Surface Roughness and Wear Properties of Al–Al_2O_3 Metal Matrix Composites Fabricated Using Friction Stir Processing

N. Fatchurrohman and Azriee Abdullah

Abstract Friction stir processing (FSP) involves the mixing reinforcement particles on metal surface and the control of its dispersion is more difficult to attain with conventional techniques such as casting. The objective of present work was to perform tribology characterization of Al alloys Al-6061 and Al-6061 with 5 weight % Al_2O_3 produced using FSP. The parameters involved were rotation speed 1000, 1200 and 1400 rpm and traversed speed constant at 25 mm/min. The results show that the surface roughness with the presence of the reinforcement demonstrated better surface roughness compared to specimens with no reinforcement. Furthermore, high increment of the tool rotation speed indicates the declined value of the coefficient of friction of the specimen material.

Keywords Metal matrix composites · Friction stir processing
Tribology · Al-6061 alloy · Al_2O_3 particles

1 Introduction

Friction stir processing (FSP) is a technique of changing the properties of metal through inserting a suitable reinforce particles into the work piece in order to achieved surface modifications of the work piece. It was known that this is a solid-state modification process formerly established for aluminum alloys by evolving technique of metalworking that involved localized heat treatment. This technique also controlled the microstructure of the near-surface layers of metallic modules [1].

FSP was used to improve of surface metal matrix composites properties including abrasion resistance, hardness, strength, ductility, corrosion resistance, fatigue life and formability. This can be done while unchanging the bulk properties

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of the matrix material. Besides that, friction stir processing is an ideal process for producing low cost and high performance surface modification. Surface composites exhibit enhanced characteristics of composites on-the surface while retaining properties of the base material. FSP effectively eliminates casting defect, break up or dissolves second phase particles and lead to the considerable improvement in properties [2].

In recent investigations, FSP has been introduced to modify the upper surface of metallic materials [3]. FSP has been developed for the application with aluminium alloys, with the goal of high-strain-rate processing [4]. FSP is a fast technique with simple processing and low cost to in situ synthesizes particulate-reinforced composites especially in aluminium alloy [5, 6]. FSP improved the distribution of the reinforced particles which resulting more homogeneous and thermodynamically more stable in metallurgical properties as the matrices and reinforcement have a strong interfacial bonding [7]. FSP or friction stir welding (FSW) was initially applied to Al alloys [7] and extended to other metals such as Cu alloys [8], Mg alloys [9], or Ti alloys [10]. Until now, Al alloys are the most commonly used materials in FSP applications. Research have been dedicated to the effect of FSP parameters on the affected zone such as by Karthikeyan et al. [11, 12]. They studied the friction stir performance of the Al alloys in order to examine effect of feed rate and rotational speed on microstructure and properties. They informed the increased tensile, yield strengths ductility and grain size reduction because of FSP.

The objective of this preliminary study was to investigate the surface roughness and wear properties of Al, Al_2O_3 metal matrix composites fabricated using FSP.

2 Materials and Methodology

2.1 Material Selection

The materials used were Al alloy Al-6061 and reinforcement Al_2O_3 particles. The size of Al-6061 with dimension of (100 mm × 120 mm × 10 mm). The average particle size of Al_2O_3 was 30 microns and reinforce up to 5 weight %. The physical properties of the materials are shown in Table 1.

Table 1 Material properties of Al-6061 and Al_2O_3

Properties	Al-6061	Al_2O_3
Density (g/cm$^{3)}$	2.70	3.95
Molecular weight (g/mol)	26.98	101.96
Melting point (°C)	580	2072

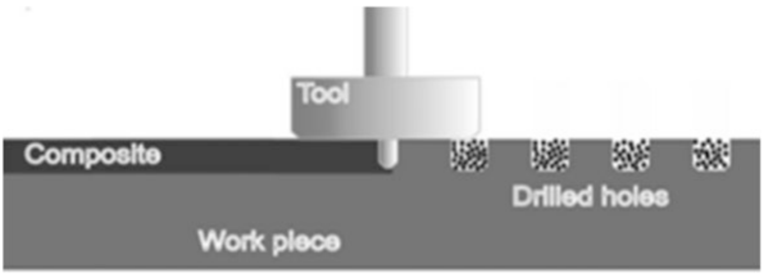

Fig. 1 Schematic process of FSP [2]

2.2 Sample Preparation

The specimens were prepared using FSP process with three different parameters. The rotation speeds of 1000, 1200, 1400 rpm and traverse speed of constant at 25 mm/min. The schematic of the process is as in Fig. 1.

The surface roughness of the samples was then measured using a calibrated Mahr-Perthometer surface roughness tester. Surface roughness is generally described using two methods: arithmetic mean value and root-mean-square average. The arithmetic mean value (Ra, formerly identified as AA for arithmetic average or CLA for center-line average) is based on the schematic illustration of a rough surface, which in figure the arithmetic value, Ra is defined as follow.

$$Ra = \frac{a + b + c + d + \cdots}{n} \tag{1}$$

The wear test was conducted using calibrated Tribology Test Rig in order to gain the coefficient of friction (COF). The COF of wear sample was calculated from the friction force and load applied through Eq. 2.

$$\mu_k = F_k / N \tag{2}$$

where is the COF, F_k is the friction force and N is the load applied from the wear test machine.

