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Production and characterization of mechanical and microstructural behaviour of friction stir welded Al6063 composites reinforced with Gr/B_4C/SiC particles

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The present study elucidates the influence of reinforcement particles in friction stir welded aluminium (Al 6063) matrix composites on mechanical properties of the metal matrix composition. Initially composites were successfully fabricated with different weight percentage and combination of reinforcements (graphite (gr), B_4C and SiC) through stir casting technique. All sets of composite specimen were welded through solid state joining process of friction stir welding technique, the parameters such as tool rotational speed (800, 1000 and 1200 rpm), welding speed (20 and 40 mm/min) and axial loading (10 and 20 kN) are taken for characterization of fabricated composites. The effects of friction stir welding parameters were examined by mechanical and microstructural characterizations. The composites microstructure and dispersion of particle reinforcements were analysed through optical microscope and also the mechanical properties of yield strength, ultimate strength and elongation were analysed using universal testing machine. The optimized friction stir weld parameters were identified for 20% weight fraction reinforced hybrid composites.

Key word: Hybrid composites, Particles, Microscope, Hardness, Friction stir welding.

Introduction

The composites are desirable materials for variety of engineering applications due to its simple processing techniques, high strength to weight ratio and good corrosion resistance. The aluminium alloys are promising materials for different kind of applications like automobile, aerospace and marine. In general the reinforcements and processing techniques are highly influencing the physical and mechanical properties of metal matrix composites in all aspects. Stir casting technique was effectively employed to fabricate various products of metal matrix composites [1]. In addition to that the solid state techniques of friction stir welding (FSW) process plays a vital role on the surface of metal matrix composites (MMC). In FSW process the distortion and residual stress are much lower comparative to other welding techniques. There is no need of filler material in the case of FSW process. The mechanical properties are affected by welding defects in general, from this point of view the FSW process enables materials to be joined without any defects like blowholes and shrinkages. The sound parametric analyses were carried out on FSW process to improve physical, chemical and mechanical properties [2-4]. Apart from aluminium alloys, MMCs exhibit better mechanical properties. In this current scenario many research articles clearly depicts the influence of particle reinforcement of aluminium alloys on improved mechanical properties. Influence of friction stirred and TiB2 reinforced aluminium composites on mechanical, wear and metallurgical properties were evidently studied, it is concluded that FSW process gives better grain structure on composites [5-7]. Al 7075 reinforced with B_4C composites were produced through casting process, hardness of value increased 10% of B_4C particle weight percentage and also increasing the volume percentage of B_4C increasing wear rate as comparatively base matrix [8]. The mechanical and tribological properties of composites such as strength, hardness and ductility were improved based on the proper dispersion of particle inside the composites. Also many of particle reinforced MMCs research articles have been reviewed recently to find the influence of particles sizes on mechanical properties of composites [9-12]. In continuation with that adding of two particles in composites gives clear interfacial bonding between matrix and reinforcements. The binding ability is very important to improve physical and mechanical properties. More number of experiments have been performed in order to understand the effects of various particles on aluminium alloys. The reinforcing particles are silicon carbide, silicon nitride, boron carbide, graphite and aluminium oxide. The hybrid composites reinforced with graphite and boron carbide greatly influences the tensile properties and also the hardness of composite decreased with increasing on graphite particles. Similarly in other studies hybrid SiC+B_4C

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reinforced composites have physical and mechanical properties were analysed [13-14]. Reinforcing hybrid ceramic particles on aluminium based MMCs has developed better mechanical, physical and tribological properties than unreinforced MMCs. An attempt was made to study the mechanical and wear behaviour of SiC+B_4C reinforced aluminium composites [15]. Also the presence of graphite (Gr) with hybrid composites decreases the coefficient of friction [16]. Moreover in this study an attempt has been made to analyse the influence of hybrid reinforcements on mechanical properties of aluminium alloys. The present study elucidates the influence of friction stir welded Al 6063 matrix composites reinforced with hybrid ceramic particles on mechanical properties. The composites were fabricated with different weight percentage and combination of reinforcements (Gr, B_4C and SiC) through stir casting technique to analyze physical and mechanical properties.

