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Morphological study of friction stir processed aluminium metal matrix composites

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ABSTRACT

This paper demonstrates the morphological study of friction stir processed (FSPed) aluminium metal matrix composites. Friction stir processing was implemented during fabrication process to produce metal matrix composites (MMC). The MMC consisted of aluminium alloy AA6061 and rice husk ash (RHA) particles. The morphological study compared the wear performance of as-received AA6061, FSPed AA6061 and FSPed AA6061/6 vol% RHA. The result showed that the FSPed AA6061/6 vol% RHA had the best wear performance among the other specimens. This was specified by less delamination, smoother worn surface and shallower grooves on this FSPed composite compared on the alloy material as presented in the scanning electron microscopy (SEM) morphological study.

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1. Introduction

Aluminium with high strength-to-weight ratio is possible to replace steels in various sectors. However, aluminium alloy has low hardness and poor wear performance. Aluminium reinforced with hard ceramic or well known as Al-metal matrix composites had gained a lot of attention. This new material can meet the demand of industrial and transportation sectors by providing high strength, light weight and non-corrosive properties [1]. In this regard, surface modification and surface composite promote intensification of surface properties to boost the hardness profile and wear performance. In the past, several methods have been commonly used on the surface of the alloy in which to modify surface layers, including surfacing, spraying or remelting on the surface of the alloy [2–4]. Some researchers have fabricated AMC reinforced with rice husk ash (RHA) as well by using stir casting approach. The casting technique which associate melting process of the matrix alloy as the liquid metallurgy processing leads to inhomogeneous distribution, agglomerations, porosity, poor bonding and interfacial reactions. During casting, RHA demonstrates poor wettability within the molten aluminium which leads to poor mechanical and tribological properties in the matrix [5,6]. Moreover, the density gradient causes the ceramic particles to move freely within the aluminium melt during these processes [7,8]. Fabricating composite material below the melting temperature of the matrix could help in countering the problem. In this regard, FSP has been developed as it can be used either to modify the aluminium surface or fabricate the aluminium surface composite.

FSP has garnered researchers' attention due to its benefit on-surface modification and surface composite. FSP is a relatively fast, cost effective, simple and easy to control process [9–11] to refine grain at the surface layer [12]. Furthermore, FSP produces surface composite which could enhance the mechanical properties [13]. In metal matrix composites (MMC) production, FSP provides a homogenized particles distribution and better bonding with the base material while FSP conducted in the solid-state process can prevent interfacial reaction and deformation of the material's detrimental phases [14–17].

This work will contribute to the improvement of aluminium alloy and its composite. FSP is believed will improve grain refinement of material and beneficial in developing surface composite. FSP promotes several advantages including enhancing material properties, as well as beneficial to the environment and energy consumption as well as low-cost production.

The significant of this work is we had proposed rice husk ash (RHA) as the reinforcement in the Al metal matrix composites. Currently there is limited research had been done on MMC reinforced

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RHA. Additionally, friction stir processing (FSP) method was proposed. FSP is relatively new approach in fabricating surface MMC.

The purpose of this study is to characterize the wear mechanism of as-received AA6061, FSPed AA6061 and FSPed AA6061/6 vol% RHA. This will be achieved by examining closely the microstructure after the wear test is performed. The wear performance will be characterized in terms of its ability wo withstand delamination during the wear test.

2. Materials and methodology

This research focused on surface modification of 6000 series aluminium alloy, namely AA6061. In this regard, AA6061 is a lightweight material which demonstrates high mechanical properties and good in resisting corrosion. In the meantime, FSP was done using a vertical milling machine. The tool used in FSP was created from H13 tool steel with a cylindrical probe design. For the process parameter, traversed speed was selected to 25 mm/min while 1000 rpm was fixed for the rotational speed. The AA6061 aluminium subjected to FSP was referred as FSPed AA6061. To fabricate the of surface composite, a set of small holes were made on the base material which was subjected to 6% volume fraction of RHA to produce FSPed AA6061/6 vol% RHA. The FSP would travel along the holes to produce a thick surface layer of composite. Subsequently, the microstructural characteristics of AA6061, FSPed AA6061, and FSPed AA6061/6 vol% RHA would be examined under scanning electron microscopy (SEM). Wear test must be established in order to determine the wear behaviour. The morphological study on the worn surface was inspected using scanning electron microscopy (SEM).

Wear test was conducted to predict the wear performance or wear property to determine whether the surface material is adequate for a specific application. These specimens were cut using EDM wire cut with a dimension of 25.4 mm $\times$ 25.4 mm $\times$ 10 mm as in Fig. 1.

