Fabrication of Al/Graphite/Al_2O_3 Surface Hybrid Nano Composite by Friction Stir Processing and Investigating The Wear and Microstructural Properties of The Composite

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Abstract

Friction stir processing was applied for fabricating an aluminum alloy based hybrid nano composite reinforced with nano sized Al_2O_3 and micro sized graphite particles. A mixture of Al_2O_3 and graphite particles was packed into a groove with 1 mm width and 4.5 mm depth, which had been cut in 5083 aluminum plate of 10 mm thick. Packed groove was subjected to friction stir processing in order to implement powder mixture into the aluminum alloy matrix. Microstructural properties were investigated by means of optical microscopy and scanning electron microscopy (SEM). It was found that reinforcement particle mixture was distributed uniformly in nugget zone. Wear resistance of composite was measured by dry sliding wear test. As a result, hybrid composite revealed significant reduction in wear rate in comparison with Al/AL_2O_3 composite produced by friction stir processing. Worn surface of the wear test samples were examined by SEM in order to determine wear mechanism.

Keywords: Friction Stir Processing, Hybrid Nano Composite, Scanning Electron Microscopy, Wear Resistance

1. Introduction

Aluminum has been one of the most applicable engineering materials in different areas of usage from automation to aerospace industries due to its high ratio of strength to weight, low density, excellent erosion resistance and etc. However, low tribological properties of the aluminum are a great barrier for its application in other fields [1]. One way to deal with this problem is fabrication of discontinuous reinforced aluminum based metal matrix composites with ceramic reinforcements like alumina and SiC. These composites have higher hardness and wear resistance in comparison with aluminum [2].

However applying the ceramic particles to the aluminum alloys has some disadvantages, too. As we know, the mechanical strength and hardness of the composite will be increased in addition to the wear properties. Increase in hardness usually causes the increase in wear rate of the Counterface [3] and deterioration in machinability of the composite [4]. Furthermore, by applying the hard ceramic particles to the aluminum alloy, the friction coefficient between the wear surfaces will be increased. As a result, the energy loss and subsequently the temperature of the wearing surfaces will be increased [5]. Another problem associated with using hard ceramic particles in composites is detaching of ceramic particles from the composite. These particles can cause third body abrasives wear by sitting between wearing surfaces and subsequently, deteriorate wear properties [6].

Recent investigations have indicated that applying solid lubricants like graphite, MoS2 and Boron Nitride with ceramic particles can reduce the adverse effects of ceramic particle reinforcements [4, 6, 7]. These materials form a self-lubricated film over wearing surfaces and consequently, reduce the coefficient of friction and subsurface plastic deformation. This will change the severe adhesive wear to the mild abrasive wear and improve the wear resistance [8]. However applying more than specific volumetric percent of graphite causes deterioration in fracture toughness and

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subsequently, in wear properties of the composite [9].

By utilizing some characteristics of Friction Stir Welding (FSW) like being solid state process, existence of mechanical flow and therefore, material mixing, microstructure homogenizing , Friction Stir Processing (FSP) was used for composite fabrication for the first time by Mishra et al. [10]. Composite fabrication by FSP has been the subject of numerous works [7, 11-13] and more details about the process can be found in them.

The main objective of present paper is fabrication of surface hybrid nano composite of Al/Al_2O_3/graphite by means of Friction Stir Processing. Wear and microstructural properties of the composite has been investigated in details. The worn surface of samples was investigated by SEM in order to determine the wear mechanism of composites.

2. Experimental

A 10 mm thick plate of 5083 aluminum alloy was used as a matrix with a nominal composition of 94.2% Al, 4.5% Mg, 0.5% Mn, 0.3% Si, 0.26% Cr, and 0.24% Fe. A groove with width and depth of 1 and 4.5 mm respectively had been cut on the plate. Commercially available nano Al_2O_3 (α) powder (99% pure and 80nm average particle size) and graphite powder (98.2% pure and 10-50 μm) were used as reinforcement. First, nano alumina powder and then a mixture of nano alumina and graphite powders (75% graphite) were packed into the groove. FSP tool were made of H13 hot working steel with a columnar shape (Ø18 mm) and with a threaded probe (Ø6 mm, length: 5 mm) which had been hardened up to 51RC. Rotational speed, transvers speed and tilt angel was 1250 rpm, 20 mm/min and 3° respectively and were chosen by try and error method in order to have defect free FSP region. The aluminum alloy plate was fixed on a steel backing plate. In order to prevent powder from spattering during FSP, the filled groove was closed by first FSP tool (pin less tool). Then, the second or main FSP tool was plunged into the closed filled groove and advanced. In order to have more homogeneous with less agglomeration every sample was subjected to 3 passes of FSP.

