EFFECT OF REINFORCEMENT ON MECHANICAL PROPERTIES OF AL ALLOY

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Abstract— In the present research, multi-pass friction stir processing (FSP) was employed on both reinforced and un-reinforced 1100 Al alloy. The reinforcement powder used was a Ti-6Al-4V powder. The number of passes was limited to four due to the unfavourable results observed for excessive number of passes above four. After four(4) cumulative FSP passes, the microstructures of the samples were observed with Optical microscopic while the tensile tests were done at room temperature via an Instron electronic tensile machine. The result reveals that the microstructure of the first two passes of the reinforced Al alloy shows clustering of Ti-6Al-4V particles and uneven distribution of the particles, which in turn affects the strength of the samples. Also at 2passes, the ultimate tensile stress of the reinforced 1100 Al alloy was 20% lesser than the unreinforced sample, while at 3 passes for both samples, a noticeable 30% increment was seen for the reinforced Al alloy when compared with the unreinforced sample. The result shows that to successfully reinforce Al alloy, to achieve a higher strength, better wear performance and even dispersion of particles, at least 3-passes should be employed.

Index Terms— Microstructure, multi pass friction stir processing, Tensile property, wear

I. INTRODUCTION

Many industries have used Metal-matrix nanocomposites as a consequence of their advantages and superior performance in industries like plastic, aerospace and automotive sectors over plain metals[1]. Aluminum alloys exhibit characteristics such as high ductility, good formability, and high thermal conductivity, they have high strength to weight ratio and are easily weldable[2]. These characteristics made Aluminium and its alloys play a vital role in the production of Metal matrix composites (MMCs). 1100 Al is a common choice which has been greatly used as matrix material among other alloys of aluminium due to the toughness it exhibits while at low temperatures, and also for the mechanical strength which made it commonly implemented in rivets and last for the non-toxic nature of 1100 Al alloy which has made it frequently used in contact with foodstuffs[3].

Friction Stir Processing (FSP), which has a working principle of Friction Stir Welding (FSW) is one of the techniques used to produce MMCs, and it overcomes challenges such as porosity and agglomeration of reinforcement particle in the metal matrix[4]. FSP has a rotating tool plunged inside the work piece to cause plastic deformation on the metal, the shoulder face which is in contact with the surface of the work piece generates heat and deform the work piece plastically as the tool rotates with a specific tool transverse speed and the schematic illustration is shown in Figure 1. The generated heat at the stir zone alters the microstructural properties of the material[5]. A lot of studies have investigated the use of FSP to fabricate metal matrix composite, [6] [7]. Reinforcements have also been added to base metal to improve strength, wear performance, reduction of weight, high resistance to corrosion and hardness by numerous studies[8], [9]. However, inadequate number of passes result to poor microstructure and uneven distribution of reinforcement within the matrix[10], which in turn affects the tensile properties and wear performance of the composites. Thus, a need for a suitable combination of parameters offering higher strength is important, and it's equally necessary to compare the reinforced samples with the unreinforced samples to evaluate its effect on the strength after undergoing numerous FSP passes.

In spite of several investigations done on the fabrication of MMCs via FSP, there is no report about the minimum number of passes to be used in order to achieve good mechanical properties of the reinforced samples, and no other study has compared the mechanical properties of the reinforced and unreinforced Al alloy after four cumulative passes[11]. An attempt was made in this study using multi-pass FSP on 1100 Al reinforced with Ti-6Al-4V powder and also on unreinforced 1100Al alloy, this was done to evaluate the effect of multi pass on the mechanical properties of both samples, where the tool rotational speed, tool geometry, tool traveling speed were fixed. The results obtained in the current study are presented and discussed in detail.