The specimen in Fig. 1 (b) was then subjected to the dry sliding wear experiment. A pin on disc tribometer machine (CSEM Instruments) as shown in Fig. 2 was used to perform the test. Frictional force and wear were measured by using this machine. Two specimens which were cylindrical pin and flat counter disc needed while testing the pin-on-disc wear. The position of the cylindrical pin must be perpendicular to the counter disc. This experiment requires the pin specimen to be pressed against the disc using a specified load while the disc rotates at few rotational speeds by means of a lever attached to some weights. By weighing pin specimens before and after the experiment, the amount of wear can be determined. The counter disc was used to test the specimens. The test adhered to ASTM G99 to evaluate wear properties of AA6061, FSPed AA6061 and FSPed AA6061/6 vol% RHA. The wear test was in a dry condition with a parameter load of 10 N, linear speed 10 cm/s, radius 10 mm with constant sliding distance of 800 m.

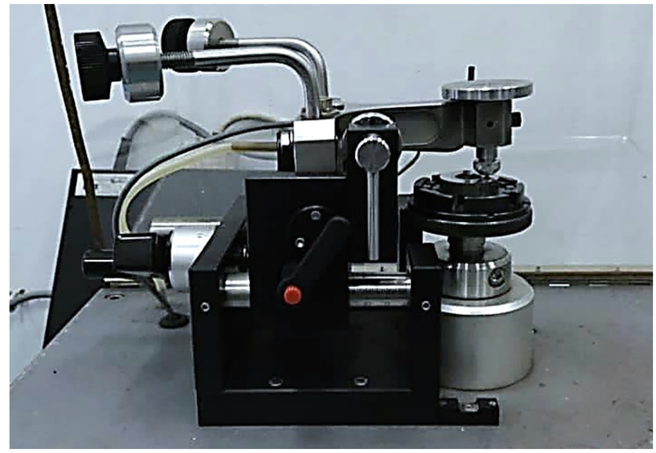
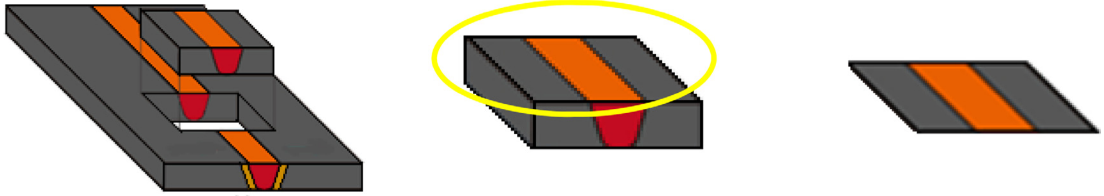


Fig. 2. Pin-on-disc tribometer.

Fig. 3. SEM equipped with EDX.

A scanning electron microscopy (SEM) machine (FEI QUANTA 450), as shown in Fig. 3 was used to study the morphology of the RHA. The magnification was set at 1000X. It was observed that



(a) (b) (c)

Fig. 1. (a) Specimen was cut perpendicular to traversed path using EDM wire cut, (b) specimen for wear test and (c) area for morphology observation.

Fig. 4. SEM micrograph of RHA particles at a magnification of 1000X.

during handling, these RHA particles were quite brittle and broken as shows in Fig. 4. Futhermore, this equipment was used to characterised the morphology of worn specimens of as-received AA6061, FSPed AA6061 and FSPed AA6061/6 vol% RHA.

3. Results and discussion

After the wear test, AA6061, FSPed AA6061, and FSPed AA6061/6 vol% RHA were collected. These specimens later were analysed for worn characterisation through SEM. By employing FSP, the wear behaviour of FSPed specimens was enhanced mainly in FSPed AA6061/6 vol% RHA as the reinforced particle helps improving wear technique. The morphological analysis for all worn surface specimens were completed using SEM at a magnification of 200X.

Adhesive wear is defined by areas with ploughs or craters of rough regions. In this regard, there is a dominant abrasive wear area as shown by the formation of fine grooves or delaminations of smooth regions are formed and this is comparable with the result in [18]. Fig. 5 illustrates the surface morphology of AA6061 after the wear test. AA6061 has rougher surface presenting an adhesive mode of wear behaviour. This finding is in-line with previous study by Mirjavadi et al. [19] which confirmed that type of wear that commonly noticed in aluminium alloys is adhesion wear. In the meantime, there are features that regarded as characteristics of adhesive wear for example removal of material, high value of plastic deformation, massive surface damage and flow of metal.

