Synthesis and Characterisation of B$_4$C reinforced Al6061 Friction Stir Processed Surface Composites

S. Mohanasundaram, S. J. Vijay, Rajakumar S. Rai, D. Emmanuel Sam Franklin

Abstract: ***Current industrial trends show increased usage of lightweight high strength materials such as Aluminium, Titanium, Magnesium, etc., in their products and components. To achieve an improved service life, particulates reinforced metal matrix composites are being favored over the monolithic alloys. Researchers have reported undesirable defects and interfacial reactions while trying to fabricate such composites using conventional methodologies. This motivates the present work to use friction stir processing, an allied process of friction stir welding, to fabricate metal matrix composites. Structurally stable and most commonly used AA6061 alloy was taken for the experiment. B$_4$C particles were used as reinforcements. Experiments were carried out using different process parameters like tool revolution and tool traverse speed or processing speed along with a constant axial force. The B$_4$C particles were packed into a 1.5 mm groove on the Al6061 plate and friction processing was carried out. The SEM investigations on the composites showed a defect-free microstructure with a homogeneous distribution of reinforcement particles. It was found that the reinforcements increased the tensile strength of the composite by 50%. The hardness and wear-resistant properties of the composites had also improved considerably.***

Keywords: ***Friction Stir Processing, surface composite, tensile strength, hardness, wear***

I. INTRODUCTION

To enhance the surface properties of engineering components, wide ranges of surface engineering technologies are used. Apart from enhancing the surface properties, they also ensure a higher service life of the machinery [1]. It has evolved as a suitable technique in several industries such as automotive, aerospace, defense, nuclear, electrical and electronics, textile, petrochemical, and steel manufacturing. In most of the engineering assemblies, the failure usually initiates from the surface. In surface engineering, the near-surface of the bulk is treated instead of working on the bulk. Surface properties are modified through mechanical processes like peening, deep rolling and shot blasting and through thermal processes like ion implementation, electron and laser beam treatment. Other processes are thermal spraying, vapor deposition, hardening, and cladding [2]. The properties can be altered by hardening through rapid solidification after melting and by surface mechanical deformation. These will allow the properties to be altered even without modifying its composition [3]. Surface Engineering leads to a better metallurgical bond with the base metal and gives a porous free structure [4]. Surface engineering improves the wear, corrosion and erosion resistance, and improves the fatigue service life of the component. The process where a material is paraphrased from a heterogeneous microstructure to a homogeneous microstructure is Friction stir processing (FSP) [5]. Process parameters like applied force, speed of travel of the tool, and rotational speed have affected the material flow, thus altering the microstructure of the material (Figure 1). Rather the tool induces plastic flow which does not affect the microstructure change [6].

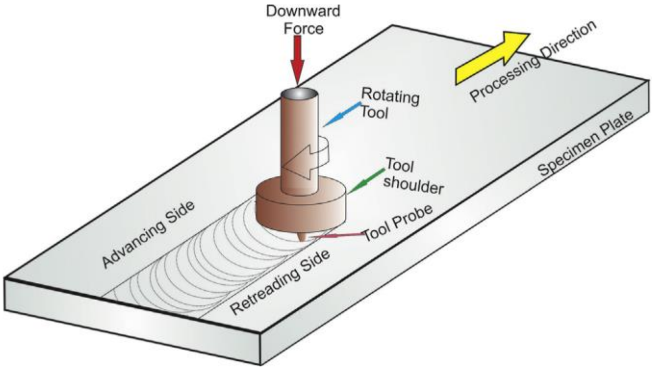

Figure 1 Schematic drawing of FSP [5]

The function of the FSP tool is to ensure proper mixing of the plasticized metal to take place, to have a good joint. FSP tool Pin profile influences the material flow and in turn controls the processing speed of the FSP process [7, 8]. Compared to other joints, the FSP area of the joint produced .by a square pin profile includes a very finely equiaxed micr ostructure. The stir zone of square pin profile produced smaller grains with uniform distribution, which yields higher strength and hardness [9].

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Heat treatable Al-Mg-Si alloys conforming to Al6061 have medium endurance and possess good welding properties over aluminium alloys and are used in pipelines, marine framework, storage tanks and aircraft applications [10].