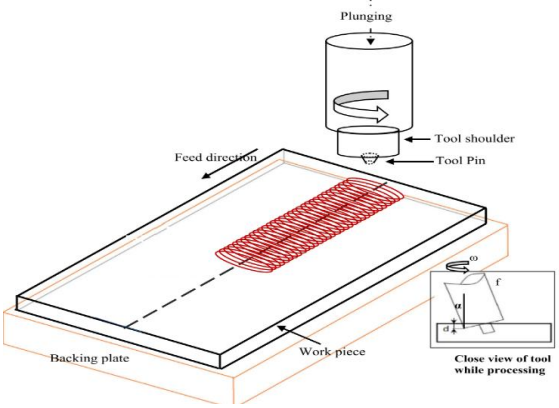


Fig 1: Schematic illustration of friction stir processing[12]

II. EXPERIMENTAL MATERIALS AND METHODOLOGY

The material used is 1100 Al alloy as base sheet, whose chemical composition (wt.%) is Al: 97. Cu: 0.15, Zn: 0.09, Fe: 0.95, Si: 0.95 and others are 0.86. The Al alloy has a sheet thickness of 5mm and the sheet cut in a rectangular form to a measurement of 250 x 200mm, grooves were made at the top surface of these sheets with 3.5 mm width and 3 mm depth cut. The reinforcing powder used is Ti-62222, the structure of the powder is spherical and non-porous with particles joined like satellites, this shows that the particles was produced via gas atomization as Yu et al had reported[13], the chemical composition(wt%) has Al; 6.02, Mo: 3.13, Cr: 2.10, Si: 0.31, and Titanium as balance. The particle size of the powder when analyzed was measured as 65.23 µm. The machine used for the process was a 12HP spindle motor FSW machine, which has the spindle rotating at both clockwise and anticlockwise direction, the system also has 50kN plunge load and 3500rpm turn speed capacity. The powder were deposited in the grooves of the aluminium sheet which serve as reinforcement, and these sheets are subsequently subjected to 100% overlap of multi pass FSP with the appearance shown in Figure 2a. The tool used for this process is a High speed steel(HSS) with a Threaded Taper tool geometry as shown in Figure 2b, these tool has a shoulder width of 20 mm with a pin width and length of 4mm. The threaded taper tool has been used frequently in FSP and has produced adequate mixture during the process which has been reported by numerous studies[14]. Optical microscopic was used to observe the microstructure of the samples while the tensile tests were done at room temperature (25 ºC) via an Instron electronic tensile machine, which has a strain rate of 2.0×10−3 s−1. The samples used for the tensile test were prepared as per ASTM standard E8/E8M-11, these samples with dog-bone shape were cut with a wire cutting machine to dimensions of 10mm length, 6mm width and thickness of 2.5mm as shown in Figure 3.



Fig 2: (a) Crown appearance of the samples (b) Threaded taper tool

Table 1: Definition of symbols

Samples	Passes	Fixed Parameters
A1	1	Feed rate (f): 30 mm/min.
A2	2	Tilt angle (α): 2.51.
A3	3	Threaded taper tool
A4	4	Shoulder penetration (d) 0.2mm.
B1	1	Plunge speed 10mm/min.
B2	2	Inter-pass overlap: 100% .
B3	3	Rpm: 1200
B4	4	All A samples are reinforced with Ti-6Al-4V
		B samples have no reinforcement

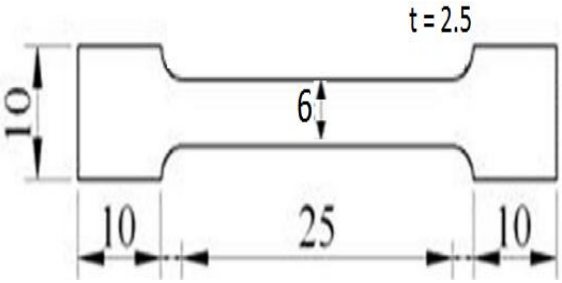


Figure 3: Dimension of tensile sample

III. RESULTS AND DISCUSSION

A. Microstructural observations

The optical micrographs of various samples are presented in Fig 4. As revealed in these figures, the reinforced samples fabricated with 1 and 2 passes(i.e A1, A2) suffers from defects such as tunnel hole and particle agglomeration, but A3 and A4 samples are free of defects. The result indicates that the 3 and 4 passes samples experience better distribution of particles than samples with 1 and 2-passes FSP. This findings can be attributed to the improved stirring action that occurs as the passes increases [15] .