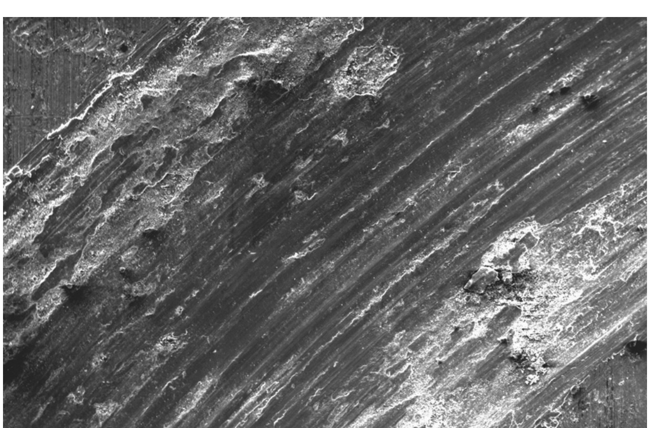


Fig. 5. SEM micrograph of AA6061.

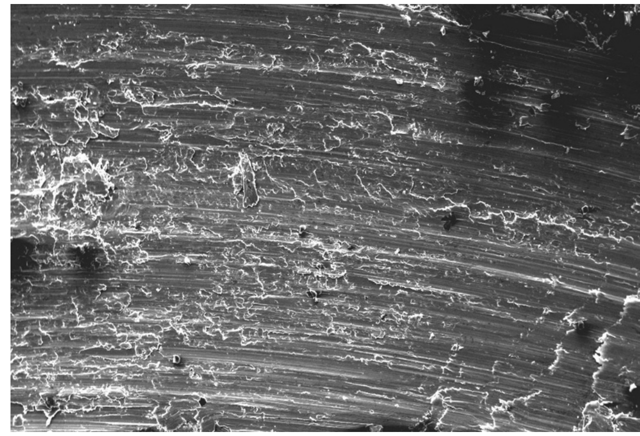


Fig. 6. SEM micrograph of FSPed AA6061.

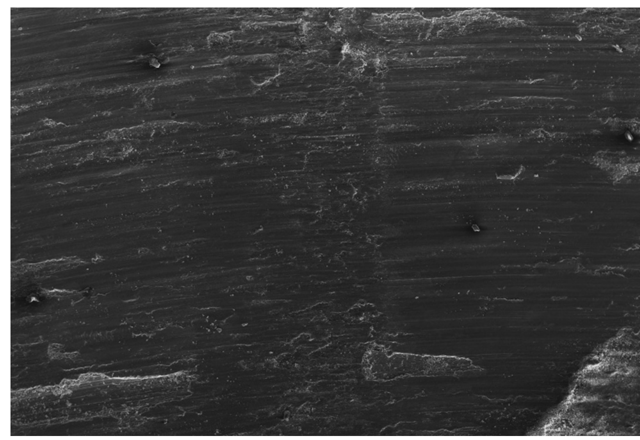


Fig. 7. SEM micrograph of FSPed AA6061/6 vol% RHA.

Worn surfaces of FSPed AA6061 at 1000 rpm were illustrated in Fig. 6 above. Both FSPed AA6061 and FSPed AA6061/6 vol% RHA exhibit rough delamination which representing an abrasive mode of wear behaviour. The findings of the current study are consistent with Alidokht et al. [20] who revealed that the FSPed of aluminium alloy is correlated with abrasive and delamination methods. Shallow craters and cracks that can be seen on the worn surfaces shows the delamination wears. Fig. 7 presents FSPed AA6061/6 vol% RHA at 1000 rpm. It shows a significant amount of reduction of delamination and near surface wears compared to FSPed AA6061 and as-received AA6061 specimens. It can be confirmed that FSP and addition of RHA have improved wear resistance of aluminium alloy. The enhancement of wear behaviour can be credited to the significant improvement in hardness happened through microstructural refinement and hard particle reinforcement. Basically, the material's wear reduces when the hardness increases under abrasive wear conditions. Comparatively, this results in smooth worn surface and the formation of shallow grooves compared to deep grooves observed at the as-received AA6061 morphology.

4. Conclusion

This paper presented the morphological study of AA6061, FSPed AA6061 and FSPed AA6061/6 vol% RHA. It can be concluded that the effect of FSP and the addition of RHA into the matrix AA6061 had increased the wear performance of the composite material. The result shows that the FSPed AA6061/6 vol% RHA was exposed to less delamination after the wear test was performed. This was an initial work where the scope covered study of as-received AA6061, FSPed AA6061 and FSPed AA6061/6 vol% RHA, other addition of volume % of RHA will be done for the next phase. Hence, this opens new research path for future work where different addition of volume percentage of RHA can be varied, tested and compared.

CRediT authorship contribution statement

C.D. Marini: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Validation, Visualization, Writing - review & editing. **Nanang Fatchurrohman:** Funding acquisition, Resources, Supervision, Writing - original draft. **Zuhairah Zulkfli:** Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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