The FSPed sample was cut from transverse section and mechanically polished and etched with modified Poulton's reagent. The samples were investigated by optical microscope and SEM in order to determine the microstructural properties. Pin on disk dry sliding wear test was conducted with 25 N constant normal load and 0.24 m/s sliding speed for total sliding distance of 950 m on samples of 3×5 mm which were prepared from transverse section of FSPed samples by wire cut. Counterface was made of AISI 52100 with 58-60RC hardness and surface roughness of 0.2 μm. Wear samples were ground up to 500 grade by emery papers. Before and after performing wear test the samples were weighed to an accuracy of ±0.1 mg in order to determine the wear loss. Friction coefficient of pin and disc was obtained by dividing the friction force which was measured automatically by strain gauge to normal load. Worn surface of samples were investigated by SEM.

3. Results and discussion

3.1. Microstructural Properties

Optical micrographs of transverse section of composites are depicted in Fig. 1. As it can be seen in micrographs, no defects such voids or cracks are visible. The stir zones in Al/Al_2O_3 and hybrid composites are very well-bonded to the aluminum alloy matrix (Fig.1a, b). Graphite particles are distributed homogeneously in the stir zone. There is no sign of graphite agglomeration in the stir zone probably due to severe mechanical flow during three passes of FSP [11]. Average grain size of the stir zone in hybrid and Al/Al_2O_3 composites are 3μm and 7μm (Fig.1 c, d) which is very fine in comparison with grain size of the base metal (40μm). Hybrid composite has finer grains than Al/Al_2O_3 composite. That is probably because of less heat generation during FSP in presence of graphite particles due to graphite's lubrication characteristic. Hence, the cooling rate increases, and the grain growth is restricted.

