ANALYSIS OF FABRICATED AL METAL MATRIX COMPOSITES REINFORCED WITH TI-62222 VIA MULTI PASS FRICTION STIR PROCESSING

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Abstract—. This paper investigates the fabrication of Aluminum Matrix Composite (AMC) and Ti-62222 powder by multi pass Friction Stir Processing (FSP). Grooves were machined on the Aluminum sheets to deposit the titanium powder, which is the reinforcement and the sheets were processed at some sets of parameters. Scanning Electron Microscopy (SEM) and an optical system were used to observe the microstructures. To determine the wear behavior, pin-on-disc apparatus was used to analyze the wear resistance of the samples. The results indicate that the number of passes greatly affect the particle distribution of the reinforcement as expected, which subsequently influenced the composite characteristics such as the wear resistance and hardness profiles. A homogenous distribution of the Ti-62222 particles in the Al matrix was observed at the third pass from the SEM and EDX analyses and a significant enhancement in the Vickers micro hardness was observed. Lastly, the grain sizes of the processed samples were characterized, the finest grains measured were found to be an average size of 1.6µm, which is 97.5% smaller when compared to the parent metal at 65.23µm, these grain sizes are produced by the sample fabricated after three passes. The sets of processing parameters considered and the number of passes can be considered for typical surface engineering applications.

Index Terms— Ti-62222, multi pass friction stir processing, composite materials, mechanical properties, microstructure.

I. INTRODUCTION

Aluminum and its alloys have excellent formability and are easily weldable, it is well established that aluminum and its alloys exhibit high ductility, strength to weight ratio, electrical and thermal conductivity[1].Consequently, wide range of industries utilizes aluminum and its alloys as the major materials for construction and also majorly used in the aerospace. Although, Al and its alloys have good strength and also exhibit a high strength to weight ratio, however, they have low wear resistance and poor abrasion properties [2].

Research has shown that Al and its alloys can have better mechanical properties and high hardness by reinforcing them with ceramic particles. However, in comparison with metals without reinforcement, metal-matrix composites(MMC) with ceramic particles as reinforcement shows a higher strength to weight and better wear resistance behavior, these composites however, undergo more loss in toughness and ductility as a result of the combination of non-deformable ceramic particles[3]. For various applications, it is appropriate that only the surface layer of metals is reinforced by ceramic particles for improvement of tribological behavior while the majority of the metals maintain the original structure with a greater toughness[4-5]. Friction Stir Processing(FSP) is a solid state processing method that has been employed to modify microstructures, the process was developed based on the principle of Friction Stir Welding(FSW)[6]. A non-consumable and rotating tool with a pin and shoulder is inserted into the material and transversed along a chosen path.

Usually, Al metal matrix composites are strengthened by different ceramic particles for example Al_2O_3, C, B_4C, AlN, SiO_2, TiC, BN, SiC and $ZiSiO_4$[7], [8]. Ti-6-2-2-2-2 is the most broadly used titanium alloy after Ti-6Al-4V, an $\alpha + \beta$ alloy[9]. This alloy has been produced for aerospace applications to enhance better mechanical properties of titanium while keeping intact the resistance to corrosion[10]. The tribological properties such as wear, lubrication and friction are superior with Ti-6-2-2-2-2 than for pure titanium[11], the Ti-6-2-2-2-2 is an alloy which has been created to give a better toughness[12]. In the current study, 1100 aluminum alloy reinforced with Ti-6-2222 powder were produced through FSP to improve the mechanical properties. No other study has examined the Ti-6-2-2-2-2 as reinforcement to commercial aluminum sheet. The results obtained are presented and discussed in detail.

II. EXPERIMENTAL MATERIALS AND METHODOLOGY

The materials used in this research are 1100 Al as base sheet and Ti-62222 powder as reinforcement element. The as-received Ti-62222 powder was characterized using a Particle Size Analyzer and the average size of the particles was found to be 65.23 µm. Table 1 shows the chemical composition of the 1100 Al, while the chemical composition of the Ti-62222 powder is presented in Table 2. The aluminum sheet with a thickness of 5 mm was cut in a rectangular form of measurement 250 x 200 mm and every single sheet has four grooves with 3.5 mm width and 3 mm depth cut all through the top surface of the aluminum sheet. The tool used for the process is a high speed steel (HSS), this tool produces adequate frictional heat required for the process as

well as fruitful mixture of Ti-62222 powder into the alloy structure. The tool used for the process is a high speed steel (HSS) with shoulder width of 20 mm and pin length of 4mm with a pin width of 4 mm. The tests were conducted with a fixed tool rotational speed of 1200 with 10mm/min plunge speed and a constant traverse speed of 30mm/min. Vickers microhardness tests were carried out by means of a digital microhardness tester with diamond indenter in accordance to ASTM E92-82[13]standard by using 300KN load and 15 seconds dwell time. The samples were degreased with acetone and grinded with a proper abrasive paper to obtain a smoother surface before taking measurements on the top surface.

