



Significantly Improved Mechanical Properties of 1100 Aluminium Alloy via Particle Reinforcement

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Abstract. In this study, metal matrix composite is fabricated on 1100 Aluminium alloy by multi pass friction stir processing using different reinforcement particles namely Fly Ash, Palm Kernel Shell Ash, Ti62222 and 304 Stainless steel. Metal matrix composites with average grain size of 6.5 μm are achieved. The addition of reinforcements at the stir zone has enhanced the mechanical properties of the 1100 Al alloy, finer grain structure is also evident after three cumulative passes. Higher strength ranging from 268 to 454 MPa is achieved. Microhardness of the developed metal matrix composites reinforced with various particles exhibits an improved average microhardness values that ranges from 75 to 95 HV. 304 stainless steel serves as the best reinforcement to be used, offering higher hardness values and good tensile strength of 454.18MPa. The sets of new alloys fabricated in this study can be considered for typical surface engineering applications

Keywords: fly ash; multi pass FSP; PKSA; surface metal matrix composites; Ti-62222; 304 Stainless Steel

1 Introduction

Due to good corrosion resistance and high strength of aluminum alloys, they are majorly used in industries such as automobile, marine and aerospace. Aluminum(Al) 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(Asif, Chandra, and Misra 2011).Consequently, wide range of industries utilizes aluminum and its alloys as the major materials for construction. Although, Al and its alloys have good strength and also exhibit a high strength to weight ratio, however, they have low corrosion resistance (Sivakumar et al. 2014). Research has shown that Al and its alloys can have better mechanical properties and high hardness by reinforcing them with ceramic particles. However, these fabricated composites undergo loss in toughness and ductility as a result of the combination of non-deformable ceramic particles (R. S. Mishra, Ma, and Charit 2003). For various applications, it is appropriate that only the surface layer of metals is reinforced by ceramic particles to improve the mechanical properties while the majority of the metals maintain the original structure with a greater toughness(Adetunla and Akinlabi 2018; Ikumapayi, Akinlabi, and Majumdar 2018). A lot of methods have been established and used to prepare Al matrix aggregates such as stir casting, squeeze casting, and friction stir processing. Friction Stir Processing (FSP) purposes great advantages in fabricating surface composites when compared to other methods (Rana, Badheka, and Kumar 2016).

Friction Stir Processing (FSP), which has same working principle as Friction Stir Welding(FSW) is one of the methods used to create MMCs. Limitations such as porosity, microstructural defects and particle agglomeration can be solved with FSP(Khodabakhshi et al. 2015). During FSP, plastic

deformation of metal is caused by the rotating tool inserted the work piece, heat is generated by the tool shoulder which is in contact with the surface of the metal thus deforming the work piece. Reinforcements such as SiC(Luo et al. 2018), Al₂O₃(Ahmadkhaniha et al. 2016), SiO₂(Khayyamin, Mostafapour, and Keshmiri 2013) have been added into Aluminum alloy to improve its mechanical properties and resistance to corrosion by some studies.

In this study, multi pass FSP is employed on 1100 Al alloy to study the effect of reinforcements on its hardness, tensile strength and corrosion performance. The reinforcements used are Palm Kernel Shell ash, 304 Stainless steel, fly ash and Ti-62222 powder. The aim of this study is to attain improved mechanical properties of 1100 Al by comparing the effect of various reinforcements on it, reinforcement particles offering the highest hardness, finest grain size, highest tensile strength and good corrosion resistance will be investigated. The reinforcement used in this study has been investigated by some studies to reveal their peculiar characterization(Abegunde, Akinlabi, and Madyira 2017; Ikumapayi, Akinlabi, and Majumdar 2018; Panwar and Chauhan 2018). No published literature compared the effect of the various reinforcements used in this study as far as the authors know. The results obtained are discussed extensively.

2 Experimental Methodology

5mm sheet thickness of economically accessible 1100 Al alloy were used for the experiment, with its Chemical and mechanical properties presented in Table I. Four different reinforcements are used, namely Fly ash, 304 Stainless steel, Palm Kernel Shell Ash (PKSA) and Ti-62222 powder. Table II shows their chemical compositions and their average particle size of the powder were found to be 59.75 μm for PKSA, 69.26 μm for Fly ash, 57.14 μm for 304 stainless steel and 65.23 μm for Ti-62222 powder. 20% of the strengthening particles were deposited into the different grooves made on the aluminum alloys and subsequently subjected to three cumulative passes.