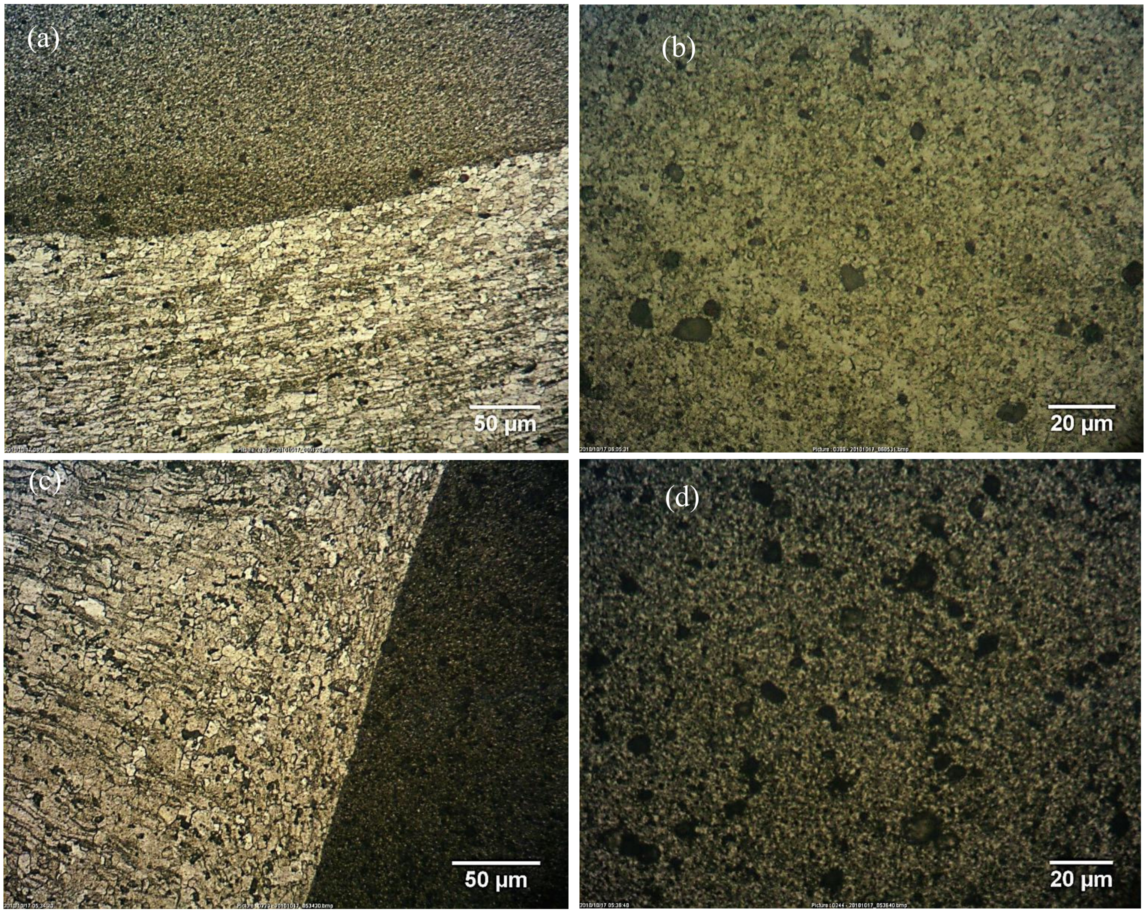

Fig. 1. Optical micrographs of the composites a) different FSP zones in Al/Al_2O_3 composite b) different FSP zones in Al/Al_2O_3 /Graphite composite c) stir zone in Al/Al_2O_3 composite d) stir zone in Al/Al_2O_3 /Graphite composite

SEM image of hybrid composite is shown in Fig. 2. Presence of micro-sized graphite particles and nano-sized alumina particles can be seen in SEM image. However, there are some signs of clustered nano alumina particles which it has been noted in several papers [11, 12].

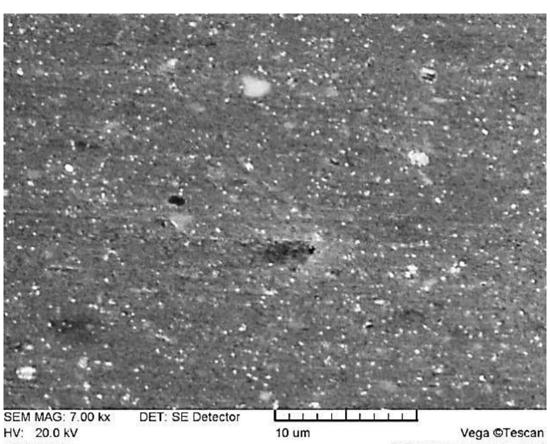

Fig. 2. SEM image of Al/Al_2O_3 /Graphite hybrid composite

3.2. Wear properties

Fig. 3 shows the wear rate of base metal, Al/Al_2O_3 and Al/Al_2O_3/Graphite composites. Hybrid composite has the lowest wear rate; thus, it has the best wear condition in comparison with Al/Al_2O_3 composite and base metal. This result is in line with different researches [4, 6, 14].

Variation of friction coefficient with sliding distance of base metal and composites are shown in Fig.4. As it can be derived from Fig.4, average friction coefficient of hybrid composite during wear test was lower than the Al/Al_2O_3 composite and base metal. Graphite particles act as solid lubricant and diminish the coefficient of friction [6, 15]. Base metal has the higher coefficient of friction than the

Al/Al_2O_3 nano composite. It can be the reason for heavy noise and vibration during the wear test of base metal. Alumina particles which are detached from the aluminum matrix act as lubricant and lower the friction coefficient [11]. A two-stage form can be seen in variation of friction coefficient of base metal with sliding distance. At first stage the friction coefficient steadily grows but after about 50 meters a drastic growth can be seen in coefficient of friction. Shafiei-Zarghani et al. [16] related this two-stage form in variation of friction coefficient to a conversion from initial abrasive wear mechanism to final adhesive wear mechanism. There is no sign of two-stage form in hybrid or Al/Al_2O_3 composites.