At elevated temperature aluminium-based metal matrix composites showed improved mechanical properties like specific strength, stiffness, hardness, wear-resistance and stability [11]. In a bicycle frame, the Al–B_4C composites are used as a hardness agent. Due to their low-density, high hardness, and excellent thermal and chemical stability, it is used in defence, nuclear research and transport applications [12].

II. MATERIALS AND EXPERIMENTAL WORK

The Al6061 10 mm plate, with the cross-section of 100 mm length and 50 mm wide, was investigated in this study. In the middle of the plate, the grooves having a depth of 5 mm and width of 1.5 mm were made for the entire length using Wire EDM. Table I displays the composition of Al6061. The Boron Carbide (B_4C) reinforcement particles (Vajrabor Boron Carbide of 800 mesh from Bhukhanvala Industries Private Limited) were packed and compacted manually inside the grooves. The semi-automatic vertical milling machine was used to carry out FSP.

Table I: Chemical composition of Al6061

	Al	**Mg**	**Si**	**Cr**	**Cu**	**Fe**	**Mn**	**Zn**
Al 6061	97.2	0.9	0.6	0.19	0.27	0.45	0.10	0.20

The blunt tool (Pinless FSP tool as shown in Figure 2) made of carbon tool steel (hardened) was plunged on the top of the groove into the substrate for a depth of 0.2 mm then moved in the traverse direction Figure 4. Then a 6 mm square pin FSP tool (Figure 3) made of carbon tool steel (hardened) was employed to perform the processing operation (Figure 5) for rotational speeds of 960, 1080, 1210 and 1400 rpm and tool traverse speeds of 20, 40 and 60 mm/min. The process parameters for performing experiments are tabulated in Table II.

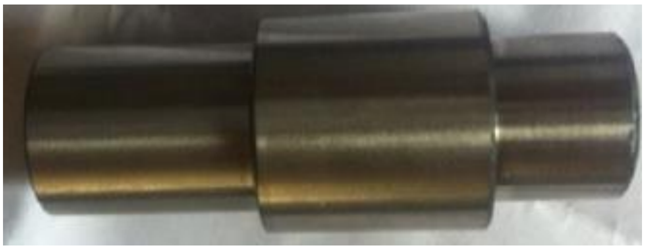


Figure 2 Pinless FSP Tool

Figure 3 Square Pin FSP Tool

Figure 4 Grooves closed with a blunt tool

Figure 5 FSP operation with Square Pin Tool

Table II: Process Parameters for FSP

Parameter	**Values**
Groove width (W) mm	1.5
Traverse speed (F) mm/min	20, 40, 60
Rotational speed (N) rpm	960, 1080, 1210, 1400
Axial load (P) kN	3
FSP Tool	Square Pin

Table III: Experiment Matrix for FSP

S. No	**W**	**N**	**F**
1	1.5	960	20
2		1080	
3		1210	
4		1400	
5	1.5	960	40
6		1080	
7		1210	
8		1400	
9	1.5	960	60
10		1080	
11		1210	
12		1400	

The rotating square pin FSP tool is plunged into the Al6061 plate with an axial load and allowed to dwell for 5 seconds and then made to move in the traverse direction. The dwelling period of the rotating tool helps the substrate to gain plasticity temperature. Friction stir processing operation is then carried out for different combinations of process parameters, as shown in Table III.

III. RESULTS AND DISCUSSION

Heat is an important phenomenon which assists any friction process. The parameters of rotational and traverse speed help to achieve the required temperature and material flow. The heat generated is increased as the rotational speed increases. The dwell time given after plunging the tool on the plate increases the temperature to plasticize the material, thus enabling the proper distribution of reinforcement in the base metal. FSP Tool geometry also influences the material flow. The forging pressure obtained through the axial load contributes to the stability and surface finish of the processed plate. The FS processed composites tensile strength, hardness and wear are measured and listed in Table IV.

