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Microstructural Modification of Al-base Composite by Friction Stir Processing

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Abstract

A novel surface modifying technique, Friction Stir Processing, is used to enhance mechanical properties of Al-Si / Al_2O_3 composite, through micro structural refinement and homogenization. The effect of processing parameters on resultant microstructure and wear rate is investigated in this work.

The Friction Stir Processing resulted in significant breakup of the coarse Si and Al-dendrites and uniform distribution of Si and Al_2O_3 in the matrix with significant micro structural refinement. These microstructures changes lead to significant improvement in wear resistance of composite.

Keywords: Microstructure, Composite, Friction Stir.

تعديل التركيب الحجري للمواد المتراكبة باستخدام المعالجة بالخط الاحتكاكي

الخلاصة

استخدمت تقنيه جديده لتعديل بنيه السطوح هي المعالجه بالخلط الاحتكاكي وذلك لتحسبن الخواص الميكانيكيه للمواد المتراكبه المنتجه من سبيكه الالمنيوم –سليكون,المقواه بدقائق من الالومينا, من خلال تنعيم ومجانسه الينيه المجهريه . في هذا البحث تم دراسه تاثير متغيرات العمليه على البنيه المجهريه ومعدل البلى. اظهرت النتائج ان اسنخدام تقنيه الخلط الاحتكاكي ادت الى تكسير دقائق السليكون وطور الالمنيوم الشجيري اضافه الى التوزيع المتجانس للسليكون ودقائق الالومينا في السبيكه الاساس مع حدوث تنعيم في البنيه المجهريه.ان هذه التغيرات في البنيه المجهريه ادت الى تحسين واضح في مقاومه البلى للماده المتراكبه.

1-Introduction

The strong demand for weight reduction in car and aircraft fabrication leads to the replacement of conventional materials by lighter metals such as aluminum alloys. However aluminum alloys are not sufficiently stiff or strong for many purposes and their reinforcement is necessary. Aluminum based metal matrix composites are outstanding candidates for these applications owing to the high ductility of the matrix and the high strength of the hard reinforcing phases [1].

Al-alloy matrix composites containing hard dispersoids are gaining immense industrial importance because of their excellent combination of physical, mechanical and tribological properties over base alloys [2]. It is reported that Al-alloy composite provides comparable mechanical properties but better thermal conductivity and specific heat than the cast irons [3].This leads to the use of these composites in several automobile and engineering components where wear in, addition to , weight saving are advantages[4].

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For many applications, the useful life of these components often depends on their surface properties, such as wear resistance [5].

In recent years, several surface modification techniques, such as high-energy laser melt treatment, high-energy electron beam irradiation, plasma spraying [6, 7, 8] has been developed to fabricate or modify surface metal-matrix composites. The surface composite exhibits high micro hardness and excellent wear resistance compared with untreated sample . It should be pointed out that the existing processing techniques for surface composite modification are based on liquid phase processing at high temperatures. In this case, it is hard to avoid the interfacial reaction between reinforcement and metal-matrix and the formation of some detrimental phases [9].Obviously, if processing of surface composite is carried out at temperatures below melting point of substrate, the problems mentioned above can be avoided. In this work, Friction Stir Processing is used as a new solid-state technique that applies the basic principles of friction stir welding for surface modification of composites.

In Friction Stir Processing (FSP)technique a cylindrical rotating tool with a concentric pin and shoulder is plugged into the material to be processed, and traversed along the line of interest. Localized heating is produced by friction between the rotating tool and the work piece to locally raise the temperature of the materials to the rate where it is easily plastically deformed [10, 11]. During this process, the materials undergo intense plastic deformation at elevated temperature resulting in significant grain refinement (12).

The objective of the present work is to evaluate the extent to which Friction Stir Processing can improve wear resistance and microstructure properties of Al-Si/Al_2O_3 composite.

2- Experimental Work

Preparation of composites

The chemical composition of the matrix alloy used in the present work is given in table (1). The alloy was melted in resistance heating furnace at a temperature (700) ˚C, Al_2O_3 particles with 98% purity and average particle size (20μm) were preheated to 250˚C and introduced into the molten alloy by means of special feeding attachments. Simultaneously, the molten metal matrix containing 5% weight Al_2O_3 was well agitated in graphite crucible by means of mechanical impeller rotating at 800 rpm to great vortex. The melt was next poured into squeeze casting die. A (10) ton hydraulic press was used for applying pressure on the melt poured into die position below the main ram for direct squeeze casting. The die was made of (H13) steel with die cavity of size (150*30*30) mm. The initial die temperature was maintained at about (100-120) ˚ C. The liquid alloy with 5% Al_2O_3 particles was poured in the die cavity before the application of pressure of (10)MPa ,with (2)min dwell time .

