48

Pramila-bai, B. N. , Ramasesh, B. S. and Surappa, M. K. 1992. Wear, 157, pp. 295.

Prasad, B. K. , Modi O. P. and Jha, A. K. 1994. Tribology International, 27, pp. 153.

Ramachandra, A. and Murali, M. S. 2000. in: Processing and Fabrication of Advance Material VIII, World Sci. Publishing Co. Pte. Ltd., UK., pp. 705.

Ramchandra, M. and Radhakrishna, K. 2005. Materials Science and Technology, 21, pp. 1337.

Singh, G.,Yu, Y., Ernst, F. and Raj,R. 2007. Acta materialia, 55, pp. 3049.

Skibo, M. D. and Schuster, D. M. 1988. U.S. paten No. 459995, July, 26, 1988.

Sugishita, J. and S. Fujiyoshi, S. 1982. Wear, 77, pp. 181

Surappa, M. K. , Prasad, S. V. and Rohatgi, K. 1982. Wear, 77, pp. 295.

Venkatamaran, B. and Sundarajan, G. 1996a-b. Acta Mater., 44, pp. 451.

Wang, A. G. and Hutching, I. M. 1989. Journal of Materials Science and Technology, 5, pp. 71.

Xiao, B. and Perby 1991. in: R. Morrell and G. Partridge (Eds.), British Ceramics Proceedings, The Institute of Ceramics, pp. 153.

Yeh, J. J., Chen, L. D. and Lin, C. B. 1997. Vol. III: Metal Matrix Composite and Physical Properties, Eleventh International Conference on Composite Materials., Woodhead Publishing Limited, 3 , pp. 699.