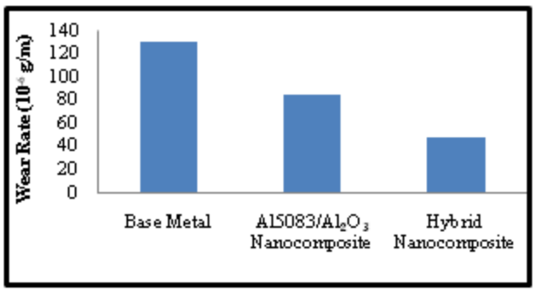

Fig. 3. wear rate of base, Al/Al_2O_3 and hybrid composites

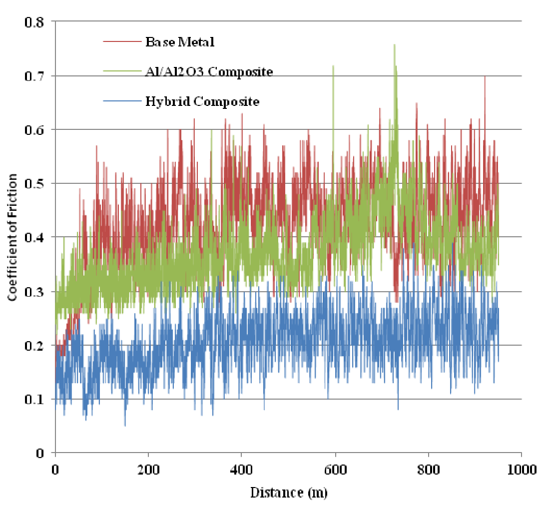

Fig. 4. Variations of friction coefficient with sliding distance

Fig. 5a, b shows SEM micrographs of worn surface of the base metal. Presence of large pits and grooves in Fig.5a shows both abrasive and adhesive wear mechanisms. Large pits can be formed due to difference between the hardness of aluminum alloy base and hardened steel counterface. Nucleation and growth of micro cracks (Fig. 5b) near the grooves and joining them to each other causes formation of large pits or delamination[19]. Grooves can be the remaining grooves of first stage of wear in base metal which causes abrasive wear mechanism in first stage, and then, gradually these grooves forms large pits due to crack growth and localized welding of worn debris to the base.

As it can be seen in Fig. 5c, d, Al/Al_2O_3 composite shows shallow grooves on SEM image of worn surface. Small pits are visible on worn surface; however, these pits are very smaller than those in worn surface of aluminum base. Hence, the better wear properties are reasonable for Al/Al_2O_3 composite than aluminum base. Ceramic particles, which are uniformly dispersed within the base metal, can decrease the direct contact load and thus, lower the wear rate. Smooth worn surface and shallow grooves are visible in SEM images of hybrid composite as it can be seen in Fig. 5e, f. lower friction coefficient and worn surface specifications indicate better wear properties for hybrid composite in comparison with Al/Al_2O_3 composite. Graphite particulates addition reduces the wear and friction of the composites due to formation of a thin lubricating graphite rich film on the tribosurface [17]. Existence of high concentration of particles on the worn surface of hybrid composite which can be easily seen in Fig. 5e, f proves the formation of tribofilm on the worn surface.

4. Conclusions

In this investigation an attempt has been made to fabricate hybrid composite of Al/Al_2O_3/Graphite and investigate microstructural and wear properties of the composite. According to the results of this research following conclusions can be made:

1- The hybrid nano composite was fabricated successfully on aluminum alloy matrix without any visible voids or cracks.

2- Microstructural investigations show that reinforcing particles were dispersed uniformly in nugget zone. Average grain size of nugget zone in hybrid composite is less than Al/Al_2O_3 composite.

3- The addition of graphite reinforcement to Al/Al_2O_3 composite further lowers the wear rate and friction coefficient in hybrid composite.

4- Aluminum base shows abrasive wear mechanism with low friction coefficient at initial stage and then adhesive wear mechanism at later stage of wear.

5- Nano alumina particles decrease the direct contact load and thus, decrease the wear rate.

6- Graphite addition in hybrid composite forms a lubricant tribofilm and lower the friction coefficient.