Friction Stir Processing

The prepared Al-Si/ Al_2O_3 composite samples were cut into rectangular pieces of dimensions (50*30*30) mm for processing. A milling machine type (Bridgeport CNC Milling Machine) was used for friction stir processing. The maximum spindle speed was (4000) rpm and (2) Hp. High speed tool steel (H13) with shoulder of (12.5) mm diameter, and a cylindrical pin of (6) mm diameter, and (4) mm length was used for processing. Single stir pass was done at three tool rotational speeds (800, 900, 1000) rpm, (4)kN downward force and constant traverse speed (40)mm/min Figure(1)shows the principle of Friction Stir Processing.

Microstructure test

Metallographic examination was performed on cross-sections of the unprocessed and on stir processed samples. The samples were polished using 1200 mesh abrasive paper and alumina solution having a particle size of 0.05 µm , then etched using 5% Hf. Microstructure observation were carried using Carl Ziess Optical Microscope and Shimadzu(S200) Scanning Electron Microscope.

Hardness test

Vickers micro hardness tests were performed on the cross-section perpendicular to the tool traverse direction of the Friction Stir Processed specimens. The hardness test was done using (200) g load (30) sec dwell time .The hardness value was calculated from the equation:

Hv=1.845P/d^2 …..(1)

Where , Hv: Vickers hardness(Kg/mm2).

P:Appied load (Kg) ,d:Indent diagonal (mm**)**.

Wear test

The dry sliding wear tests of unprocessed and friction stir processed samples were carried out using pin on disc apparatus. The specimen were cylinders having a diameter of (10)mm with a height of (12)mm. The disc was made from hardened steel with hardness of (58-60)HRC. The specimens were weighted prior to and after the wear test using digital electronic weight balance having an accuracy of (0.01)mg. The tests were carried using different load (20,40,60)N and different sliding distance (500,1000,1500)m. the wear rate was calculated from the equation :(13)

$$\text{Volume wear rate}\frac{m^3}{m} = \frac{w_2 - w_1}{2prnrt} \qquad \text{…. (2)}$$

w_1,w_2 is sample weight before and after test respectively (gm)

r: track radius of test sample (m)

n: rotation speed of the disc.(rpm)

r : sample density (kg/m^3)

t: test time(min)

3-Result and discussion

Microstructures

Figure (2) shows an optical micro graph of the cross section normal to the tool traverse direction. The friction stir processed zone appears brighter than the unprocessed zone (as cast composite). Figure (3) shows SEM micrographs of the friction stir composite. It can be seen that the as cast composite sample consists of large acicular needle like eutectic silicon, columnar primary aluminum matrix ,and single and somewhat aggregated Al_2O_3 particles in the Al-Si matrix as shown in Figure(3-a). The microstructure of the stir processed zone shows fragmentation of needle-shaped eutectic silicon into more or less spherical one, smaller primary Al-grain and uniformly distributed Al_2O_3 particles as shown in Fig(3-b) .

The microstructure of friction stir Al- Si/Al_2O_3 composites processed at different tool rotation speed is illustrated in Fig (4and5). The microstructure shows, that increasing tool rotation speed, tend to decrease the size and the aspect ratio of the Si particles. Also the Al_2O_3particle distribution was significantly improved .The homogenous distribution of Si and Al_2O_3 particles was related to the mixing action which break the large Si particles and redistributes them in the matrix,(Si *particles should be easily break down due to the plastic deformation*) .Finer Si particles were uniformly formed, and ,distributed with fine Al-grain, The grain refinement was attributed to the dynamic re crystallization during friction stir processing(14) and due to the pining effect of Al_2O_3 particles which retard the grain growth of the AL- grain in the matrix[15].