Table IV Experimental Results

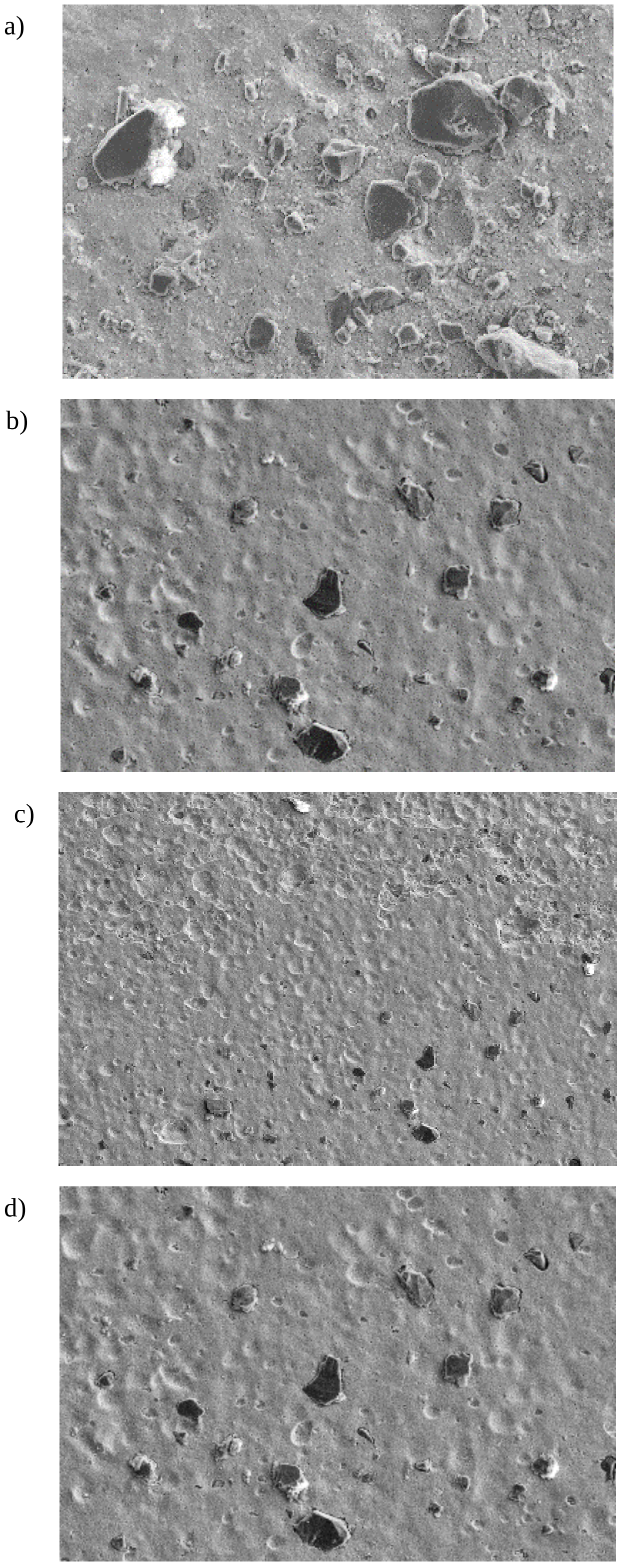
S. No	N rpm	F mm/min	Tensile Strength (N/mm^2)	Hardness HV	Wear µm
1	960	20	155.78	82.2	69.58
2	1080		132.14	95.4	85.12
3	1210		152.84	104.3	109.50
4	1400		142.68	112.5	118.21
5	960	40	150.54	74.1	95.84
6	1080		160.13	84.5	111.28
7	1210		180.06	103.2	126.84
8	1400		175.22	110.1	144.58
9	960	60	155.78	82.5	89.17
10	1080		160.13	74.1	126.03
11	1210		185.16	77.2	163.03
12	1400		165.65	89.3	168.68

A. Microstructure

The composites were fabricated with the combination of process parameters mentioned in Table III. Figure 6 exhibits the influence of rotational speed on the Al6061/B_4C surface composites' microstructure. The SEM image shows good bonding between the B_4C particulates and Al6061. The microstructure shows that as the speed of rotation increases, the distance between B_4C particles also increases. It is attributed to the lack of penetration of heat during higher tool feed, which causes the material not to become soft while undergoing plastic deformation thus resulting in improper filling of the material. It is evident from Figure 6 that the increase in feed rate and rotational speed causes reinforcement particles to escape from the groove and decreases the rate of reinforcement. The distribution of B_4C particles is not uniform at lower speeds.

The phenomenon is visible in Figure 6 (a), (b), (c) and (d) by the appearance of numerous dimples over the surface. The number of voids shows the amount of ductility in the material. It is an indication that the material has undergone elongation and then fractured [13]. The results of fractography are shown in Figure 6 (e) and (f), where one can see that the base metal's fracture surface is typical of viscous fracture with many cells and cell ridges resulting from plastic deformation. The processed samples also demonstrate some brittle fracture zones [14].