Table I: Chemical composition and mechanical properties of 1100 Al alloy

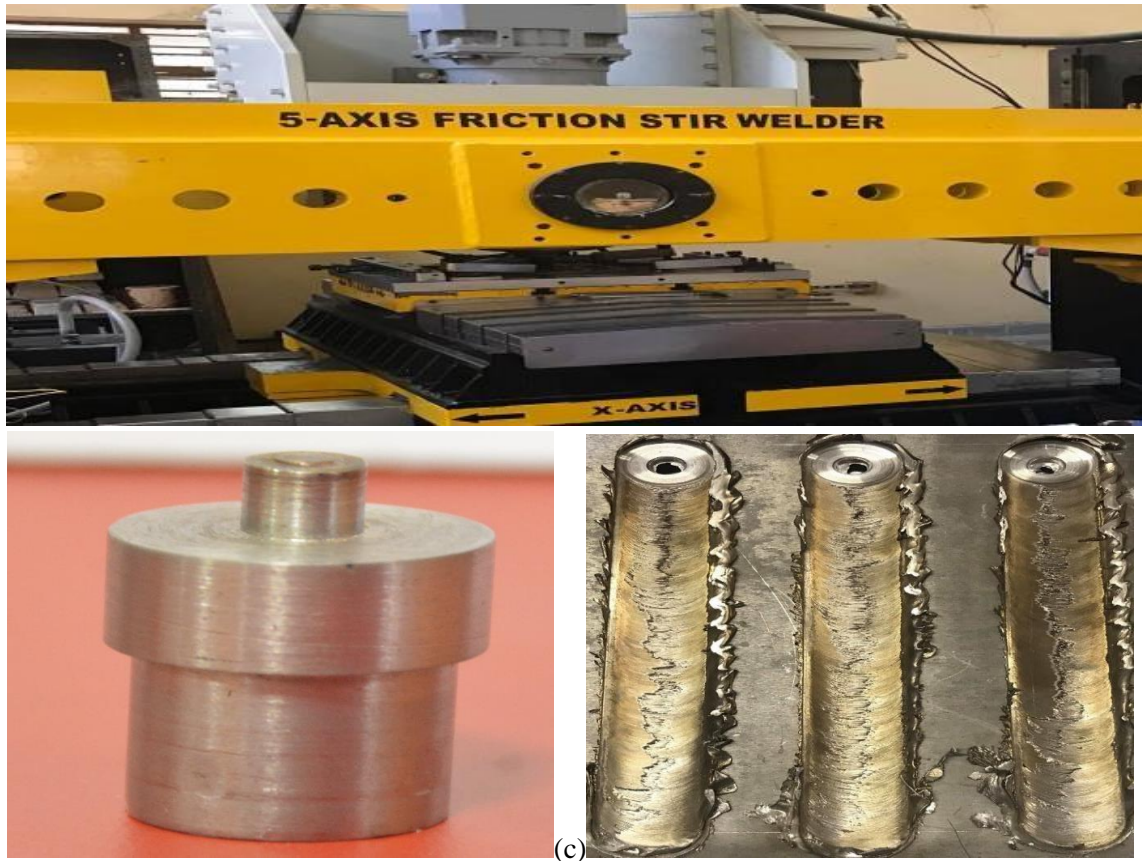
Chemical composition/wt-%						Mechanical properties		
Al	Cu	Zn	Fe	Si	Others	Tensile Hardness	Strength	Elongation
97	0.15	0.09	0.95	0.95	0.86	110MPa	12%	28HV

Table II: Chemical composition of all reinforcements in wt (%)

304 Stainless Steel	Cr 18	Ni 8	Mn 2	N 0.10	Si 0.75	Fe Balance
Ti-62222	Al 6.02	Ti 88.45	Mo 3.13	Cr 2.10	Si 0.31	
Fly Ash	SiO ₂ 35.22	Al ₂ O ₃ 27.40	Fe ₂ O ₃ 30.80	CaO 6.81		
Palm Kernel Shell Ash(PKSA)	SiO ₂ 20.00	Al ₂ O ₃ 6.00	Fe ₂ O ₃ 3.00	MgO 4.21	CaO 63.00	