Micro hardness

Table (2) shows Vickers micro hardness distribution on the cross-section perpendicular to the tool traverse direction of the Friction Stir Processed zone produced at different tool rotation speed. The processed zone exhibited a higher hardness than the as cast zone. In addition, increase in pin rotation speed increases the hardness within the processed zone. This is due to reduction in the casting defect, a fine dispersion of Si particles, and the Al- grain refinement. The hardness and the grain size d have been determined using the Hall–Petch equation:

$H_V = H_o + k_H * d\wedge(-1/2)$. Where H_o and k_H are appropriate constants. Because H_V is proportional to ($d\wedge$-1/2), the finer the grain size, the higher the hardness value is [4].

Wear

Figure (6,7,8) show the variation of wear rate as a function of sliding distance for squeeze casting and friction stir processed $Al\text{-}Si/Al_2O_3$ composites. It can be seen that as the sliding distance increases, the wear rate decreases for all applied normal loads. The wear rate of friction stir processed composites is significantly lower as compared to the squeeze cast composite for all applied normal loads. Also, the wear rate of processed composites decreases with increasing tool rotation speed of constant normal load and sliding distance. The improved wear resistance due to fiction stir processing is attributed to the redistribution of reinforcing Al_2O_3 particles and Si particles in the matrix and refinement of Al-grain. Figure (9) shows SEM micrograph of worn surface of as cast and stir processed composites. The micrograph reveals that the worn track width decreases in friction stir area compared to un processed area. It is evidence that the extent of wear in FSP composite is lower than that of squeeze cast. The depth and width of the grooves generally imply that an amount of material removed from the specimen surface [16]. In view of this fact, it is expected that uniform distribution of Al_2O_3 particles and Si particles and modification of Al-grains will lead to a high wear resistance.

4-Conclusions

1- Metallographic examinations indicate that friction stir processing of $Al\text{-}Si/Al_2O_3$ composite is effective for refining microstructure of both matrix alloy and reinforcements. The breakup of large Si particles is due to severe deformation caused by friction stirring action generated by a rotating pin

2- The hardness of friction stir processed composite is higher than that of as- cast composite. Increasing tool rotation speed, increases the hardness of stir zone

3- The wear rate of friction stir processed composites is less than that of unprocessed composites.

4- Increasing tool rotation speed decreases the wear rate of processed composites.

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Table (1) Chemical composition of Al–Si alloy in weight percent

Element	Si	Mg	Cu	Fe	Ti	Al
Wt%	7.80	0.04	0.06	0.09	0.13	balance

Table (2) Micro hardness measurements of Al-Si/Al_2O_3

sample	HV kg/mm^2
Squeezes cast composite	80
Friction Stir Processed composite at 800r.p.m	100.07
Friction Stir Processed composite at 900r.p.m	121.21
Friction Stir Processed composite at 1000r.p.m	133.6

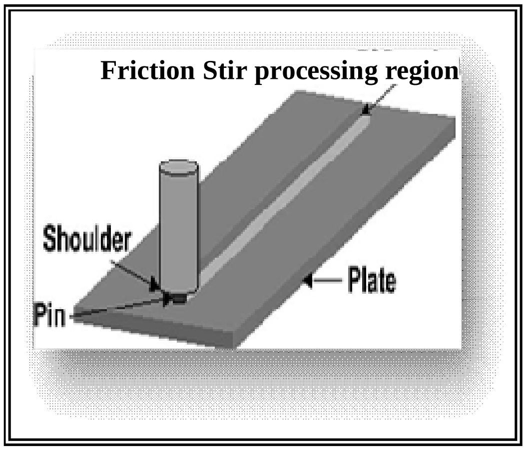


Figure (1)Principle of Friction Stir Processing[11]