Materials and Methods

Materials

The composites comprise of Al 6063 as a matrix material and graphite, boron carbide, silicon carbides act as hybrid particle reinforcements. The chemical composition of Al 6063 shown in Table 1. The role of particle reinforcements in MMCs is very important to depict the mechanical and physical properties of composites. In this study the graphite, boron carbide, silicon carbides are used in powder form in the range of particle size 32 to 40 microns. Table 2 represents the chemical composition of boron carbide reinforcements.

Production method of composites

The hybrid composites initially were fabricated through stir casting process, optimized stirrer speed was maintained for all 36 specimens. The bottom pouring stir casting machine was used to done fabrications of composites. To pre-heat particle reinforcements the muffle furnace was used, the particles were preheated about 350 ºC. The perfect vacuum arrangement was done by various tight screws for effective casting of composites. In order to get improved mechanical and physical properties dispersion particle plays a crucial role, the mechanical stirring process is a key element to effectively disperse

Table 1. Chemical composition of Al6063.

Si	Fe	Cu	Mn	Mg	Zn	Ti	Cr	Al
0.6	0.35	0.1	0.1	0.9	0.1	0.1	0.1	Balance

Table 2. Chemical composition of boron carbide.

B_4C	B_2O_3	Total B	Free B	Total C	Free C	Si	Al	Fe
96	0.5	76	0.24	19.5	1.27	0.15	0.05	0.2

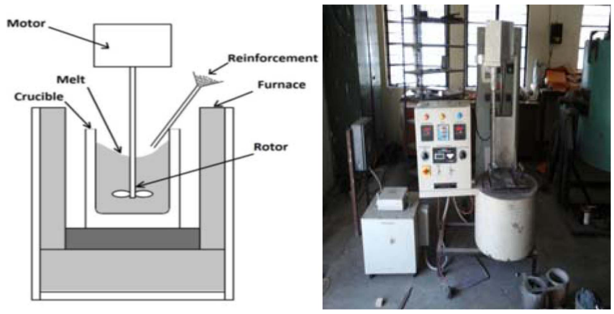

Fig. 1. Stir casting techniques.

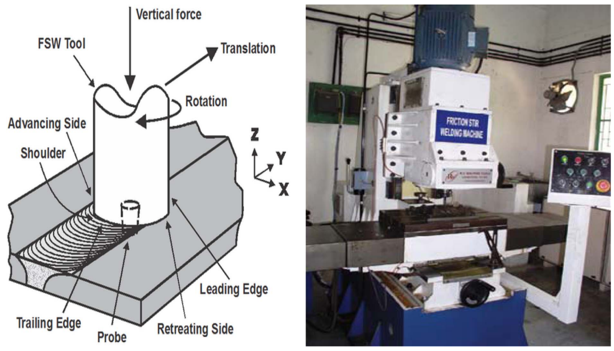

Fig. 2. Friction stir welding techniques.

Fig. 3. Universal testing machine arrangements.

hybrid particle inside the composites. Fig. 1. clearly depicts the stir casting process and its various elements.

Friction stir welding (FSW) techniques is an evolving solid state metal joining process to join two metals without melt and recast, also it is an ideal processing techniques to produce low cost high performance joints. The main intention of this study is to characterize the different parameters of FSW process, such as tool rotational speed, axial load and welding speed. The stir casted hybrid aluminium composites were dimensioned in to two halves, using FSW techniques the dimensioned hybrid composites were welded for all combinations of particle reinforced composites. In this, the different parameters and its magnitudes such as tool rotational speed (800, 1000, 1200 rpm), welding speed (20, 40 mm/min) and axial load (10, 20 kN) were maintained in different levels. Fig. 2. shows the working of FSW process and its elements.