Friction stir processing machine used to fabricate the samples is shown in Figure 1a, it has 12 HP spindle motor with a clockwise as well as anticlockwise spindle rotation, it also has a capacity of up to 3500 rpm turning speed and 50kN plunge load capability. The FSP tool utilized for the procedure was made of heat-treated H13 steel, with 20mm shoulder diameter, pin length and width of equal 4mm as seen in Figure 2b. Figure 2c represents the appearance of the already processed aluminum sheet. The parameter used for the FSP samples was a plunge speed of 100mm/min, a constant tool rotational speed of 1200rpm, and 30mm/mm traverse speed. To ensure even distribution of particles when reinforcing metal matrix composites during FSP, at least three passes must be employed (Adetunla and Akinlabi 2018b), thus, three cumulative passes were used to fabricate the Al alloy with 100% overlap. Optical Microscopy (OM) was used to examine the microstructural evolution and the grain sizes of the processed samples. A microhardness tester was used to conduct the Vickers microhardness with standard in line with ASTM E92-82 (Wu et al. 2015), dwell time and load are 15 seconds and 300KN respectively. Instron tensile machine was used for the tensile tests with $2.0 \times 10^{-3} \text{ s}^{-1}$ strain rate.



(a)

(c)

(b)

Figure 1: (a) 5 axis Friction stir welding machine developed for FSP, (b)FSP tool used, (c) Crown appearance of the specimen after one pass showing macrostructural defects

3 Results and Discussion

3.1 Microstructural Observations of the composites

After three cumulative passes, the microstructure of the composites were observed with Optical microscope (OM). No macrostructural defects were observed within the matrix of all composites, the particles were evenly distributed as shown in figure 2. It can be seen from the microstructure that multi pass friction stir processing helps to break down the reinforcing particles, thus making the particles evenly distributed within the matrix. The stirring action associated with multi pass FSP causes plastic deformation of metals, thus making the stir zone of the metal matrix composites to be characterized with fine grains. 304 Stainless reinforced sample exhibits the finest grain size measured to the average of 5.1 μm and the least grain refinement can be seen with the fly ash reinforced samples, owing to the tendency of fly ash to cluster together at the grain boundaries.