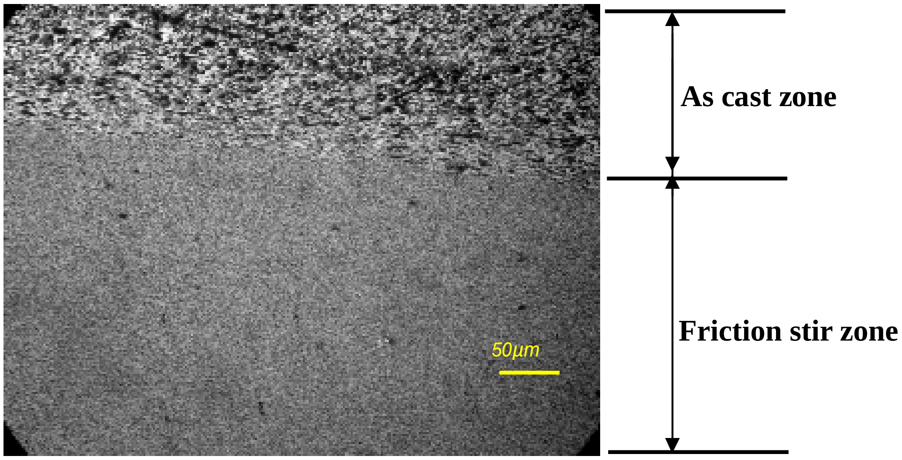
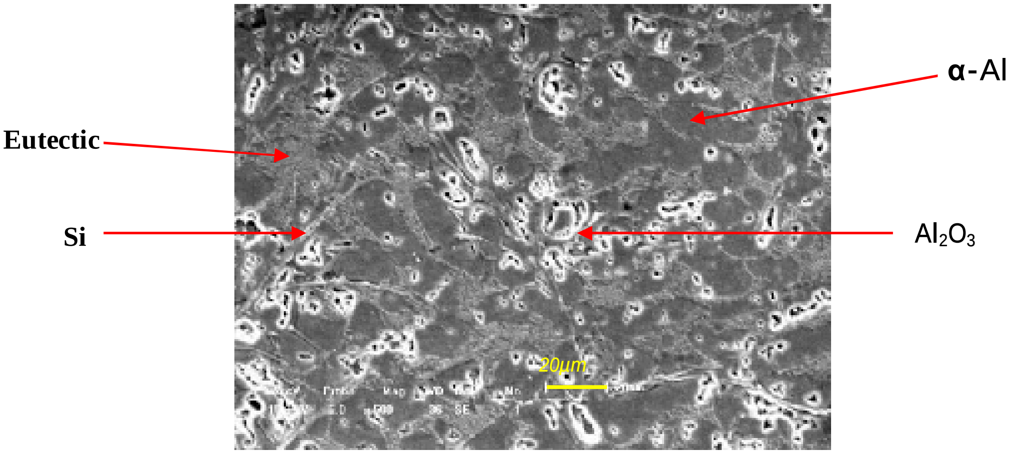
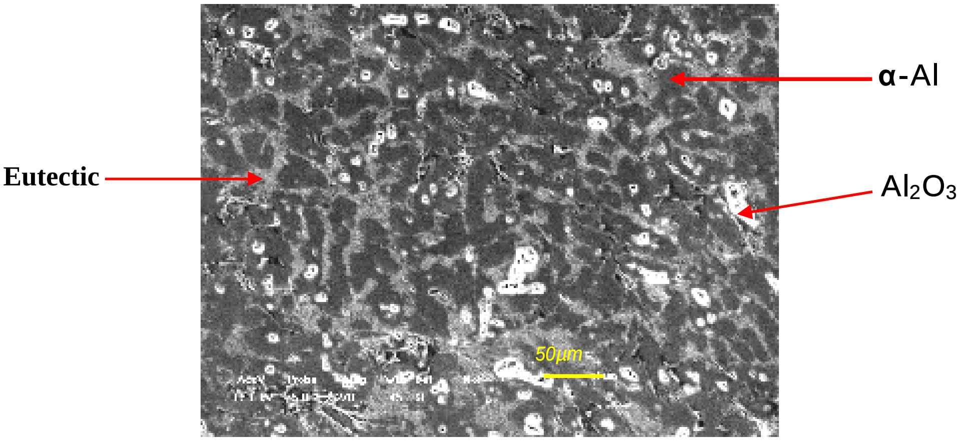


Figure (2) Optical micrograph of Friction Stir Al-Si/Al_2O_3 Composite

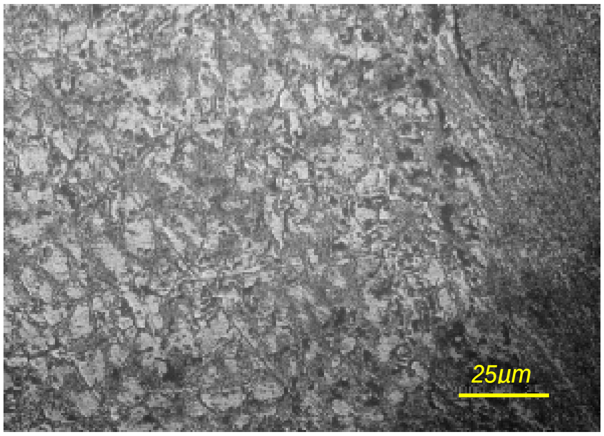


(a)