A TESCAN Scanning Electron Microscope(SEM) equipped with oxford instrument was used to analyze the distribution of the particle and surface morphology at high magnification and the EDX analysis. The wear performance of composites and as-cast 1100 Al were tested by conducting pin-on-disc tests and profilometer was used to measure the mass loss of each sample after the test while the worn surfaces was studied with the use of SEM

Table1. Chemical composition of the 1100 Alloy

Element	Al	Cu	Zn	Fe	Si	Others
Percentage(%)	97	0.15	0.09	0.95	0.95	0.86

Table 2. Chemical composition of Ti-6-2-2-2-2 powder in wt %

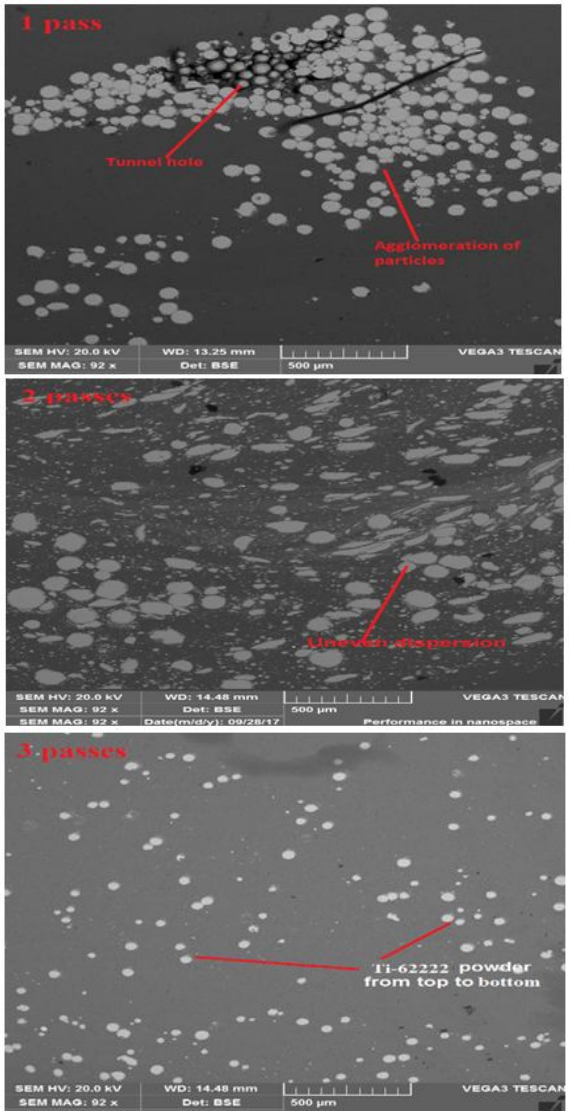
Element	Al	Ti	Mo	Cr	Si
Weight	6.02	88.45	3.13	2.10	0.31

III. ESULTS AND DISCUSSIONS

A. Microstructure

Fig. 1 a, b and c present the optical micrographs of the composites fabricated via one pass, two passes and three passes respectively. As shown in Fig 1a, the samples with one pass suffer from defects like agglomeration of particles, tunnel hole and pin hole due to low heat input and stirring force. Also, the dispersion of the Ti particles in the Aluminum alloy are not uniform, there are large particles of the Titanium powder clustering in some areas as observed. However, the samples produced with two passes are almost free of defects with lesser grain size and better distribution compared to composites produced after one pass, which are seen in Fig 1b. For the composites produced via three passes in Fig 1c, it can be observed that the particle distribution in the 1100 Al alloy is better in the 3-passes samples, there is also a significant reduction in the size of the Ti particle and a more uniform distribution, also more equiaxed and a finer particle in the composite fabricated via three passes. A change in the size and the morphology of the Titanium particles are also evident.