Defects such as porosity and wormhole have been identified in specimens due to the rotational speed being low. Low speed of rotation leads to insufficient stirring that leads to these defects. The particle distribution reduces as the traverse speed is increased. As the difference in the particle distribution is not that significant, the effect of the traveling speed of tool on the dispersion of the particles is less [15].



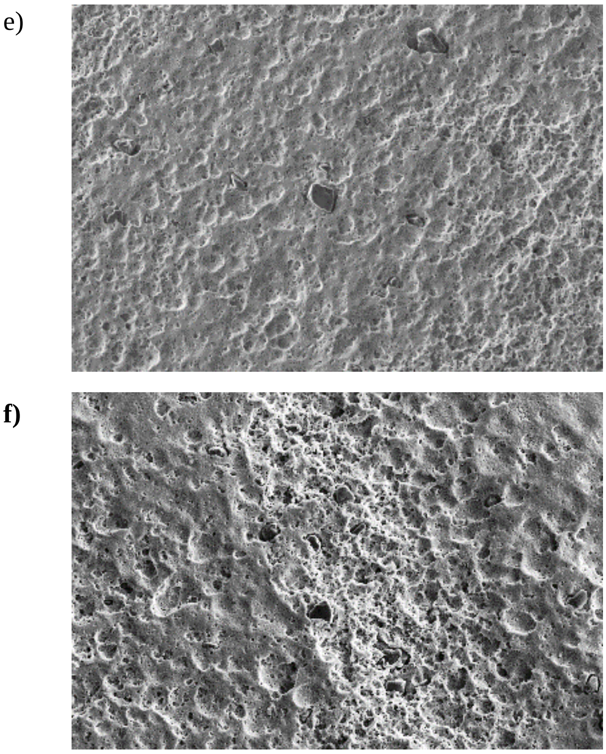


Figure 6 SEM images of the FS processed specimens

B. Tensile Strength

The FS processed composites were cut in Wire EDM according to the ASTM standard as shown in Figure 7 with a thickness of 10 mm parallel to the processed direction. The rotational speed is in direct line with tensile strength till a threshold value after which they inverse. As the tool rotational speed increases from 960 to 1210 rpm, the tensile strength improved from 132 N/mm^2 to 180 N/mm^2. The tensile strength reduced to 142 N/mm^2 at 20 mm/ min, 175 N/mm^2 at 30 mm/min and 165 N/mm^2 at 60 mm/min, at a speed of 1400 rpm as shown in Figure 8. At higher rotational speeds the reinforcement particles escaped from the grooves decreased the tensile strength.