Microstructure analysis

The optical microscope technique was used to capture required microstructure from surface of composites. The particle dispersion in hybrid composites plays a vital role to improve properties of composites in all aspects, the particle dispersion of fabricated hybrid composites for set 1 (SiC+B4C), set 2 (SiC+Gr) and set 3(Gr+B4C) were captured. The SEM micrograph evidently exposes the effective performance of stir casting and friction stir techniques through particle dispersion inside hybrid composites.

Characterisation

In this work the tensile test was carried out using Universal Testing Machine, in that the yield, ultimate and elongation values are taken in to account for all 36 samples of hybrid composites. In general the tensile test values are used to predict the ability of materials to sustain maximum static load, also the specimens were prepared as per ASTM E8-08 standard. Room temperature uniaxial tensile test was performed at a constant cross-head speed of 1 mm/sec for flat hybrid composite specimens. The specimens were loaded hydraulically. Fig. 3. shows the arrangement of specimens at universal testing machine and the load at which the specimen has reached the yield point and break point were values noted.

The physical property of hardness value is much important behaviour for composite specimen, the employability of composites based on the hardness value. The hybrid composites hardness test was performed using Rockwell hardness tester. Multiple hardness test were performed to evaluate accurate harness value. The specimens were directly loaded on polished surfaces about 10 sec. The effect of FSW process parameters are studied for various magnitudes.

Results and Discussion

Effect of FSW parameters and hybrid particle on hardness behaviour of composites

Table 3. Rockwell hardness properties of hybrid composites.

S.No	T R S (rpm)	W S (mm/min)	A L (kN)	Hardness (RHN)		
				Al+B4C +SiC	A+B4C +Gr	Al+SiC +Gr
1	800	20	10	50	40	33
2	800	40	20	52	42	34
3	800	20	10	53	43	32
4	800	40	20	51	41	30
5	1000	20	10	54	45	32
6	1000	40	20	55	45	34
7	1000	20	10	53	46	36
8	1000	40	20	53	44	35
9	1200	20	10	56	43	33
10	1200	40	20	54	42	32
11	1200	20	10	55	40	34
12	1200	40	20	56	43	35

The stir casted hybrid composites hardness properties were increased in general adding 20% volume fraction of hybrid composites. Dispersion of particle inside the composites plays a major role especially in hybrid composites, initially in casting process the particle agglomeration takes place while adding hybrid particle fully after melting of matrix materials. This shows ineffectiveness in stirring, improper particle dispersion and slag formation while casting of hybrid composites. Many trail experiments were conducted to know the particle dispersion inside composites, to overcome this both Al6063 and hybrid particles were added gradually to ensure proper distribution of particles. From the preliminary observations in stir casting process, it is evident from Table 3 that Rockwell hardness properties were increased adding 20% volume fraction of hybrid particle reinforcements. Also Figs. 4(a-b) depict the tensile and hardness value for all sets of hybrid composites.

In part of FSW process the Rockwell hardness value differs for different magnitudes of FSW parameters such as tool rotational speed, welding speed and axial load. From preliminary observations, it is observed that the hardness value has increases about to adding of

(a) (b)

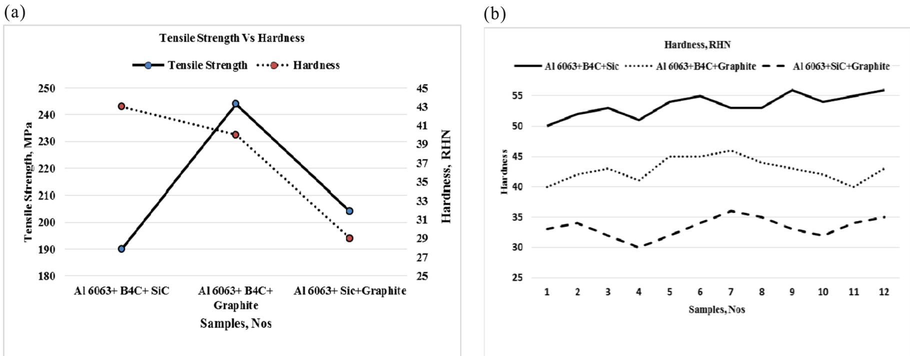

Fig. 4. (a) Tensile and hardness properties of hybrid composites, (b) Hardness of a specimen.