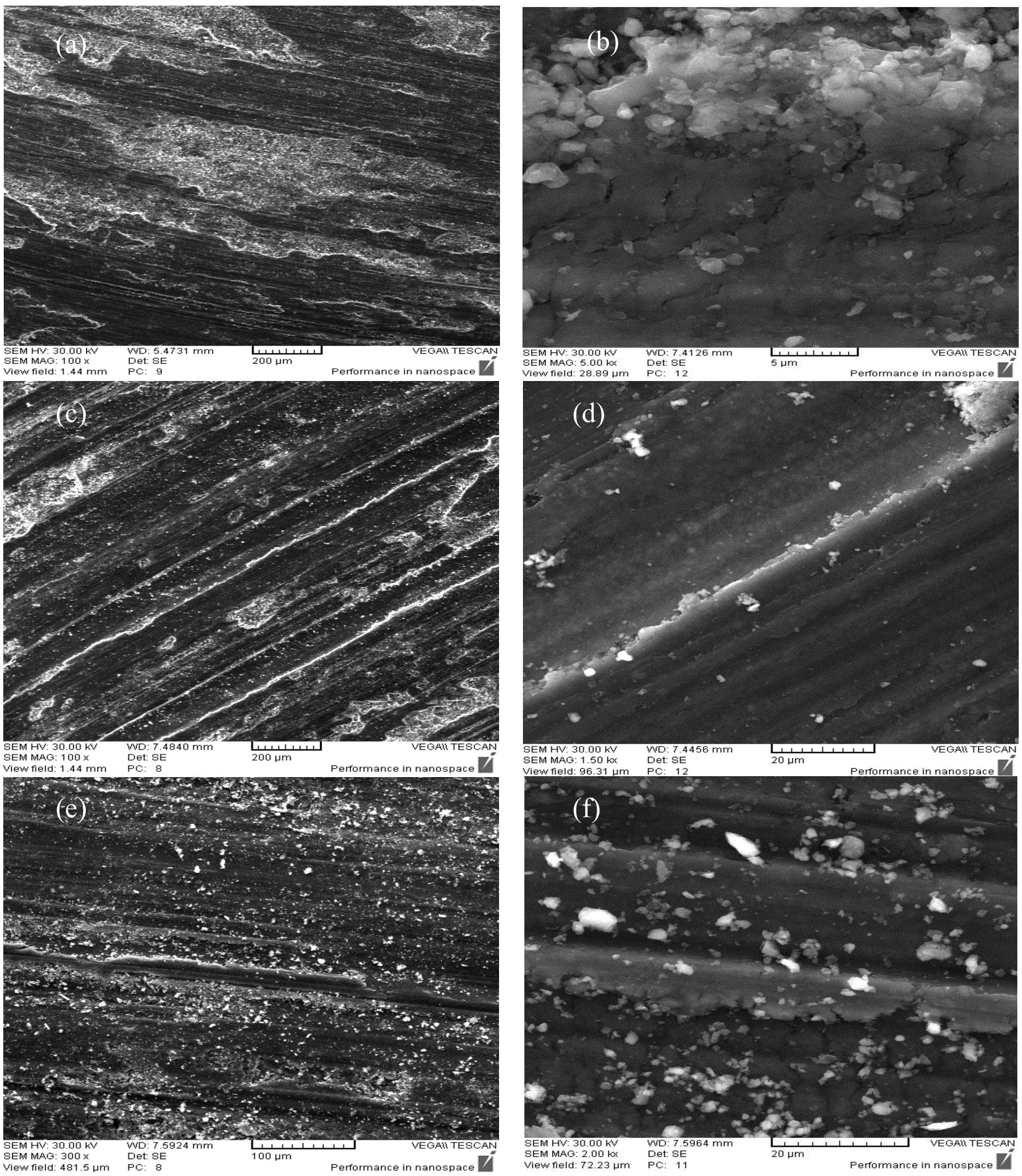

Fig. 5. SEM images of worn surface: a, b) worn surface of base at low and high magnifications respectively c, d) worn surface of Al/Al_2O_3 composite at low and high magnifications respectively e, f) worn surface of hybrid nano composite at low and high magnifications, respectively.

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