Fabrication of AA2014 with B4C and Graphite hybrid composite by Stir-casting method: study of mechanical and welding properties

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Abstract. Aluminium metal matrix composites have high strength to lightweight ratio. The AA2014/B4C/Graphite Hybrid Composites fabricated with different wt. % of reinforcement by stir casting. The Welding and Mechanical properties of hybrid composites were studied, and those results revealed that the SEM microstructure had shown the uniform dispersion of the reinforcement particles in the AA2014 with the addition of reinforced B4C and Graphite particles. The impact strength of the composite material is increased from 20 joules to 25 joules in the case of Izod test. Increase the tensile strength of welded composites up to 15.64% compared to base alloys. The hardness increased before welding 12.98% and after welding 38.32% compared to base alloys.

1. Introduction
The AA2014 aluminum alloy used for lightweight structural materials, especially in the rapidly growing aerospace and automotive industries. B Adaveesh et al. [1] explains that ZA43 alloy B4C particulate composites were successfully produced by stir casting method with weight % (6wt. % and 3wt. %) of reinforcement. The hardness improvement is up to 48% after addition of 6 wt. % of B4C particulates.DM Nuruzzaman et al. [2] Addition of SiC particulate, the density increased to the composite material. The hardness of Al/SiC composites increased with increase in the volume of SiC particles. Metal Matrix Composites of Stir Casting Process by G. G. Sozhamannan et al. [3] analysis of microstructure, the particles were uniformly distributed during the casting process. Friction stir spot weld of AA2014 by S. Babu et al., [4] for 3 mm thick sheets of aluminum alloy, the process parameters on the formation of joint and effects of tool geometry investigated. Friction stir welding of AA2014 Aluminum Alloy, by S. Ugender et al.,[5]. The weld with free of the defect was obtained at a speed of tool rotation of 900 rpm and transverse speed of 40 mm/min respectively. Micro Mechanical Behaviour of AA2014 Alloy by K. Ashok et al. [6] explained that behaviour of duralumin alloy during the hot tensile test. The Mechanical properties were measured and studied along with the changes of microstructure at all experimental conditions.F. Bonollo et al.,[7] studied the impact, tensile and fractographic characteristics for discontinuously reinforced metal matrix composites. Al 2024 based Hybrid metal composites, by Preetam Kulkarni[8], the ultimate tensile and compressive strength increases in Al2024, due to the addition of E-glass fiber.Hot deformation behaviour of AA2014–10 wt% SiC Composite, by Aruna Patel et al., [9]. From microstructural standpoint, the dispersed SiC particles impart higher hardness and thermal stability to the alloy system given their high hardness.
Van Suchetelen, et al. [10], explains that the composite materials consisting of heterogeneous elements, on a microscopic level are in contact with each other. In a macroscopic level, they can also consider as homogeneous materials with the same physical property.

2. Experimental Details

2.1. Materials

For the preparation of AA2014 alloy and hybrid composite, the compositions of the AA2014 aluminum alloy given in table 1. Two different ceramic particles have taken, first of them boron carbide (B₄C) and second is Graphite.

| Element | Si  | Fe  | Cu  | Mn  | Mg  | Zn  | Ti  | Ni  | Cr  | Al  |
|---------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Composition | 0.5-0.9 | 0.5 | 3.9-5 | 0.4-1.2 | 0.2-0.8 | 0.25 | 0.2 | 0.1 | 0.1 | Bal. |

2.2. Stir casting

Casting has been done by stir casting method for the light metal matrix. The capacity of the mold is 1154 grams, the temperature of furnace 800°C and stirrer rotation speed of 450 rpm. If the melting of the materials is completed then put the slag removing agent in the form of Bi-potassium-hexa-fluorotitanate (K₂TiF₆), Slag removed unwanted materials. Preheat the reinforcement material up to 650°C then feed it in the furnace at the slow rate. Metal matrix composites are prepared by stir casting method as shown in Figure.1 [11], in which first casting is without reinforcement and second casting to fourth(1 wt.% B₄C constant and 0.5, 1 and 1.5 wt% Gr ) the Complete designation given in table 2 and images of the cast shown in Figure. 2.

| Casting | Composition |
|---------|-------------|
| Sample 1 | AA2014       |
| Sample 2 | AA2014/1wt% B₄C/0.5wt%Graphite |
| Sample 3 | AA2014/1wt%B₄C/1wt% Graphite   |
| Sample 4 | AA2014/1wt%B₄C/1.5wt% Graphite  |
Figure 1 Stir casting machine [11].