particle reinforcements, this is because coarse grain structures of stir casted composites, it has been observed from microstructure analysis. In part of secondary observation, FSW process parameter leads to decrease in hardness value and improved grain structure. This is due to optimized magnitudes of tool rotation speed, welding speed and axial loads. From Fig. 4(b), it is observed that the tool rotation speed 1000 rpm, welding speed 20 mm/min and axial load 10 kN were optimized process parameters to develop fine grain structures inside the hybrid composites. Also the optimized process parameter tends to arrange the hard hybrid particles in a proper way to achieve fine grain structure and too the molecular interaction between Al6063 matrix and particle reinforcement were improve drastically. Fig. 4(b) evidently exposes the influence of FSW parameters on hybrid composites.

Effect of FSW parameters and hybrid particle on tensile behaviour of composites

The core objective of this research work is to predict the mechanical properties. The tensile strength, it's derivatives of ultimate, yield and elongations of the composites were calculated experimentally using universal testing machine. The effects of FSW process parameters on tensile properties of hybrid composites were clearly observed in this study. Tensile behaviour was calculated for all three sets of composites respectively set 1 (Al 6063 (80 wt%)+SiC(10 wt%)+B_4C (10 wt%)), set 2 (Al 6063 (80 wt%+SiC(10 wt%)+Gr (10 wt%)) and set 3 (Al 6063 (80 wt%)+Gr(10 wt%)+B_4C (10 wt%)). The effect of tool rotational speed, welding speed and axial loads discussed on the following segments.

The hybrid composites were fabricated as per ASTM standard E8-08, the dimensions of ASTM E8-08 shown in Fig. 5. All the fabricated joints were analysed to

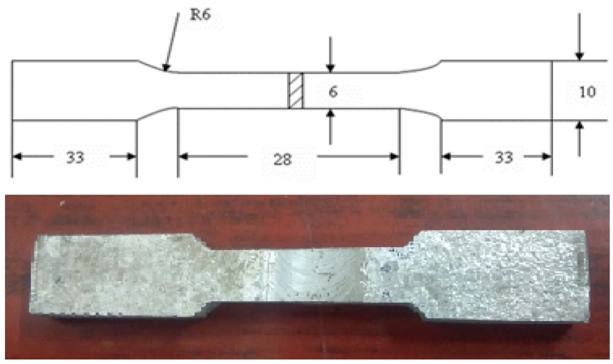

Fig. 5. Tensile specimen of hybrid composite.

ensure the influence of the tool rotational speed on tensile behaviour.

Tool rotation speed is taken as the most significant process variable since it tends to influence the welding performance, the tool rotational speed magnitudes are 800, 1000 and 1200 rpm taken in to account for this study. As the tool rotation speed increases, the welding region increases results strong joints takes place, also the strong joints based on the axial load and welding speed given to the spindle. The most important requirements of FSW process is axial load, which tends to create friction between tool and specimen. The friction due to axial load ultimately produces heat to reform the particle distribution on welding joints and also which improves fine grain structures. Totally 36 specimens were fabricated by varying the axial forces in to two magnitudes 10 kN and 20 kN. In this study the weld joint fabricated using 10 kN axial load exhibits better tensile behaviour compared with the axial load of 20 kN. In addition to this, the welding speed taken in to account to express overall influence

