ARTICLE IN PRESS

Wear ▮ (▮▮▮▮) ▮▮▮–▮▮▮

Contents lists available at SciVerse ScienceDirect

Wear

journal homepage: www.elsevier.com/locate/wear

Effect of applied load on the dry sliding wear behaviour and the subsurface deformation on hybrid metal matrix composite ☆

S.A. Alidokht, A. Abdollah-zadeh *, H. Assadi

Department of Materials Engineering, Tarbiat Modares University, PO Box 14115-143, Tehran, Iran

ARTICLE INFO

Article history:
Received 22 July 2012
Received in revised form
17 November 2012
Accepted 20 November 2012

Keywords:
Sliding wear
Non-ferrous metals
Metal-matrix composite
Other surface engineering processes
Electron microscopy
Wear testing

ABSTRACT

In this study, a new processing technique, friction stir processing (FSP) was used to incorporate SiC and MoS_2 particles into the matrix of an A356 Al alloy to form surface hybrid composite. The tool rotation rate was changed from 630 to 1600 rpm and a tool tilt angle of 3° was applied. Higher tool rotation rate was found to causes a more uniform dispersion of reinforcing particles and thus, decreases particles clustering. Dry sliding wear tests were conducted using a pin-on-disc machine. The subsurface deformation was assessed as a measure of variation in microhardness along the depth normal to the cross-section of the worn surface. It was found that the wear resistance of the processed samples improved significantly as compared to that of the as-cast alloy. Microstructural analysis showed that a MoS_2 rich layer on the top of worn surface helped to decrease the plastic deformation in subsurface region and alleviate severe wear. The improvement in wear resistance of surface hybrid composite compared to that of the as-cast alloy was found to be more pronounced under higher applied loads.

1. Introduction

Among the materials of tribological importance, surface metal matrix composites preferentially have received considerable attention, because they exhibit superior properties such as high strength, high elastic modulus, and good wear resistance which make them suitable for engineering applications [1–3]. It is widely reported that the hard reinforcements such as SiC improve the hardness and wear resistance of the composites by acting as load-bearing components [2,3]. Nevertheless, they increase the wear rates of the counterfaces and lead to high coefficients of friction [3]. Moreover, these hard particles detached from the matrix, entrapped between the sliding surfaces and act as third body abrasives; promote worn surface damage [4]. Recent investigations [4–6] indicate that the tribological properties of surface composites can be further improved by adding solid lubricant particles, in order to produce hybrid composite. This is due to the combination of increase in bulk mechanical properties as a result of addition of hard particles and decrease in friction coefficient as a result of formation of lubrication film.

Dispersion of reinforcing particles in a surface layer is difficult to achieve using conventional surface modification techniques based on liquid phase processing at high temperatures [7,8]. In these techniques, there is evidence of poor interfacial bonding between reinforcement and metal matrix, because of formation of intermetallic phases and this may be detrimental to the mechanical properties of these composites. Furthermore, critical control of processing parameters is necessary to obtain the desired solidification. In order to avoid these problems, an effective processing technique which carried out at solid state is highly desirable.

Recently friction stir processing (FSP) was developed by Mishra et al. [9] as a generic tool for microstructural modification based on the basic principles of friction stir welding (FSW). In this technology, a rotating tool with a specially designed pin and shoulder is inserted into a substrate and produces a highly plastically deformed zone (stir zone). This process was explained in detail elsewhere [9]. While FSP has been mostly advanced as a grain refinement technique, it is also a very attractive technique to produce surface composites on aluminum substrate [10], homogenization of powder metallurgy aluminum alloy [11], microstructural modification of metal matrix composites [12] and property enhancement in cast aluminum alloys [13]. Recently, studies were conducted by Mishra et al. [10] to incorporate ceramic particles into surface layer of aluminum matrix to form surface composite by means of FSP. They reported that SiCp (SiC particles) were well distributed in the Al matrix, and good bonding with the Al matrix was achieved. In addition, the processing of surface composite during FSP can be carried out at solid state temperature; so that the mentioned problems accompanied by techniques based on liquid phase processing

☆ This paper was presented at the WOM 2013 conference, Portland, Oregon USA.

* Corresponding author. Tel./fax: +98 21 88005040.
E-mail addresses: zadeh@modares.ac.ir, sima.alidokht@gmail.com (A. Abdollah-zadeh).

0043-1648/$ - see front matter © 2012 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.wear.2012.11.043

can be avoided. Therefore, one of the potential applications of FSP could be fabrication of surface hybrid composite. The present authors have reported fabricating of the surface hybrid composites by the FSP using the SiC and MoS_2 particles [14]. The aim of this study is to evaluate the microstructure due to different values of tool rotation rate. The hardness and tribological behavior of surface composites under various applied loads have been evaluated in detail, as well.

2. Material and methods

As-cast A356 plates of 10 mm thickness with a nominal composition of 7.18Si–0.4Mg–0.1Fe–bal Al (in wt pct) were used as the substrate material. SiC powder (99.5% pure and 30 μm average particle size) was used as hard reinforcements owing to its high hardness and MoS_2 powder (99% pure and 5 μm average particle size) was used as soft reinforcement due to its layered structure and excellent lubricating properties. To add the powders, a groove with a depth and width of 3.5 and 0.6 mm, respectively, was machined out of cast A356 workpieces, in which the premixed SiCp and MoS_2 powders with equal volume percent were filled in. The simplified FSP unit was a modified form of a conventional milling machine. The FSP tools made of hardened H-13 tool steel consisted of a shoulder (Φ:20 mm) and a threaded pin (Φ:6 mm, length:3.7 mm). The pitch distance of threads was 1 mm. The tool rotation rate was varied from 630 to 1600 rpm, and its advancing speed was set to be 50 mm/min. The tool tilt angle with respect to the workpiece normal of 3° was applied. This tilt of the spindle towards trailing direction ensured that the shoulder held the stirred material and moved material efficiently from the front to the back of the pin [9]. The same procedure was used to fabricate A356/SiCp composite.