Figure 2 Images of cast AA2014 alloy and hybrid composite.

2.3. Friction Stir Welding (FSW)
The solid-state Friction Stir Welding is joining process. The plate dimension (50*40*4mm) to welded with tightly clamped. In this process, the FSW as shown in Figure 3 consists of shoulder diameter 18mm and pin diameter 6mm with the tool rotating speed of 1000rpm, until the tool shoulder touches the surface of the material in the mid-line of the plate to be welded.

Figure 3 Procedure of FSW (a) Set up for FSW (b) Welding processing (c) Welding image of plate (d) Welded plate.

2.4. Weld Tool Fabrication
The FSW conducted in vertical end milling machine. The friction stir tool shown in Figure 4 made of OHNS (Oil Hardening Non-shrinking) die steel of various pin diameter 6mm. The tool shoulder diameter of 18mm, pin length 4mm with the constant rotating speed of 1000 rpm (counterclockwise direction) at welding feed rate of 20 mm/min. With 30second continuous indentation time, the unthreaded tool was plunged at mid-line until the tool shoulder touches the surface of the plate that leads the weld tool to perform welding.
2.5. Testing
AA2014 alloy and Hybrid composites specimens are prepared as per ASTM standard, the Tensile test, Hardness and Impact test. For the study of optical and SEM microstructure, the sample prepared by step by step like Sectioning, Sampling, Rough polishing, Rough grinding, Mounting, Intermediate polishing, Fine polishing, and Etching process. The Vickers hardness test done as per the ASTM E92 standard. The Izod and Charpy impact test samples prepared as per ASTM E23 standard, the Specimen size: 10×10×75mm, Notch at 25mm from any one end, V-notch: 45° with 2mm depth and 0.25mm radius at the middle of the specimen. The welded tensile strength specimens are prepared as per ASTM E8 standard. Maximum length is 100mm; Gripping is 2×32.5, Gauge length is 25mm, Radius of curvature is 2×5mm.

3. Result And Discussion

3.1. SEM analysis of Alloy and Composites
The SEM microstructural studies showed in Figure. 5. The Ceramic particles are well distributed, and they present bonding link with the base material. However, significant reactions take place between matrix and reinforcement then bonding strength between matrix and reinforcement by preheating. The composite materials, Figure.5 shows the SEM microstructures of the composite with the B₄C and Graphite particles have uniform distribution in AA2014 alloy. The stir casting process indicates that Some of B₄C particles have settled down in the grain boundary of the composite. In the Figure. 5(b-d), the B₄C and graphite microparticles uniformly distributed in all the composites.

3.2. Hardness Test
The hardness value measured for AA2014 alloy and composite materials reinforced by the percentage combination of B$_4$C&Graphite. It observed that hardness increases by 12.98% due to uniform distribution of reinforcement (B$_4$C & Graphite) of fourth composites samples to base alloy (AA2014) similarly 10.21% increases to second composite sample and 12.16% increases in the third composite sample to base alloy shown in Fig.6. From the overall all composites, the fourth composite is good hardness strength. The hardness of the welded AA2014 aluminum alloy and hybrid composites measured by the Vickers hardness test. Due to the addition of B$_4$C&Graphite reinforcement particles, the oxide layer developed in composite materials on the surface, the stress relieves, and density of the composites are increased then hardness of the composite material are increased gradually with increasing ceramic particles. From Figure. 7, it observed that the hardness value is increased up to 38.32% due to uniform distribution of reinforcement. The fourth composites samples compare to base alloy (AA2014), similarly 14.43% increases to second composite sample and 32.46% increases in third composite sample compare to base alloy which shown in Figure.7. The percentage of ceramic particles is increased hardness values are increased monotonically. In Figure. 6 & Figure.7 shows that the hardness of samples increased as wt. % of graphite increased.

