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Improving tribological behavior of friction stir processed A413/SiC_p surface composite using MoS_2 lubricant particles

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Abstract: The effect of MoS_2 lubricant particles on the microstructure, microhardness and tribological behavior of A413/SiC_p surface composite, fabricated via friction stir processing (FSP), was studied. For this purpose, the FSP was carried out with tool rotational speed of 1600 r/min, tool travel speed of 25 mm/min and tool tilt angle of 3° through only a "single pass". The optical and scanning electron microscopies, microhardness and reciprocating wear tests were used to characterize the samples. The results showed that the addition of MoS_2 lubricant particles to A413/SiC_p surface composite leads to the decrease of friction coefficient and mass loss. In fact, the generation of mechanically mixed layer (MML) containing MoS_2 lubricant particles in A413/SiC_p/MoS_{2p} surface hybrid composite results in the reduction of metal-to-metal contact and subsequently leads to the improvement of tribological behavior.

Key words: friction stir processing; surface hybrid composite; microstructure; microhardness; tribological behavior

1 Introduction

A specific feature involving high specific strength of cast Al−Si alloys leads to the decrease of fuel consumption and increase of mechanical performance of these alloys in the engineering industries [1]. A413 cast Al–Si alloy (with 11%−13% Si, mass fraction) is widely used in the engine components such as pistons, housings, connecting rods, marine fittings and water manifolds because of excellent castability, good dimensional stability and high corrosion resistance [2]. However, the high silicon content in this alloy results in the superior casting characteristics, low shrinkage and poor machining [1]. MAHMOUD and MOHAMED [2] reported that A413 cast Al–Si alloy is characterized by various defects like casting porosities and silicon flakes which limit the using of this alloy in many applications. They used the friction stir process (FSP) to eliminate the casting porosities and to break the silicon flakes.

The FSP as a new solid state technique, based on the friction stir welding (FSW), can be used to the development of microstructural refinement and fabrication of surface composites. MISHRA and MA [3] developed the FSP technique in which a non-consumable tool, with a specially designed pin and shoulder, inserted into the groove which was machined out of workpiece and was filled with powders. This tool then rotates around the own axis and traverses along the surface groove. Figure 1 shows the schematic drawing of FSP setup. In addition, the FSP is known as a metal forming process including forging and extrusion [4]. In fact, during the FSP, the metal is exposed to intense plastic deformation and high frictional heating which results in softening the material around the pin. Then the combination of tool rotation and tool translation leads to the movement of material from the front of pin to the back of pin [3]. As a result of this process, a surface composite is produced in the "solid state" because the FSP is carried out at the temperature below the melting point of substrate. The mechanical properties and tribological behavior of this surface composite are better than that of the base metal.

The excellent mechanical properties and tribological behavior of metal matrix composites (MMCs), where hard ceramic particles have been distributed in a relatively ductile matrix, lead to the widespread applications of these composites in the engineering industries [5]. Several investigations have shown that the addition of reinforcement particles such as SiC and

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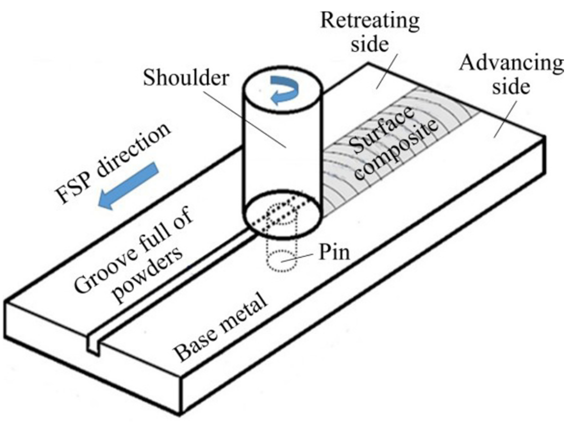

Fig. 1 Schematic drawing of FSP setup

Al_2O_3 into the matrix of Al alloys using FSP, leads to the improvement of mechanical properties and tribological behavior of Al alloys [5−7]. However, these hard reinforcement particles increase the wear rate and mass loss of counter faces, and change the wear mechanism and tribological behavior of contact surfaces because of detaching from the matrix and acting as third-body abrasives in the wear [8]. Recent investigations have shown that the addition of lubricant particles such as MoS_2 and graphite together reinforcement particles such as SiC and Al_2O_3 into the matrix of Al alloys using FSP, leads to further improvement of tribological behavior of Al alloys [8−10].