Figure 1: SEM images of composite samples



B. Hardness measurement

Fig 2 shows the hardness profile of samples fabricated with different FSP passes. The mean hardness value of as-cast 1100Al is reported as 26.52HV, 29.83Hv for single pass, 34.5Hv for two passes and the mean value of three-pass FSP composites is 41.8HV. The values shows that the as-cast 1100Al has a lower mean value compare with the composites. The result also shows that number of pass increases the mean hardness value of the composites. These findings correlate with the results reported by some other authors[14][15]. The hardness of the composites increased as a result of the Titanium powder present in the Aluminum alloy. With a finer and even dispersion of Titanium powder in the 1100Al Matrix, a better hardness of the composites was achieved. Furthermore, breakage of acicular Titanium powders and a better distribution of the powder with removal of porosity during the process will give a higher hardness value[16]. With Hall-Petch equation, It has also been proven that the refinement of grains during the process can produce a

better hardness value, which happen due to dynamic recrystallization at the stir zone(SZ)[17]. The main factors affecting the mechanical properties of 1100Alare likely to be the severe plastic deformation association with FSP and the temperature of the SZ during the process.

Fig 3 shows the grain sizes of the different passes of the composite specimens in the stir zone. As can be seen below, the grain size in the sample with 3 passes is smaller than that of two and one pass samples. Two reasons could be attributedto this result: (1) thenumber of passes increases the severity of breakage of the grains present in the parent metal, and (2) grain growth is restricted by the reinforcing powder, which serves as hindrance against grain boundary during the Friction Stir process. The severity of this hindrance of the powder increases as their distribution improves with the increase in the number of passes. One pass composite samples produced an average grain size of 3.5µm while that of two passes has 2.1µm and the samples fabricated via three passes have 1.6µm average grain size. As a result, the 3-passes samples produce better grains than the 2-passes FSP does. The finest grains are measured to the average size of 1.6µm which is 97.55% smaller than 65.23µm of the parent metal. This grain sizes are produced by three pass FSP samples.

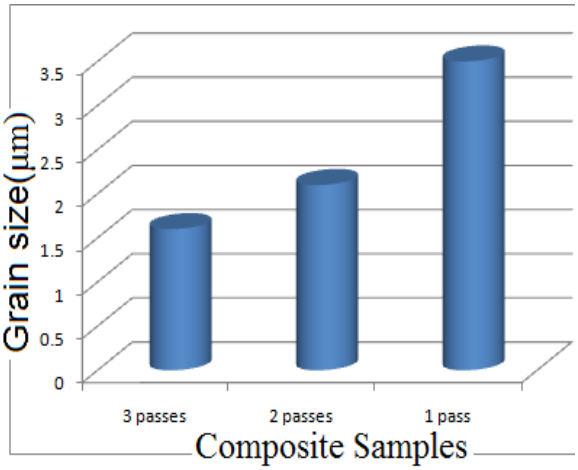


Figure 3: Average grain sizes of all composite samples

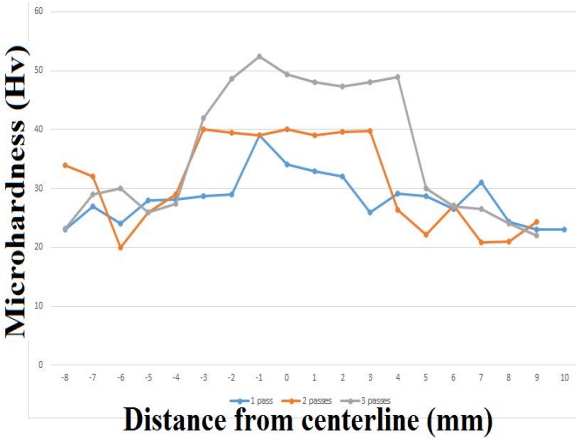


Figure 2: Microhardness profile of composite samples

C. Al-Ti phase formation and analysis

The Al-Ti phase was observed in the processed zone of composite fabricated after three passes FSP as shown in Fig. 4, as a result a reaction between the Titanium powder and the Al metal matrix. The presence of the Al-Ti at the interface of the Titanium particles with the Al metal matrix was confirmed with the analysis of the Energy Dispersive X-ray Spectroscopy (EDS) from the images shown in(Fig. 2b-2c)). It is therefore shown that the FSP is capable of producing AlTi intermetallic in 1100 Alloy and it was observed that as the number of pass increases, there is an improvement in the reaction between the Al metal matrix and the Titanium powder. Rahsepar et al and Rathee et al[18][19] reported similar investigations in the case of 5052 and 6061 Al sheets, they observed that the FSP caused the Ti particles to be surrounded by Al metal matrix as a result of stirring and severe plastic deformation that occur while fabricating via FSP.