![Figure 6](image1.png)

**Figure 6** Vickers hardness vs. Samples for composites.

![Figure 7](image2.png)

**Figure 7** Vickers hardness vs. Samples for welded composites.

### 3.3. Izod Impact Test

From Figure. 8, Izod test, it is observed that the toughness increases by 25% of the fourth composite sample compare to base alloy similarly 10% increases to second composite sample and 20% increase in third composite sample compare to base alloy(AA2014). The wt percentage of ceramic particles increased, the toughness energy increased monotonically. In Figure.8 showed that the toughness of all the composite samples increases as wt. % of graphite increases.
3.4. Fractographic study of Izod test

Fractographic of Izod test can observe from impact fractured surfaces. The dimples have been detected by SEM image as can be seen in Figure. 9(a-b). The AA2014 alloy has no ceramic particles then crack propagation is more compared to the composite material because nonuniform bonding of the grains particles shown in Figure.9-a. Addition of ceramic particles bonding strength of the composites is increased and crack propagation reduced Figure. 9(c-d). The toughness of the composite materials is increased gradually due to the increasing reinforced materials which uniformly distributed. The highest impact strengths were shown in the Figure. 9 (d) composite compare to base alloy, due to uniform distribution and good wettability with the good bonding of reinforcement and then maximum fracture energy is absorbed in that stage.

![Figure 9](image)

**Figure.9:** Fractographic SEM image of izod test at 500µm (a) AA2014 (b) AA2014+ 1wt % B$_4$C+0.5% Graphite (c) AA2014+1% B$_4$C+1% Graphite (d) AA2014+1% B$_4$C+ 1.5% Graphite.

3.5. Tensile Test

The Ultimate tensile strength of the alloy and hybrid composites are, having constant 1 % wt. of B$_4$C and 0, 0.5, 1, 1.5wt% of Graphite reinforcements. The tensile strength is done as per ASTM E8 standard, results of the ultimate tensile strength of alloy and hybrid composites given in Figure. 10 & 11 with varying composition of Boron carbide and graphite particles. The Ultimate tensile strength increasing from 294MPa to 340 MPa the tensile strength is increased up to 15.64%, on the addition of 1wt % boron carbide and 1wt % Graphite. On subsequent addition of graphite particulates of 0.5 and 1% wt. B$_4$C tested specimens the tensile strength is increased up to 5.44% of UTS, when compared to the base alloy. The UTS is rising from 294MPa to 323MPa, on the addition of 1wt % B$_4$C and 1.5wt% Graphite particle reinforcement, the ultimate tensile strength is increased up to 9.86%. Compare to base alloy.
Figure 10 True stress vs. true strain graph for tensile test.

Figure 11 Graph for load variation of tensile test.

3.6. Fractographic study of tensile test

Typical UTS fractured surfaces obtained from AA2014 alloy and AA2014/B$_4$C/Gr composites. The fracture surfaces of SEM images shown in Figure. 12. The AA2014 alloy and composites examined by SEM; the dimples are less in unreinforced base material Figure. 12(a). The fractured surface of the reinforced composite material Figure. 12 (b-d) contained more dimples than the fracture surface of the unreinforced material AA2014 alloy.

Figure 12 Fractographic image for tensile test at 500µm (a) AA2014 (b) AA2014+ 1% B$_4$C+0.5% Graphite (c) AA2014+1% B$_4$C+1% Graphite (d) AA2014+1% B$_4$C+ 1.5% Graphite.

But the higher percentage of graphite some agglomeration happen then composites showed brittle fracture failure as shown Figure. 12(d). Few crack propagation in the fracture SEM image and there is
an indication of ductile failure in the metallic matrix. The fracture results showed a very few fracture transversally and split-longitudinally as shown in Figure. 12 (b). The fracture failure in the composite is attributed due to the increase in stress on the specimen. As the load on the fracture increases, it induces the strain in the particles.

4. Conclusions
From the study of SEM microstructure the uniform dispersion of the reinforcement particles in the AA2014 aluminum alloy matrix with the addition of reinforced B$_4$C and Gr particles. The hardness of hybrid composites is increased from 92.05 HV to 104 HV by addition of 1wt % of B$_4$C and 1.5wt % of graphite and the hardness up to 12.98% compared to base alloys. The impact strength of the composite materials are increased from 20 joules to 25 joules in the Izod test. Increase the tensile strength up to 15.64% compared to base alloy. Hardness strength increased to welded composites of 1wt% B$_4$C and 1.5wt% Gr, from 66.56HV to 92.06HV, the hardness is increased up to 38.32% compared to base alloy.

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