In this research, A413/SiC_p/MoS_{2p} surface hybrid composite was produced using FSP as a novel research. The mechanical properties and tribological behavior of this surface hybrid composite were evaluated and the microstructural changes were observed.

2 Experimental

The material used in this research was A413 cast Al−Si alloy plate with dimensions of 8 mm × 60 mm × 80 mm. The chemical composition of the alloy was given in Table 1. The reinforcement particles of SiC (purity of 99.5% and average particle size of 7 μm) and lubricant particles of MoS_2 (purity of 99% and average particle size of 10 μm) were used to fabricate the surface composites. The FSP tool was made of hardened H-13 tool steel and had a columnar shape with a shoulder (diameter: 16 mm, height: 68 mm) and a pin (diameter: 6 mm, height: 3 mm).

Table 1 Chemical composition of A413 aluminum alloy (mass fraction, %)

Si	Fe	Cu	Zn	Ni	Mn	Sn	Mg	Al
11	2	1	0.5	0.5	0.35	0.15	0.1	Bal.

A groove with depth and width of 3 and 2 mm, respectively, was machined out of the workpieces for the insertion of powders. The groove opening was initially closed by means of a pinless tool to avoid the escapement of powders from the groove during the process. Then, the FSP was performed under the rotational speed of 1600 r/min, travel speed of 25 mm/min and tilt angle of 3° through only a “single pass”. To study the effect of lubricant particles, in initial stage, SiC reinforcement particles, and then in the second stage, the mixture of (SiC_p+MoS_{2p}) with equal volume fraction were packed into the groove. As known, the main source of FSP heating is friction between tool and workpiece. In addition, the additive materials in the present work are MoS_2 lubricant particles which have low friction coefficient. Consequently, using high rotational speed and low travel speed, as in the present research, leads to the increase of frictional heating and subsequently improvement of material fluidity during the FSP [2]. Moreover, the increase in rotational speed and the decrease in travel speed reduce the agglomeration of particles [11]. The angle between tool axis and workpiece normal leads to the improvement of forging action at the shoulder trailing edge [4,8].

The cross section of samples in the planes perpendicular to the FSP direction was performed for the metallographic analysis. The samples were prepared according to standard metallographic practice and etched with Keller’s reagent (2 mL HF, 3 mL HCl, 20 mL HNO_3 and 175 mL H_2O). The optical microscope (OM) was used to characterize the microstructure of transverse section of samples.

To study the mechanical properties of samples, the Vickers microhardness test was applied. The microhardness tests were carried out with 50 g load and 15 s duration in the points with 2 mm distance from the upper surface in the transverse section.

The tribological behavior of samples was evaluated using the reciprocating wear test. Type of contact was cylinder on plate (line contact), so that the pin axis was perpendicular to the specimen surface. For the test, the plate specimens with dimensions of 8 mm × 60 mm × 60 mm were cut from the FSPed samples and the cylindrical pin with diameter of 5 mm was made from AISI 52100 steel. The reciprocation amplitude of cylindrical pin on the surface of specimen was 40 mm. The wear tests were carried out at the normal load of 15 N, sliding speed of 0.14 m/s, total sliding distance of 500 m without using a lubricant. AL-SAMARAI et al [12] showed that the wear rate and mass loss increase with increasing the normal load and decreasing the sliding speed. Therefore, high normal load and low sliding speed were used in the present research in order to provide severe condition for the wear tests of surface composites.