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EFFECT OF FRICTION STIR PROCESSING ON MICROSTRUCTURE AND WEAR BEHAVIOUR OF 6063 ALUMINIUM ALLOY

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Abstract-Friction stir processing (FSP) is promising Surface modification technique. A single pass FSW was performed on Aluminum 6063 alloy at combinations of tool rotational speeds ranging 1000-1600 rpm and traverse speed ranging 40-80 mm/min with cylindrical threaded pin profiled tool having shoulder diameter of 18 mm, pin diameter of 6 mm and pin length of 5.7 mm. The effect of these parameters on tribological properties was studied. The wear resistance is found to be increased from base metal to single pass FSP sample. The results revealed that with increase in tool rotational speed the wear rate increases. FSPed alloy with tool rotational speed of 1600 rpm and traverse speed of 40 mm/min shows maximum wear rate and minimum microhardness whereas at 1000 rpm and 80 mm/min it showed minimum wear rate with maximum microhardness value of 54.3 HV. This may be attributed to the heat generation in the nugget zone which leads to more softening of the metal matrix. The high heat generation causes matrix softening which results in increased wear rate on the other hand high heat generation leads to coarse grains which also affected tribological properties. Furthermore, Microstructure results showed that FSPed alloy has more refined grain structure as compare to base material which may be resulted in enhancement of hardness and resistance to wear in FSPed alloy.
Keywords: Friction stir processing, Wear behavior, Microstructure, Aluminium alloy.

1. INTRODUCTION

Aluminum alloys are widely used in building construction, military, aerospace and transportation industries due to its high strength-to-weight ratio, light weight and excellent resistance to corrosion. But, it exhibits inferior strength and tribological properties that limit its use [1]. A proper technique can be employed to refine microstructure and make surface composites to enhance tribological properties of the material. Thermal spraying and laser beam techniques can be utilized to prepare surface composites, but it deg rades the properties due to formation of unfavorable phases. These techniques are operated at higher temperatures and impossible to avoid the reaction between the reinforcements and the material, which forms a detrimental phase [2]. Therefore a process can be employed which is operated below melting temperature of material for the fabrication of surface composites which can be used to avoid the above mentioned complications. Friction Stir Processing (FSP) is a new solid state processing technique for microstructure modification, recently FSP has become an efficient tool for homogenizing and refining the grain structure [3]. It is based on the principle of friction-stir welding (FSW) which was invented by The Welding Institute (TWI) of United Kingdom in 1991 [4]. A non-consumable cylindrical tool used in friction stir processing (FSP) consists of a pin and a concentric larger diameter shoulder. While the tool is rotating the pin is plunged into the sheet and the shoulder comes in contact with the surface of the sheet. Then the tool is transverse in the desire direction while it is rotating [5]. The friction between the tool and the sheet generate heat which softens the material without reaching the melting temperature of the material, as maximum temperature reached during FSP is of the order of (~0.8) of the melting temperature. The rotation of the pin does the stirring action of the softened material which makes the material undergo intense plastic deformation yielding a dynamically recrystallized fine, equiaxed, and defect free grain structure [6]. There are certain process parameters like translation speed, rotational speed, number of passes and tool geometry etc., which are to be controlled to achieve the desire microstructure modification, and optimization of the process.

2. EXPERIMENTAL INVESTIGATION

The material used in this experimental work is commercial 6063 Aluminum alloy sheet with thickness of 6 mm and the samples dimensions are 150 mm X 200 mm. The composition of the material is shown in Table 1.

The threaded tool of high carbon high chromium was used with shoulder diameter of 18mm, pin diameter of 6mm and pin length of 5.7mm. Pin length is slightly shorter than the thickness of the sheet which is 6mm as clearance of 0.3 mm was given. Threaded tool pin with pitch of 1 mm at angle of 60° is used. The FSP process variables are identified as rotational speed (1000 rpm, 1300 rpm, 1600 rpm) and traverse speed (40 mm/min, 60 mm/min, 80 mm/min). Single pass of FSP used for each specimen.

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Table 1: Chemical composition (wt%) of the base material Al6063.

	Al	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti
Min.	--	0.2	--	--	--	0.45	--	--	--
Max	Bal.	0.6	0.35	0.1	0.1	0.9	0.1	0.1	0.1

The microstructural investigations were done with optical microscope. The sample for microstructure analysis were polished with different grades of emery paper i.e. 600 grit, 800 grit, 1000 grit, 1200 grit, 2000 grit and then with diamond paste and later specimens were etched with keller reagent (1 part of hydrofluoric acid with 9 part of distilled water) for 10-20 sec and then rinse in running water. All samples were taken from transverse section of processed area from middle of the sheet.
Microhardness tests were carried out on samples taken from transverse section of processed area. Samples were tested with a load of 100 gf and the dwell time was 20 seconds using a Vickers digital microhardness tester.