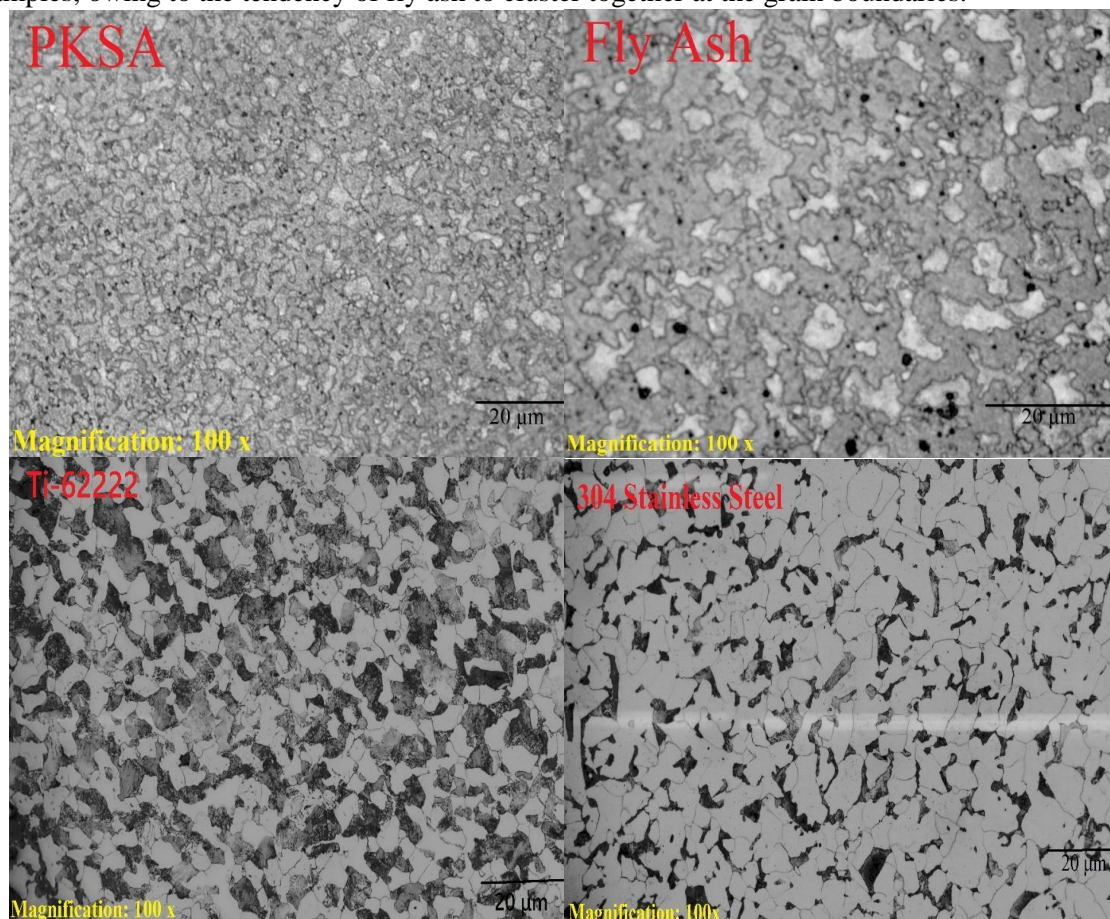


Figure 2: Optical Micrograph of various fabricated composites

3.2. Hardness and Tensile Properties

Table III presents the average hardness results of the composites. To ensure an accurate test result, three measurements were conducted for each sample and the average hardness values were reported

in this table. The addition of reinforcements improve greatly the hardness performance of 1100 Al. Multi pass FSP ensures adequate bonding between the reinforcements and the matrix leading to increase in Vickers hardness(Hashemi and Hussain 2015). 304 Stainless reinforced composite exhibits highest hardness of 95.25HV, which shows 62% increment in hardness value when compared with the 1100 Al. This result may be attributed to the properties of stainless steel, which exhibit higher hardness value. From the microhardness profile in figure 3, it can be seen that the stir zone where the powders were deposited exhibit the highest hardness value.

Table III: Average Hardness Values of Composites

Composites	Hardness Value (HV)
304 Stainless steel/ Al	95.23
Fly Ash/ Al	62.14
Ti-62222/Al	77.56
PKSA/Al	75.3

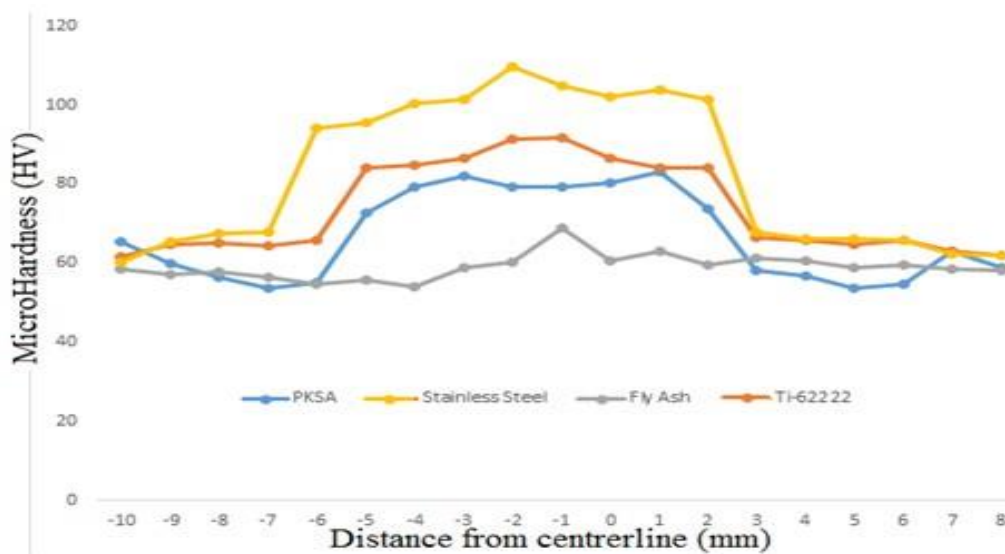


Figure 3: Micro hardness profile of composite samples

The tensile specimen were prepared as seen in Figure 4a and the images of the processed tensile samples are seen in figure 4b. To ensure accuracy, three test measurement were conducted and the average value for each sample were reported in Table 4. Deformation occurs during FSP in various region which leads to localized strain, thus, fracture occurs at the region with peak localization of strain(Sunil et al. 2016). Alloy type and morphology of the reinforcement used are the major determinant of the location where tensile fracture will occur as revealed by recent studies(Charit and Mishra 2017; Zhang et al. 2018).