(b)

Figure (3) SEM micrographs of (a)squeeze cast Al-Si/Al_2O_3 composite and(b) stir processed Al-Si/Al_2O_3 composite



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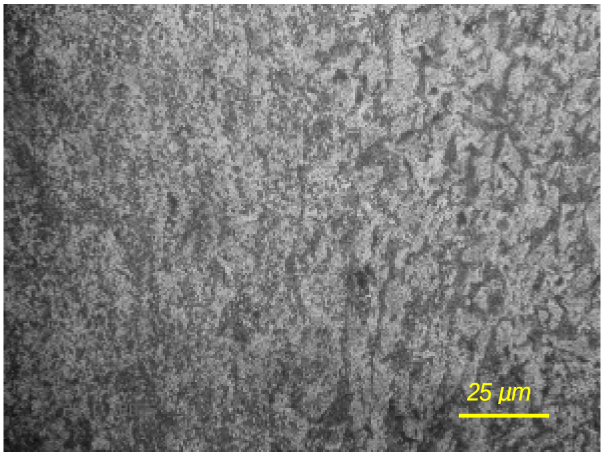
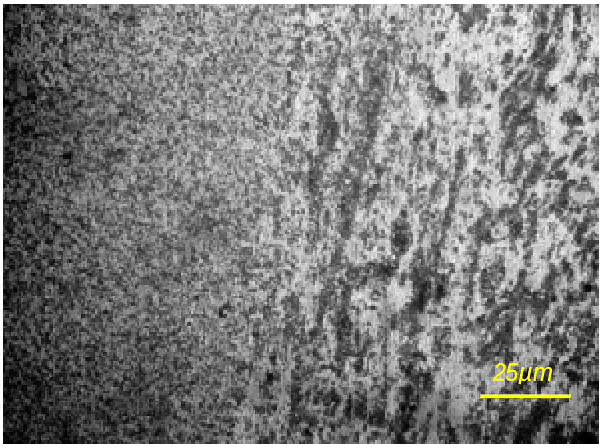
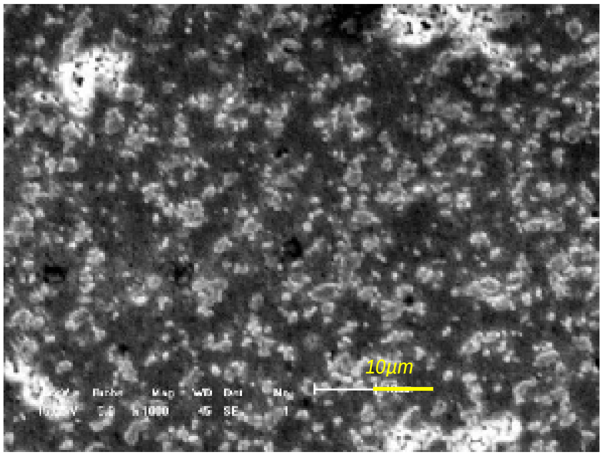


(b)

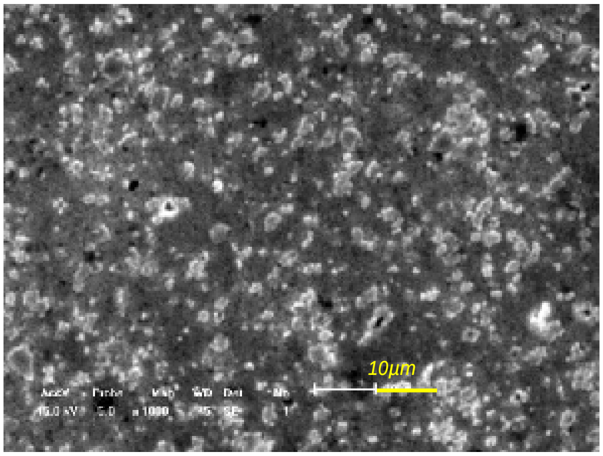


(c)