Furthermore, FSP creates shear strain, which breaks the region around the Titanium particles that has oxide, resulting to an instant contact between Titanium and Aluminum. The reaction between Al and Ti is promoted due to the hot working ability characterized with FSP, and also the reaction between Al and Titanium, which is exothermic. X-ray Diffraction (XRD) analysis in Fig 5 proves the Al_3Ti phase formation, which is as a result of exothermic reaction between the Ti-62222 powder and Al matrix during FSP. The FSP imposes severe plastic strains, which generate very high amount of localized heat of deformation. Heat generation raises the work piece temperature and causes the Al and Ti-62222 atoms to diffuse into each other to form the Al_3Ti intermetallic.

The Al– Ti reaction depends on both the time and temperature, increasing the number of passes, increased the accumulated processing time, hence leading to a more homogenous distribution of the particles[20].

The reaction between the Al and the Ti Phase caused the growth of the Al_3Ti. If all Titanium particles are broken to same size and there exist an even dispersion, there will be complete consumption of Ti particles and a creation of Al_3Ti intermetallic, this process is characterized with FSP. On the other hand, if there exists different mass sizes of the Titanium particles, it's expected that the Al_3Ti produced will be a very thin film due to limited diffusion of Al clustering the interface.

The reaction between Titanium and Aluminum was increased as the number of passes increases and the Titanium particles are finer, which consequently amounts to greater Al_3Ti particles[21].

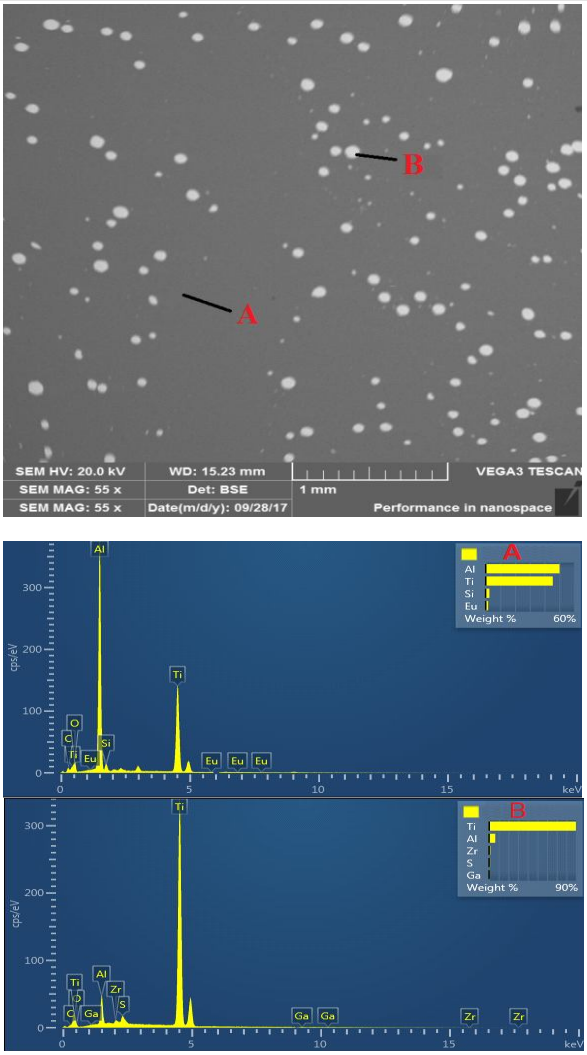


Figure 4: EDS analysis of the three passes composite. (A) the white area, (B) the matrix

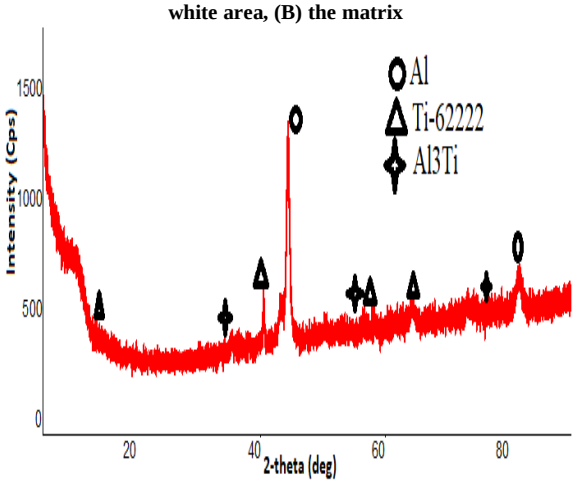


Figure 5: XRD Analysis of the stir zone Al/Ti-62222 surface composite at three passes