During friction stir process of Aluminum alloy, the materials in the processed zone are stirred directly by the pin not less than once, which subsequently undergo severe plastic deformation and thermal exposure, leading to the dynamic recrystallization (DRX) processing and the grains become refined[16]. From literature, grain refinement in the stir zone is to be expected because of the directly stirring of the pin, while it is of interest that grain refinement occurs in the transitional zone where there is a lack of stirring[17]. The grain size reduces as the passes increases, a significant reduction in grain size was observed after processing 3 passes. Optical micrographs obtained from the nugget zone of different passes of the FSP sample without the addition of particles are shown in Figure 5, grain size of the processed material seems to increase from 1st pass to 3rd pass. However, after the three passes, the grain size seems to be same irrespective of the number of passes.

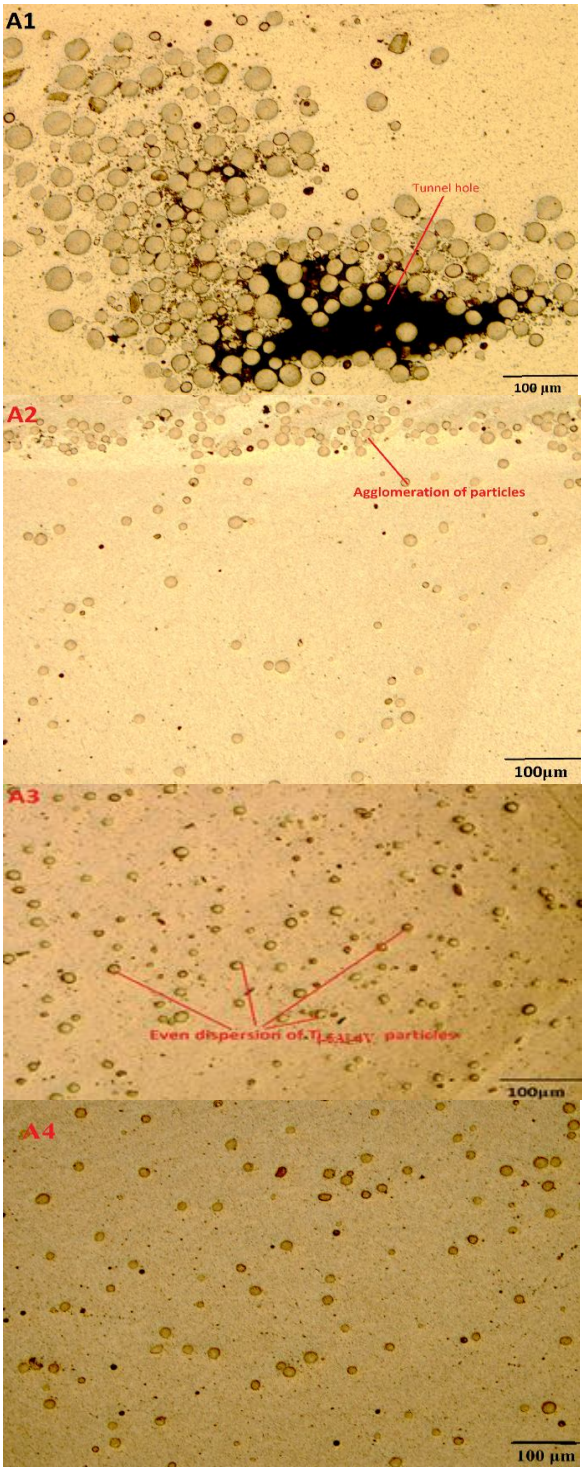
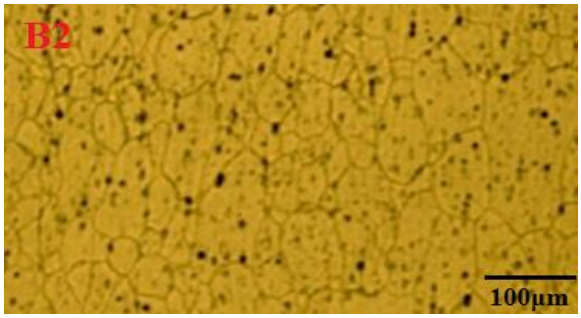