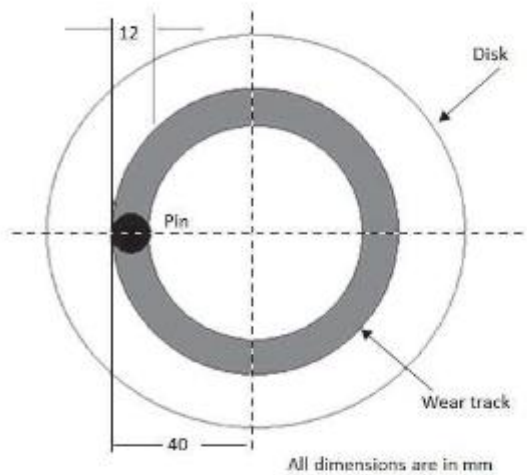

Fig.1: Schematic configuration of pinSchematic configuration of pin-on-disk tribo-meter [2].

Wear test was carried out on universal tribometer using pin-on-disc configuration (Fig.1). Square pins of 12 mm X 12 mm and of length 6mm were cut with CNC wire cut machine from base metal as well as from a FSPed alloy. Steel plate with hardness of 62 HRC was used as counter face material. Wear test specimen were polished with emery paper down to 1200 grit. For all wear test the diameter of the sliding track on the disk surface was 80 mm. The wear tests were performed under dry sliding conditions with a constant load of (20N), rotational speed (650 rpm), Time (551 sec) and sliding speed (2.72m/s) for distance of (1500m). Weight loss was determined as a function of sliding distance. Before and after each test both disc and sample were mechanically polished with acetone and were dried in air to avoid contamination.

3. RESULTS AND DISCUSSION

The microstructure results were obtained using optical microscope. The optical micrographs of grain structure of base material as well as of FSPed aluminium alloy at 1600 rpm rotational speed, 40 mm/min translational speed and at 1000 rpm rotational speed, 80 mm/min translational speed are shown in Fig.2.

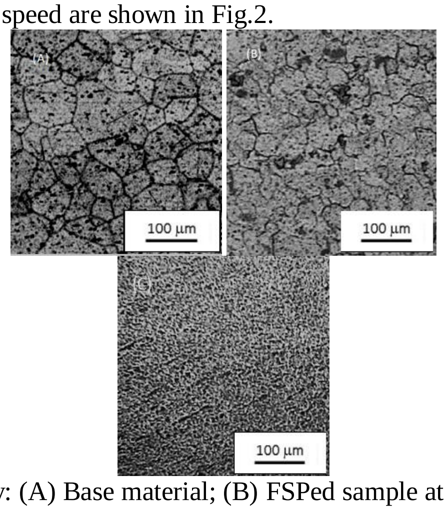

Fig.2: Microstructure of aluminium alloy: (A) Base material; (B) FSPed sample at parameters 1000 rpm rational speed and 80 mm/min translational speed; (C) FSPed sample at parameters 1600 rpm rational speed and 40 mm/min translational speed.

Results revealed that FSP resulted in significant microstructural evolution within and around the stirred zone. The as-received structure exhibit a combination of large and small grains as shown in Fig. 2(A), while the structure of the processed samples shows that the majority of grains have almost the same grain size. After FSP, the grain structure was clearly more equiaxed and more homogenized as during FSP the rotating tool gives sufficient heat generation as shown in Fig. 2(B) and Fig. 2(C). The increase in the tool rotational speed causes severe plastic deformation and thereby intense breaking and redistribution of grains. The decrease of porosity levels and scale of microstructure after friction stir processing causes an improvement in the mechanical properties of the processed alloy as compared with the parent metal. The contribution of intense plastic deformation and high temperature exposure within the stirred zone during FSP results in recrystallization of grains.

3.1 Hardness

The microhardness of samples were examined by plotting microhardness profile. Both translational speed and rotations speed influence microhardness of the material as it increases with decrease in rotational speed and increases with increase in translational speed (Fig.3). There is a considerable variation in microhardness of FSP samples (45–55 HV). FSPed sample with parameter of 1000 rpm rotational speed and 80 mm/min translational speed has maximum hardness of 54.3 HV whereas FSPed sample with parameter 1600 rpm and 40 mm/min translational speed has minimum hardness value of 45.7 HV.