Table 4. Tensile behaviour of FSW processed hybrid composites

S.No.	T R S (rpm)	W S (mm /min)	A L (kN)	Tensile Properties of Hybrid Composites								
				Al6063+B4C+SiC			Al6063+B4C+Gr			Al6063+SiC+Gr		
				Y S (MPa)	U S (Mpa)	E (mm)	Y S (MPa)	U S (Mpa)	E (mm)	Y S (MPa)	U S (Mpa)	E (mm)
1	800	20	10	175.5	180.7	3.34	210.6	216.9	3.14	203.1	209.2	3.61
2	800	40	20	179.8	185.1	2.88	217.6	224.1	3.15	196.0	201.9	3.62
3	800	20	10	181.7	187.1	3.14	208.4	214.7	3.17	210.9	217.2	3.56
4	800	40	20	185.1	190.6	3.12	211.3	217.6	3.15	190.7	196.4	3.54
5	1000	20	10	185.4	190.9	2.97	191	196.7	3.26	213.0	219.4	3.54
6	1000	40	20	186.5	192.0	3.03	193.3	199.1	3.21	214.7	221.2	3.58
7	1000	20	10	200.1	206.1	2.86	207.6	213.8	3.31	185.8	191.3	3.52
8	1000	40	20	188.5	194.1	3.08	209.4	215.7	3.56	191.0	196.8	3.48
9	1200	20	10	150.5	155.0	3.43	212.6	218.9	3.12	204.0	210.1	3.64
10	1200	40	20	158.2	162.9	3.28	205.1	211.3	3.19	199.3	205.3	3.66
11	1200	20	10	141.3	145.5	3.12	201.6	207.7	3.26	183.2	188.7	3.68
12	1200	40	20	149.3	153.7	2.77	199.4	205.4	3.27	192.1	197.8	3.71

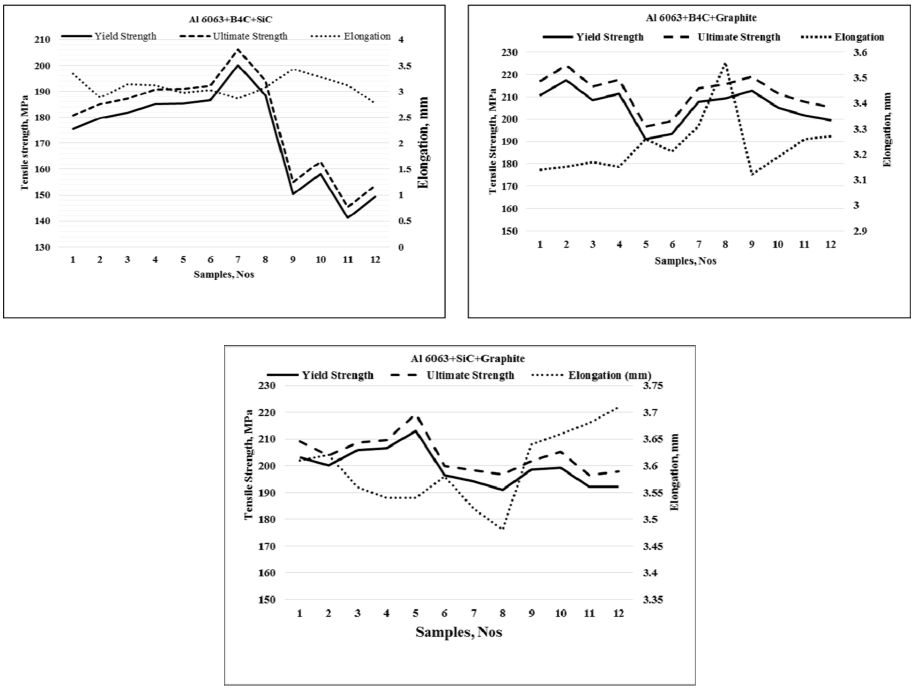

Fig. 6. Tensile behaviour of FSW processed hybrid composites.

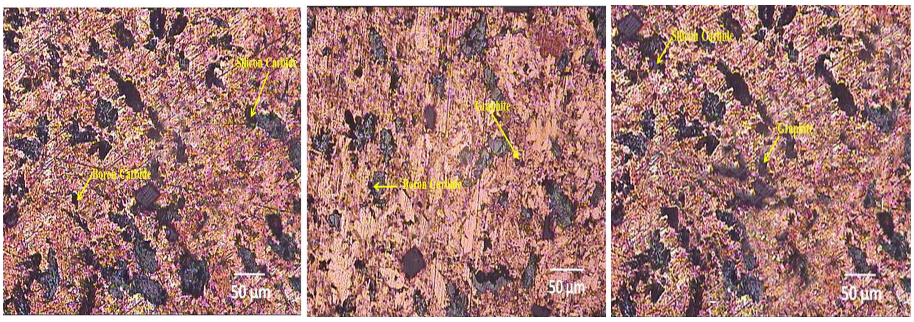

Fig. 7. SEM micrographs of hybrid composites.