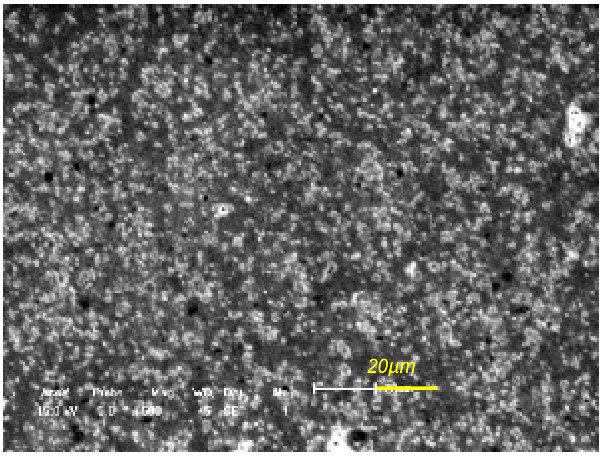
Figure (4) Optical micrographs of friction stir Al-Si/Al_2O_3 composite. (a) Processed at800rpm, (b) processed at900rpm, (c) processed at 1000rpm



(a)



(b)



(c)

Figure (5) SEM micrographs of Friction Stir Processed Al-Si/Al_2O_3 composite processed at, (a) 800rpm, (b) 900rpm, (c) 1000rpm

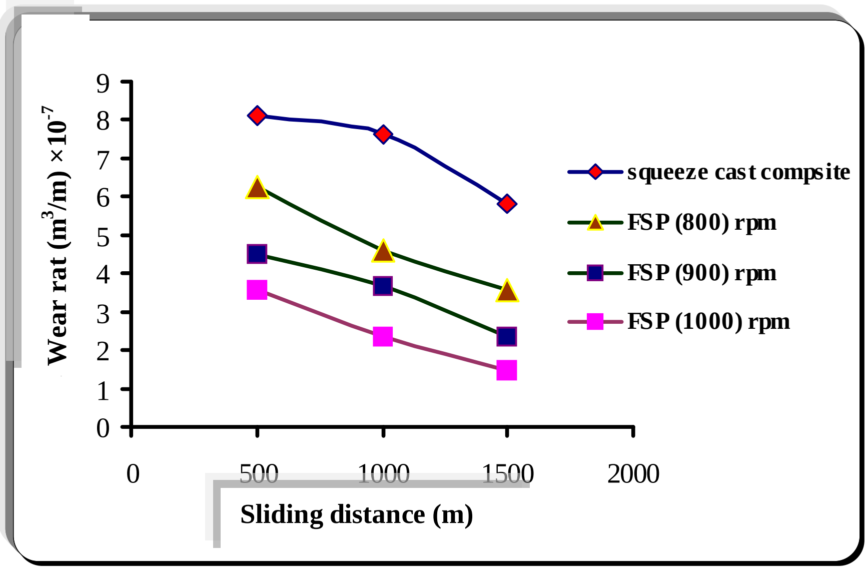


Figure (6) The effect of sliding distance on the wear rate of Al-Si/Al_2O_3 composite at20N

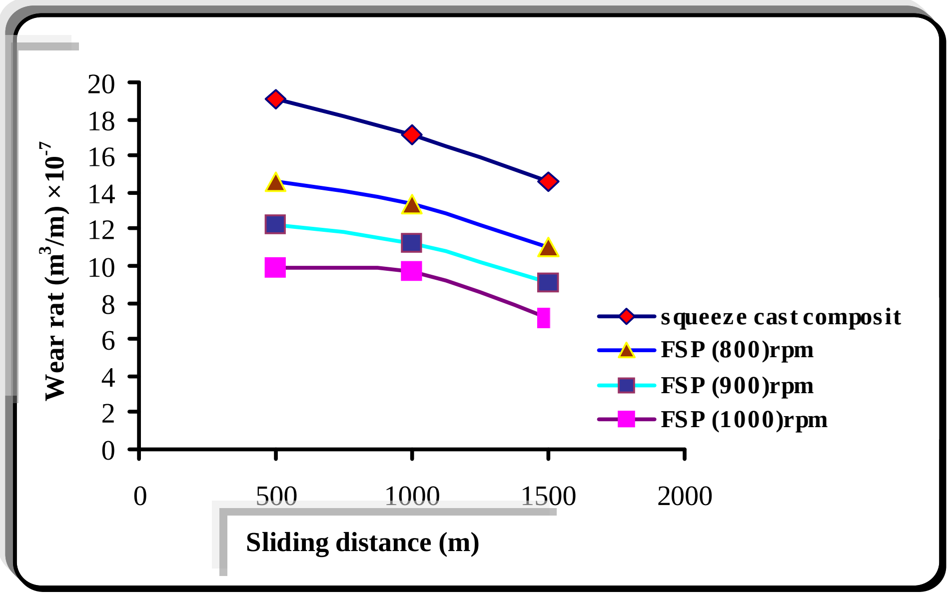


Figure (7) the effect of sliding distance on the wear rate of Al-Si/Al_2O_3 composite at40N