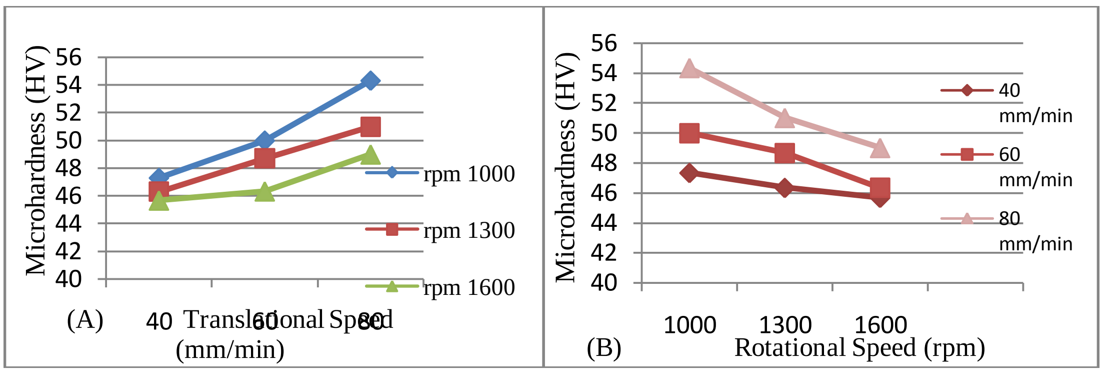

Fig.3: Microhardness of FSPed sample : (A) w.r.t translational speed; (B) w.r.t. rotational speed.

3.2 Wear resistance

Wear test was performed on pin-on-disk tribometer. Results confirm the FSP increases hardness of surface of material improves its wear resistance as compared to base metal. The traverse speed determines the residing time for frictional heat generation. A decrease in wear rate results as the tool traverse speed increases 40 mm/min to 80 mm/min (Fig. 4(a)), which might be related to a shorter exposure time at elevated temperature and higher cooling rate associated with the faster tool traverse speed.

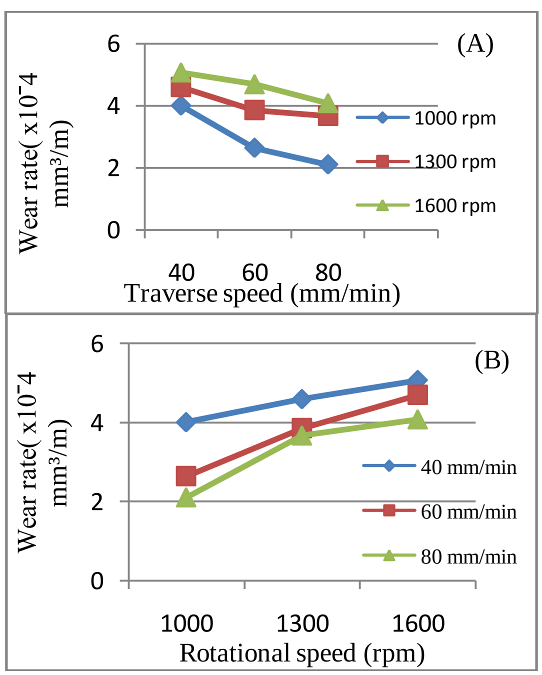

Fig.4: Wear rate of FSPed sample : (A) w.r.t translational speed; (B) w.r.t. rotational speed.

Wear rate with respect to rotational speed of samples at 40mm/min, 60mm/min and 80mm/min (Fig. 4(b)), show that the increase in the rotational speed from 1000 rpm to 1600 rpm increases the wear rate due to amount of frictional heat produced during FSP increases as tool rotational speed increases which cause softening the matrix. The high heat generation cause matrix softening which resulted as increase in wear rate.

Results revealed that FSP produce more refine and homogenized grain structure which has effect on hardness as well as on wear behavior of aluminium alloy. FSPed aluminium 6063 alloy at rotational speed of 1600 rpm and transverse speed of 40 mm/min has refined grain structure due to severe plastic deformation fragmenting the grains into fine grain. But due to high localized heat for longer time at high rotational speed. The Al-Mg particle (dark elusions in microstructure in Fig.2(C)) responsible for high hardness got severe deformation resulting in lower hardness and high wear rate. At 1000 rpm due to less duration of rotating tool at a moment, processing takes places under less exposure to heat and shows high resistance to wear resulting in minimum wear rate and maximum hardness of 54.3 HV [18].

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