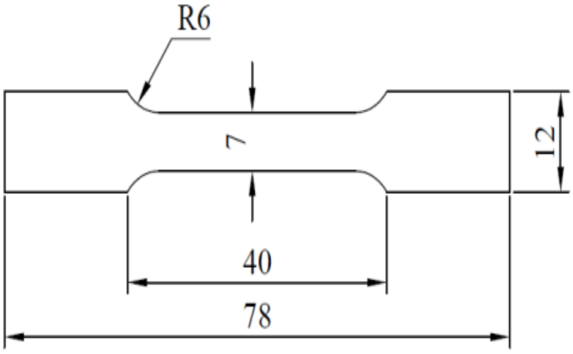


Figure 7 Tensile Specimen

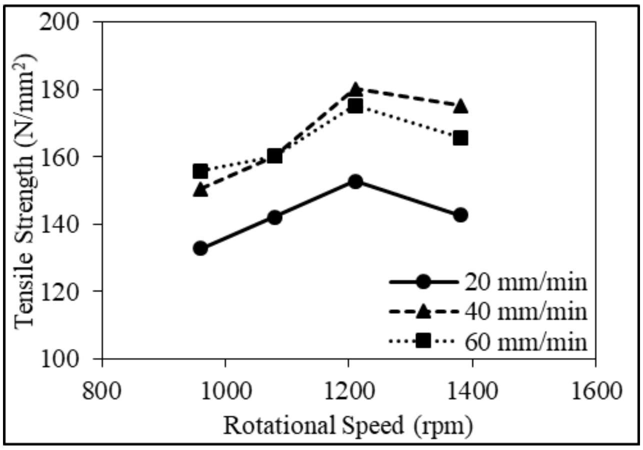


Figure 8 Tensile Strength for different rotational speeds

C. Microhardness

The FS processed composites with various rotational speeds shown an increase in hardness as shown in Figure 9. As the traverse feed increases the hardness of the processed specimen decreases due to the lack of penetration of the reinforcement particle. Microhardness of the surface composite layer increased to the maximum of 112.5 Hv, indicating that the reinforcements dispersed uniformly. At the 60 mm/min the hardness is low when compared to the other traverse speeds as the reinforcements escape from the grooves.

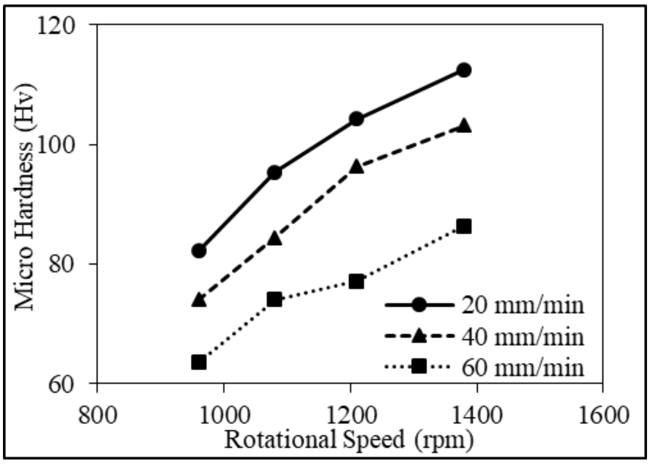


Figure 9 Micro Hardness for different rotational speeds

D. Wear Rate

Wear tests were conducted with a load of 1.5 N, by rubbing the Al/B_4C surface composite specimens. Sliding velocity and sliding distance were maintained as constant of 2 m/sec and 1000 m respectively. During the conduct of wear test, the specimen was forced against the rotating hardened steel disc by applying the load. The rotating speed of disc and time duration are calculated using the formulas. The FS processed composites with various rotational speeds are shown in Figure 10. The surface composites processed with 60 mm/min has the maximum volume loss of 4.68 mm^3. The uniform distribution of reinforcement increases the hardness and wear resistance.

$$\text{Sliding velocity} = (\pi DN)/60 \quad (1)$$

$$\text{Sliding distance} = \text{Sliding Velocity x Time} \quad (2)$$

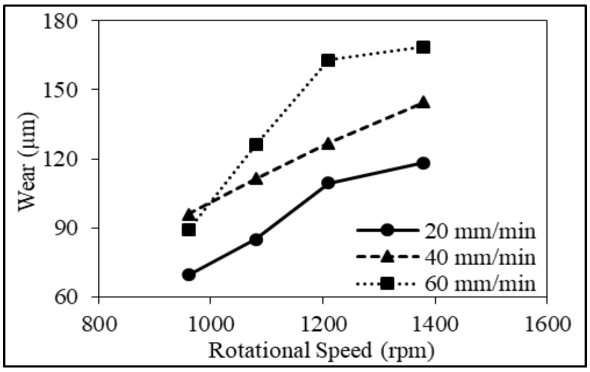


Figure 10 Wear of processed composites

IV. CONCLUSION

The Al/B$_4$C surface composites were fabricated for different tool rotational speeds of 960, 1080, 1210 and 1400 rpm with processing speeds of 20, 40 and 60 mm/min. The following conclusions were made.

- The distribution of B$_4$C reinforcements up to the tool revolution of 1210 rpm is good for the low processing speed. The reinforced particles are freed from the groove at higher tool revolution (1400 rpm) and higher processing speed (60 mm/min).
- The processed surface composites' tensile strength is decreased at higher tool revolution as the reinforcement particles tend to escape from the groove.
- The maximum tensile strength achieved in the surface composites is 180 N/mm^2, which is 50% more than the base metal.
- The hardness of the surface composites increased as the rotational speeds increased. Maximum hardness of 112.5 HV achieved for sample 4, processed at rotational speed of 1400 rpm.
- The wear rate is high for the lower compacting loads and vice versa, an increase in hardness results in an increase in wear resistance.

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