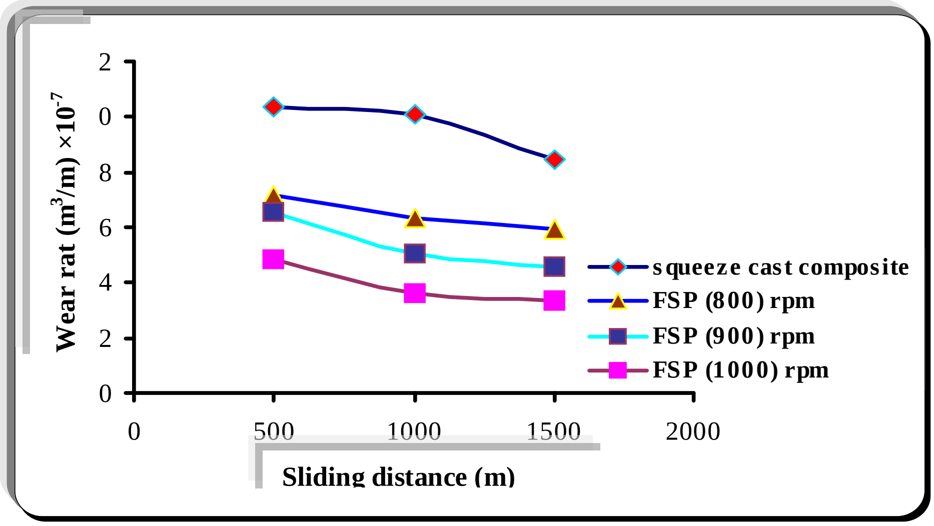


Figure (8) the effect of sliding distance on the wear rate of Al-Si/Al_2O_3 composite at60N

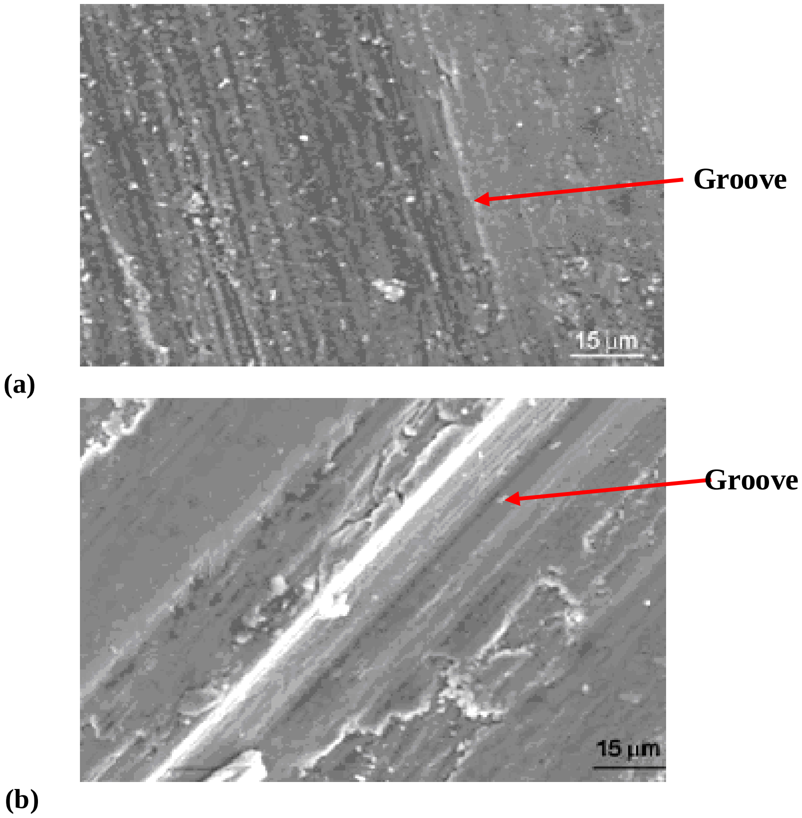


Figure (9) Worn surface morphology of Al-Si/Al_2O_3 composites (a)squeeze cast (b)stir processed