of process parameters on tensile behaviour of hybrid particle reinforced composites. A 20 mm/min and 40 mm/min welding speed was observed, the defect free joints was produced when the welding speed is slower than critical value. From microstructure analysis it is observed that the surface of hybrid composites behaves crystalline nature or defect free while 20 mm/min welding speed. From Table 4, it is concluded that the welding speed influences the performance of hybrid composites significantly. Moreover the effective employability of hybrid composites correlated from all FSW process parameters of tool rotation speed, axial load and welding speed. In this process parameter analysis all three parameters are such a way that influenced gradually based on its magnitudes and it was clearly studied. Fig. 6 show that the maximum FSW join efficiency was achieved at maximum tool rotation speed of 1200 rpm approximately for all boron carbide added composites (set 1 and set 3), because of its hardness. On the other hand, the SiC+Graphite explode better tensile behaviour at the moderate tool rotation speed of 1000 rpm. In part of axial load the minimum value of 10 kN exhibits optimistic tensile behaviour for all three sets of composites, since 10 kN of axial load reforms joint without recast of hybrid composites. At last on comparatively with tool rotation speed and axial load the optimized value of welding speed was 20 mm/min was concluded for all three sets of hybrid composites.

Finally, it is concluded that only stir casted aluminium hybrid composites possess lower mechanical and physical properties. Adding of particulate gives improved properties than base matrix Al 6063, but exhibits minimum properties as compared with friction stir welded hybrid composites. From this elaborate study firstly, various combination particle influences a lot in terms of all properties to all three sets of hybrid composites. Secondly, the FSW process evidently exposes the effect of process parameters on hybrid composites in terms of physical and mechanical property.

Microstructure and fractography analysis

The microstructures of hybrid composites (set 1, set 2 and set 3) shown in Fig. 7, showing the particle

Fig. 8. Fractured surfaces of hybrid composites.

dispersion inside the composites after FSW process. The dispersion of B_4C+SiC, B_4C+Gr and SiC+Gr in friction stirred zone evidently are shown. Fig. 8 shows the fractured surfaces of the three sets of composites samples respectively. It reveals that there are differences in the morphology on fractured surfaces. More number of trail experiments were performed up to the neck formation in particular FSW zone. The neck formation while tensile test in the friction surface welded zone takes in to account for calculation of mechanical properties. From fractured surfaces of FSW processed composites, it is observed that the fracture toughness of hybrid particle reinforced composites was good, there the elongation of FSW zone was maximum comparatively the fracture occurred in other than FSW zones.

Conclusions

Al 6063 matrix composites have been successfully fabricated by the stir casting route and friction stir welding process. The particles SiC, B_4C and Graphite exhibit better wettability and interfacial bonding together with that of Al 6063 matrix. The hardness of composites has increased for all three sets of composites specimen, in particular the hardness value is high for B_4C reinforced composites (set 1 and set 2 specimen). The presence of hard B_4C particles prevents the dislocation of atoms inside the composites, resulting higher hardness compared with other set 2 composites as well as base alloy.

The yield strength and ultimate tensile strength of stir cast composites exhibit also higher than the base alloy. Also the particle dispersions inside the composites were evidently exposed using optical microscope study.

The maximum FSW joint efficiency was achieved at maximum tool rotation speed of 1000 rpm for all sets of hybrid composites, on the other hand the axial load of 10 kN and welding speed 20 mm/min exhibit optimistic tensile behaviour for all three sets of composites. As compared to base alloy Al 6063, FSW processed hybrid composite shows improved physical and mechanical properties.

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