Figure 3: Optical Micrograph of various Al/Ti-62222 composite samples



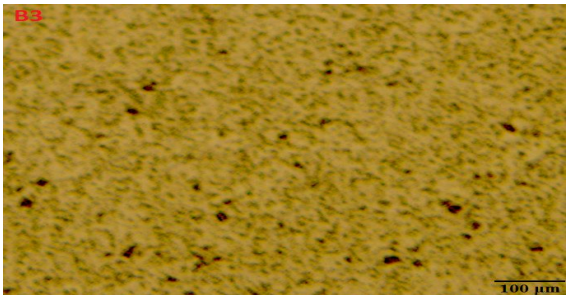


Figure 4: Optical Micrographs of samples without reinforcement

B. Tensile properties

The images of the dog-bone tensile samples before and after test are shown in Figure 6, with a constant sheet thickness of 2.5mm. The load and displacement of all samples were recorded during the test as shown in Figure 7, all samples fabricated with 3-passes(i.e A3 and B3) showed longer service life before fracture. The A3 sample which has an improved strength experience 30% improvement in tensile strength in comparison with the B3 sample as shown in Table 2, the yield stress and the Ultimate tensile stress(UTS) of all samples are shown in this table. To improve mechanical properties like tensile strength and hardness, it is important to have a better particle refinement according to Hall-Petch rule[18]. In the current work, it can be said that tensile strength increases as the grains in the 1100 Al become more refined, the samples with uneven distribution of particles encounter lower yield stress and UTS when compared with the samples without reinforcement. The fracture mode of A3 and B3 samples were analyse with SEM as shown in Figure 8, an indication of plastic deformation before failure was revealed due to the dimpled structures observed at the fracture surfaces of these samples. Ductile failure is predicted as the cause of these numerous deformed dimples seen at the surface which is in agreement with the result gotten from the tensile test.

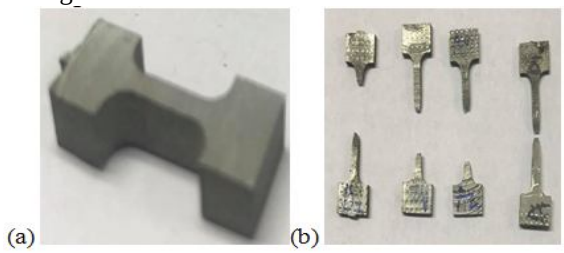


Figure 6: Images of tensile samples (a) Before(b) After

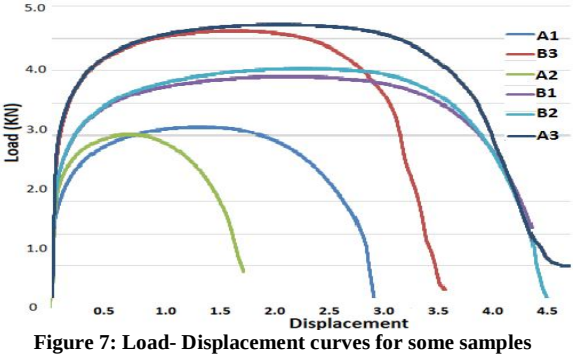


Figure 7: Load- Displacement curves for some samples

Table 2. Tensile properties of the composite samples and the 1100Al alloy.

Samples	Yield stress (MPa)	Ultimate Tensile Stress (MPa)	Elongation (%)
A1	38.16	72.44	32.00
A2	44.66	91.71	43.57
A3	79.78	125.40	60.12
A4	81.63	127.22	68.31
B1	41.85	80.42	34.26
B2	51.54	102.38	51.83
B3	60.11	110.76	54.53
B4	61.27	114.87	57.97