D. Sliding wear behavior at room temperature

The loss of weight undergone by the as-received 1100Al and the FSPed composites was shown in Fig. 6. It can be seen from the figure that the weight decreases from the as-cast metal to the composite specimen fabricated with three passes. Some studies have reported similar result previously[22] [23], wear resistance can be affected by even dispersion of Titanium particles, the size and the morphology of the particles. Areas with higher stress concentration were caused by the presence of uneven distribution and acicular Ti powders in the microstructure, hence it is possible for cracks to propagate. Consequently, the creation of cracks causes a decrease in wear resistance. Since it has been investigated that Friction Stir Process can help to improve microstructure, the processed composites exhibit better resistance to wear compared to the as-cast 1100AL. Due to the uniform distribution of Ti particles in the 1100 Al alloy in a three pass composites, it consequently exhibit a better wear behavior compared to a single pass or as-received 1100Al.

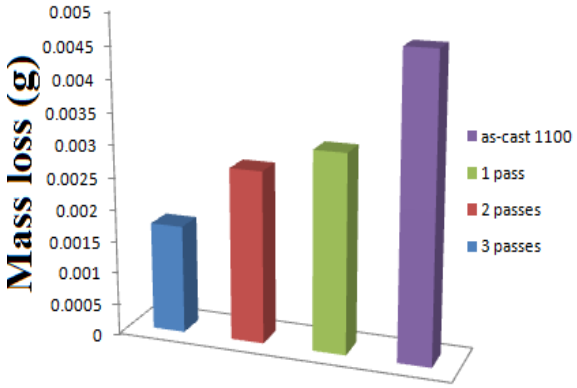


Figure 6:Mass loss of the composite samples and 1100 Al with the sliding distance of 150m (load is 10 N at room temperature)

Fig 7(a-c) presents the coefficient of friction of three samples(i.e 1pass, 2 and 3 passes). The as-cast 1100Al has a mean value for coefficient of friction as 0.72 while the composite with single pass has 0.56 and the mean value friction coefficient for the three pass composites is 0.34. In Fig 7a, the coefficient of friction of the as-received 1100Al rose up at the initial stages at a higher rate and later will noticeable fluctuations. It can be stated that localize adhesion of the wear particles during testing occurred at the pin's surface. Consequently, the wear process could be affected by the adhesive mechanism. While testing, it occurred that the Ti-62222 powders were removed from the pin's surface and the particles acting as abrasion. As can be seen in Fig. 7b of the single pass specimen with the coefficient of friction, there is smaller fluctuation compared to the as-received alloy, also it is observed that the mean value of coefficient of friction is smaller. Dinaharanet al. have proposed that surface roughness can be reduced by the presence of powder particles on the material's surface[25], consequently, it can decrease the localized contact of the surfaces undergoing wear test. Hence, it will reduce the role of mean coefficient of friction and that of adhesive wear. Wear properties can be reduced by the agglomeration of the Ti particles. It has been demonstrated that with a poor reaction between the matrix and the reinforcement. a region filled with dislocations, pores and cracks could be observed[26]. Weak bond and less plastic

deformation are characterized with agglomerated powder, it is also susceptible to cracks and its propagation.

For the composite processed with three-passes Figure 10c, the coefficient of friction with the distance shows distinct points. Firstly, the mean coefficient of friction is lower than the single pass composite and that of the as-cast 1100Al, this means the three pass composite can perform consistently for a longer time than the rest and consequently, this composite can exhibit a longer service life. In the worn surface shown in Fig 8, the three pass specimen has no grooves visible in the worn area, the three pass specimen possesses more delaminating mechanism. This result is evident due to the even dispersion of the Ti-62222 powder and the intermetallic bond of the Al_3Ti as reinforcement.