3 Result and Discussion

The surface roughness of the substrate was determined from the value of arithmetic average roughness, Ra shown in Fig. 2. Based on the overall result for the average roughness-rpm curve, the properties of the average roughness decreases if the parameter of the tool rotation increase. The blue line shows the average roughness without reinforce and the orange shows the average roughness with reinforcement.

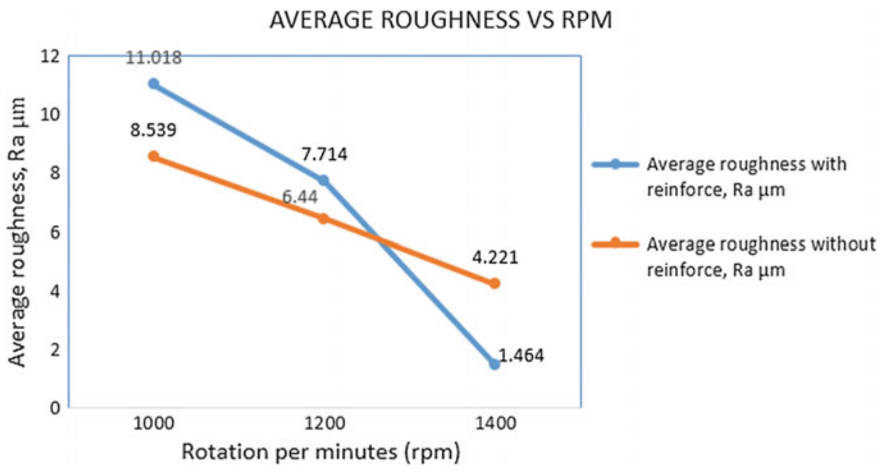

Fig. 2 The surface roughness using different tool rotational speeds

At rpm 1400 the average roughness with reinforce is lower compare to the without reinforce. Average roughness with reinforce was 1.464 µm and average roughness without reinforce 4.221 µm. The small size addition of particles contributed on the effectiveness for FSP process to produce higher surface roughness. The higher rpm makes the surface smoother because the particle mixture of the composite was well distributed using FSP process.

By reviewing on the graph in Fig. 3, it clearly shows that the average of coefficient of friction (COF) was inversely proportionally to the rpm of the tools. This was because the surface became smoother as the tool speed was increased.

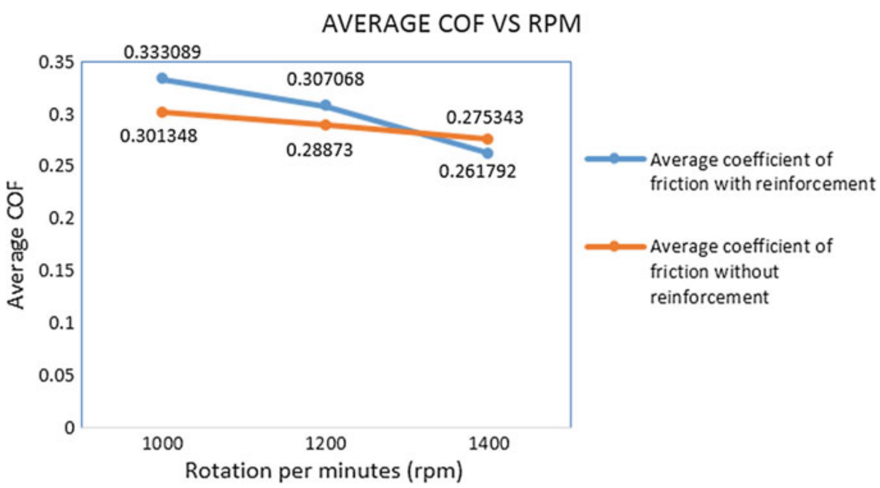

Fig. 3 The COF using different tool rotational speeds

The COF with reinforcement was higher than the average COF without reinforcement for rotation speeds 1000 and 1200 rpm. This means, by adding Al_2O_3 reinforcements it increased the hardness of the material and hence it can improve wear performance. This was due to the properties of Al_2O_3 which is a hard ceramic material. FSP caused in a significant disintegration and well distribution of Al_2O_3 particles in the Al matrix as well as elimination of porosity. This contributes to the reduction of COF the stir zone of the FSP sample.

4 Conclusion

Through this preliminary study, it can be concluded that the roughness and COF of modified surface composites were influenced by the addition of reinforcement and the rotation speed of the FSP tool. This was achieved by the formation of smaller grain in the matrix Al-6061 as the rotation speed was increased. Also the distribution of reinforcement Al_2O_3 influence the composite microstructure and in turn influenced the roughness and the COF of the material. FSP can be used as a tool to locally modify the microstructures in regions experiencing high frictional loading and significantly improve the overall performance of Al alloy matrix.

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