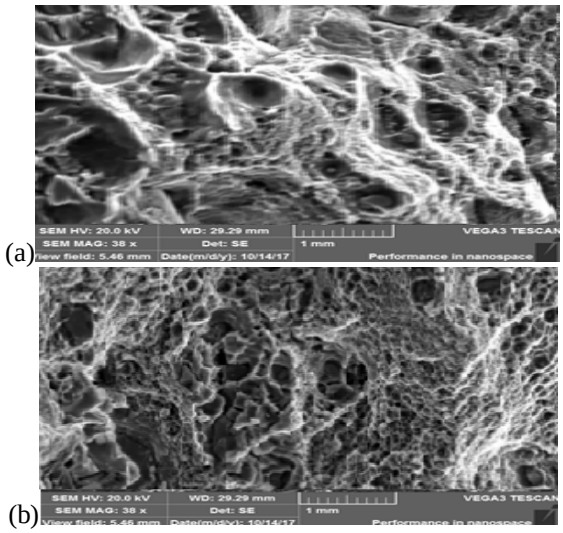


Figure 8: Tensile fracture surfaces (a) B3 (b) A3 composite sample.

C. Worn surfaces and comparison between reinforced and the unreinforced matrix

After the wear test, the mass loss of all samples were recorded as shown in Figure 9, A4 being the composite with lowest loss of mass has striations on the surface during the test, the SEM micrographs of the worn surfaces of A4 and B4 are shown in figure 10, the present of these striations in A4 suggest abrasive wear. The EDS analysis of the A3 sample is shown in Figure 11, it can be seen from the EDS peaks that the composite consists of elements present in the base metal such as Al, Cu, Zn and Si, which show that the composite experienced adhesion wear. These findings confirm that the composites are controlled by both adhesion and abrasion mechanism. From the EDS results analyzed for two selected zones (A and B) as shown in Figure 11, the peaks corresponding to zone A depicts the presence of Al_2Ti film and the peaks corresponding to zone B represents the existence of Ti-6Al-4V particles. These developments, which are outcome of tribo reactions, it can be said that the tribo-growths in addition to microstructural modifications caused by multi-pass FSP play role in improving the wear resistance of Al/Ti-6Al-4V composite. The present study has revealed that the tribo-compounds, which may be formed after the three passes, may also play role in decreasing the wear of friction stir processed composites. A comparison between the reinforced and unreinforced samples after 3 passes is shown in Table 3.