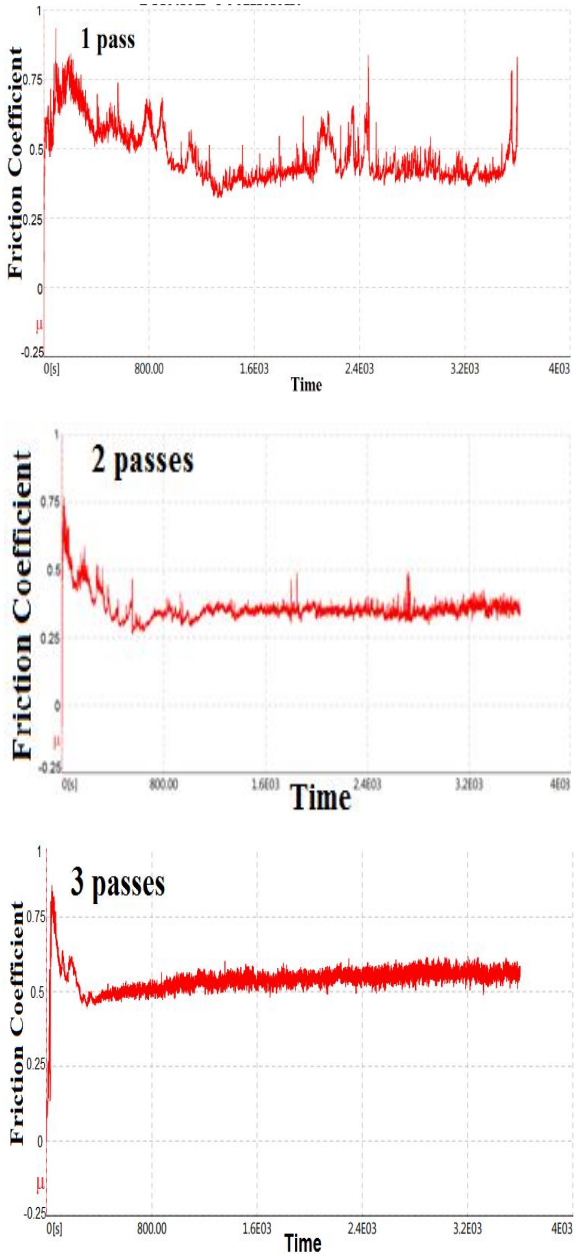


Figure 7: Variation of the coefficient of friction with time of composite specimens

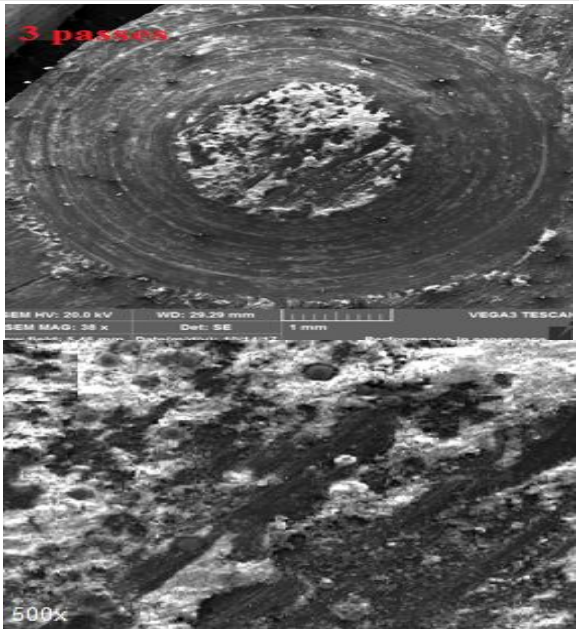


Figure 8: SEM micrograph of the worn surface of three-pass composite

CONCLUSIONS

This study effectively used multi-pass FSP of 1100Al with Ti-62222 powder as reinforcement and the microstructure features, the hardness profiles and the wear properties were examined. The following conclusions can be drawn:

- Multi-pass FSP helps to modify the evolving microstructures, such modifications includes the breakage of agglomerated Ti particles, uniform dispersion of particles and removal of defects. Irrespective of the volume fraction, even distribution of particle is evident after the third pass.
- The wear properties and the hardness of the material were greatly affected by Friction stir processing on the samples. Increase in number of passes led to an increase in the hardness values of the Al/Ti-62222 composites due to dynamic recrystallization that has taken place in the processed region.
- A finer and even distribution with less agglomeration was observed as the number of passesincreased. Also, the formation of the titanium aluminide intermetallic phase wasalso influenced by the number of passes.

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