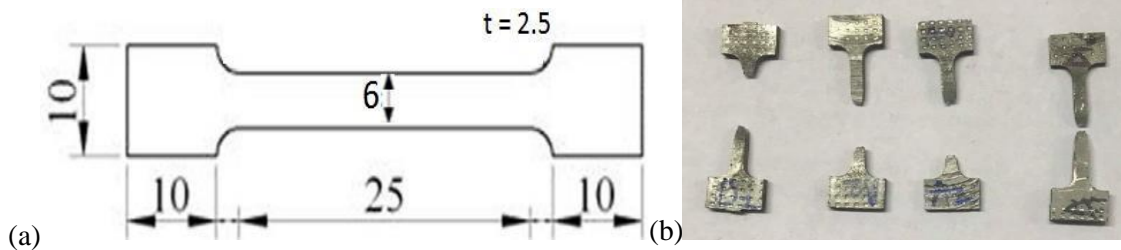


Figure 4: (a) Dimension of specimen for tensile test (b) Fractured samples after Test

Table 4. Tensile properties of the composite samples.

Composites	Yield stress (MPa)	Tensile Strength (MPa)	Elongation (%)
FlyAsh/Al	59.14	268.52	31.00
PKSA/ Al	64.36	281.71	70.34
Ti-62222/ Al	89.92	305.54	70.47
304 Stainless Steel/ Al	105.86	454.18	71.56

From the result obtained in this study, it can be said that 304 Stainless steel reinforced sample exhibits tensile properties when compared with other reinforcements used. However, the composites have almost similar percentage of elongation except for the sample reinforced with fly ash. The load-displacement curve shown in Figure 6 reveals that 304 Stainless steel has high tensile strength, which could be seen as a good reinforcing material to Al alloy. However, the fluctuating waves seen with the fly ash reinforced samples can be attributed to the morphology of the fly ash particles; fly ash has tendency to cluster together at grain boundaries, also, reinforcement particles sometimes act as inclusion and impurities within the matrix (M. K. Mishra et al. 2018).

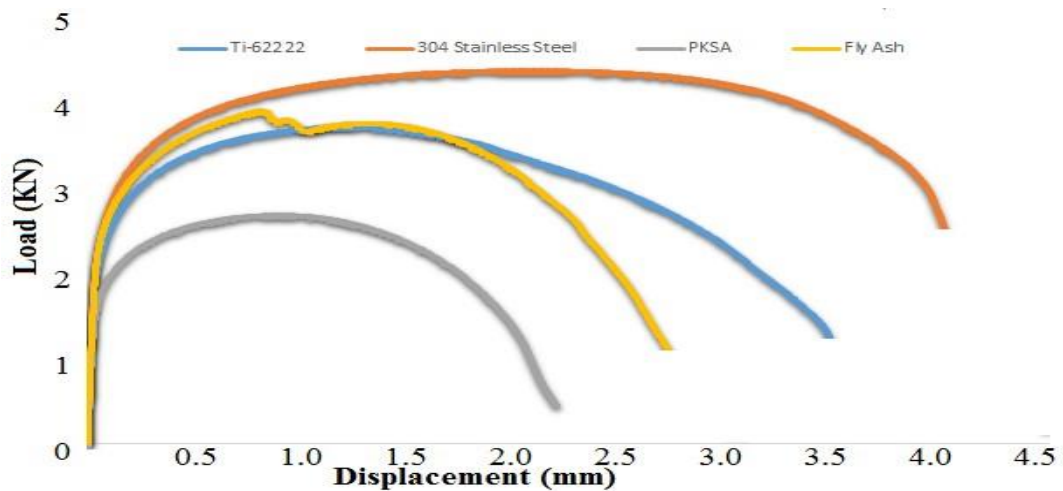


Figure 5: Load- Displacement curves for composite specimens



Conclusions

1. Multi pass-FSP can be employed to produce 1100 aluminum sheet without macrodefects. After three cumulative passes, the grains of all reinforced samples are refined with an average grain size of $\sim 6.8 \mu\text{m}$ in the stir zones, the 304 stainless steel reinforced sample has the best grain size of $5.1 \mu\text{m}$
2. From this study, it can be concluded that reinforcement is an efficient method to enhance the mechanical properties of 1100 Aluminum alloys. With the combination of the new metal matrix composites fabricated in this study, higher mechanical properties of 1100 Al are reached

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