As processed workpieces were cut transverse to the FSP direction, mounted, and mechanically polished. Microstructural observations were carried out by employing optical and scanning electron microscopy (SEM). The size of reinforcement particles were analyzed using a4iDocu software. Mechanical properties were evaluated by Brinell hardness test in the stir zone (SZ), using 2.5 mm ball indenter and 31.25 kg force. Wear testing was conducted employing a pin-on-disk tribometer. Columnar pins with a diameter of 5 mm were made from the surface of the as-cast A356 and as-processed specimens, with the axis of the pins perpendicular to the FSP direction. The counterface material used in this study was AISI D3 steel, hardness of about 58 HRc and surface roughness of 0.2 μm (R_a). Wear testing was performed under dry sliding condition for 1500 m under a constant load of 10, 25 and 40 N and a sliding velocity of 0.35 m/s. All worn-out pins were cleaned in acetone and weighed to an accuracy of ±0.1 mg prior to testing. The coefficient of friction between the pin and disk was determined by measuring the frictional force with a stress sensor. The worn surfaces were examined using SEM

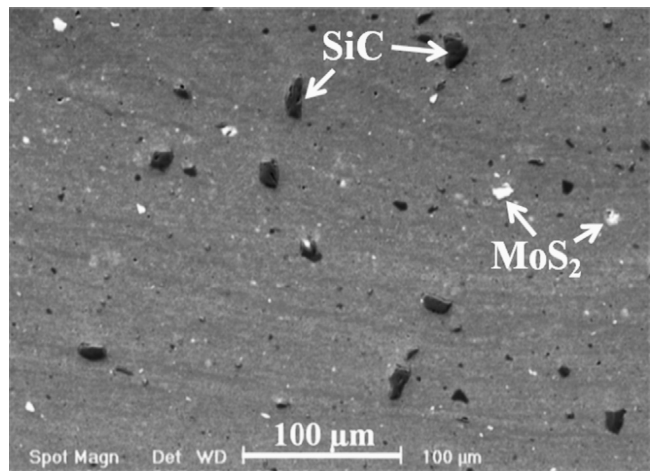

Fig. 2. SEM image of particles dispersion in hybrid composite produced by FSP at tool rotation rate of 1600 rpm.

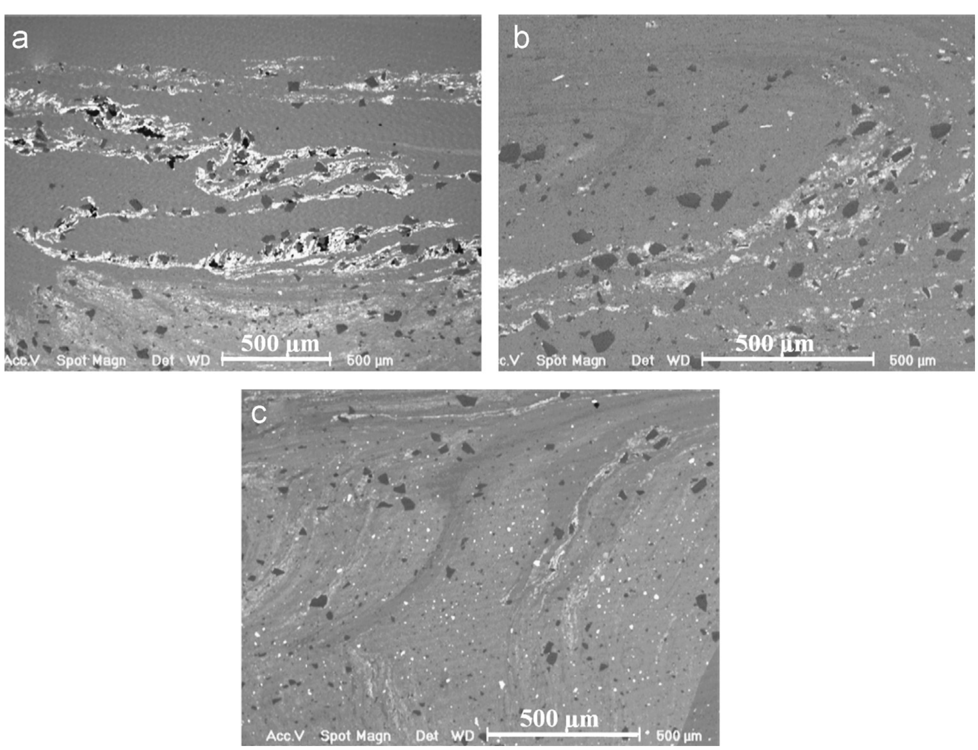

Fig. 1. Cross section SEM micrographs of hybrid composites fabricated using tool rotation rate of (a) 630, (b) 1000, and (c) 1600 rpm.

Please cite this article as: S.A. Alidokht, et al., Effect of applied load on the dry sliding wear behaviour and the subsurface deformation on hybrid metal matrix composite, Wear (2013), http://dx.doi.org/10.1016/j.wear.2012.11.043