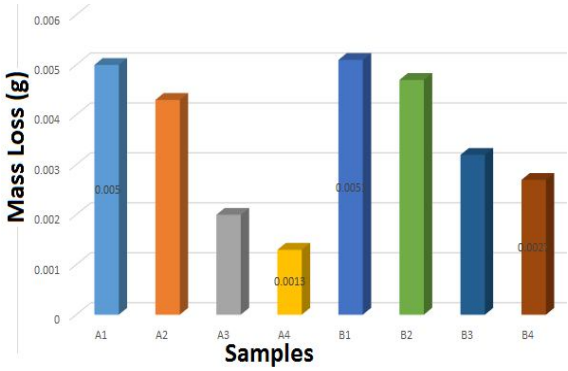


Figure 9: Average mass loss for all samples in wear test

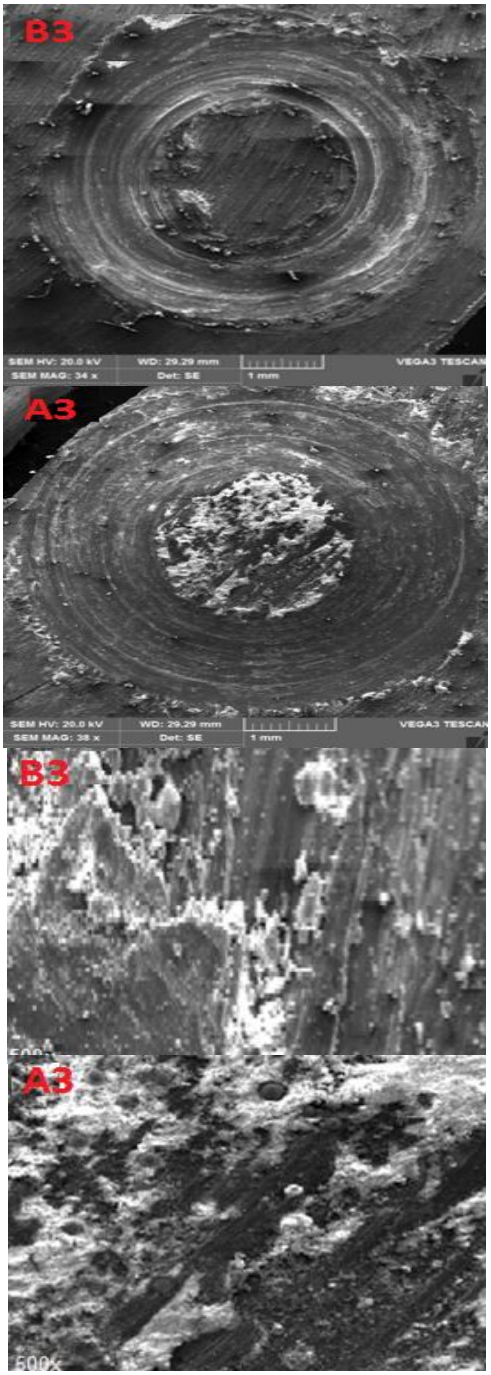


Figure 10: SEM images of the worn surfaces of A3 and B3 composite sample.

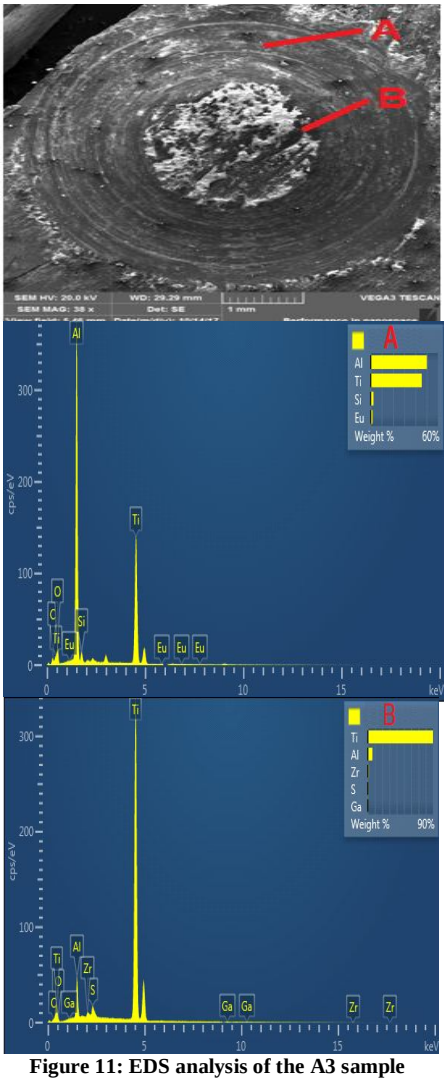


Figure 11: EDS analysis of the A3 sample

Table 4 Comparison between 3 passes reinforced and 3-passes unreinforced 1100 Al

Attribute	1100 Al	Unreinforced/3passes(B3)	3-passes composite(A3)
Mass loss(g)	0.0045	0.0031	0.0013
Yield Stress	34	60.11	79.78
Ultimate Tensile stress	90	110.76	125.40
Coefficient of Friction	0.75	0.43	0.40

CONCLUSIONS

The present study was undertaken with an objective to study the effect of multi-pass FSP on the reinforced and unreinforced Al alloy. To do so, the experiment was limited to four passes to avoid excessive heat input which may affect the property of the material. The following conclusions can be drawn from the results obtained:

- The importance of reinforcements become more evident after three passes, before the third pass, the unreinforced samples exhibit better yield stress and UTS when compared to the reinforced samples. However, a noticeable change is observed after the 3rd and 4th pass of the reinforced samples which exhibit better tensile properties.
- As the passes increase, the particle distribution becomes better for the reinforced samples. Also, a better grain refinement is evident with the unreinforced samples as the passes increase. The UTS and YS of unreinforced Al alloy increases as the passes increase. However, to achieve better tensile property with reinforced Al alloy, at least three passes should be employed.
- Wear resistance of the samples are enhanced by the increase in the number of pass. However, the agglomeration of particles seen before the third pass of the composite sample caused a lower wear resistance when compared to the two passes sample without particle. Also, a noticeable improvement in the wear resistance was observed after the third pass of the composite sample, and the mass loss is 7.5% lower than the 3-passes samples fabricated without particle.

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