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An Investigation on the Mechanical Properties of Aluminium 6061 Alloy Reinforced with Boron Carbide and Silicon Carbide

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Abstract: Aluminium alloys are widely utilised in the aerospace and automobile industries due to their low density and strong mechanical qualities, as well as their superior corrosion and wear resistance and low thermal coefficient of expansion as compared to traditional metals and alloys. These material's superior mechanical qualities and inexpensive production costs make them an appealing alternative for a wide range of scientific and technical applications. In this study, we strive to present a literature review on the overall performance of reinforced composites created by the stir casting method, as well as the effect of process factors on the properties of Aluminium-based MMC. The literature review framework in this paper provides a clear overview that the process parameters play important role for optimum properties of Aluminium based Metal Matrix Composites.
As reinforcing elements in Metal Matrix Composites, Boron Carbide and Silicon Carbide play an important role. The MMCs were successfully produced using the liquid metallurgy process. Scanning electron microscopy was used to examine the morphology and microstructure of Al-B4C and Al-SiC composites. The addition of 2, 4 and 6 wt% B4C and SiC particles increased several mechanical parameters such as ultimate tensile strength and hardness. It was also discovered that the mechanical behaviour of B4C particulates AMC is superior to that of SiC particulates AMC.
Keywords: Aluminum, Metal matrix composite, SiC, B_4C, Tensile test, Hardness test and SEM Analysis.

I. INTRODUCTION

Two components with diverse physical and chemical properties are made up of a composite material. When blended, they make a material specialised in doing a particular activity, such become stronger, lighter or more electricity resistant. You can contribute to rigidity and strength. They are preferred over traditional materials since they improve the product's quality.

"Composite materials," also known as "composition materials" or simply "composites," are materials made from two or more components that show significantly different chemical and physical properties. When these two or more fundamental components are combined, a new substance emerges with properties distinct from the individual constituents. Composites must be distinguished from material mixtures and Solid solutions, because the components of the final material structure remain unique and autonomous.

Individual ingredient components comprising these composites consist of individual basic materials. Two basic categories of component materials are the matrix (also known as binding) and reinforcement. At least one representative is required for a composite from each category. The matrix phase incorporates, encloses and supports the reinforcements' relative positions. The enhancements offer the matrix its particular physical and mechanical qualities and improve its characteristics.

The ensuing synergy between both phases produces material properties that are not apparent in the individual component materials while the designer can build perfect binding and reinforcement combinations, which result in custom produced composites.

With much of the expansion centred around renewable energy the composite industry still develops today. The engineers can design the composite according to the performance requirements, for instance, by aligning the fibres in one direction, to make the composite sheet very strong, but weaker in another direction, where strength is less crucial. In addition, the engineers can select the proper matrix material for their quality, such as heat resistance, chemical resistance and weathering resistance. In recent years, natural fibres have become a major focus in the context of environmental awareness and a knowledge of the need for sustainable development. synthetic fibres Composite materials provide greater freedom of design and a reduced part count for products, because they may be produced in nearly any form. Many sectors find composites attractive because they are capable of choosing elements, adapting them to get the needed properties and then making optimal use of these properties by designing them.

The aviation and military markets have most invested in the development and promotion of composite technology. For composites to exercise their advantage over conventional materials, the requirement for strong, stiffer and lightweight construction has offered an opportunity. Other benefits include longevity and little maintenance.

The life of the system is increased and maintenance costs are reduced. As a result of new manufacturing methods introduced and existing ones improved, manufacturing costs have lowered. The new military aircraft construction is almost entirely composed of advanced composites. Rocket motor cartridges, toys and nose cones incorporate missile applications. Advanced composites are also employed to manufacture a range of secondary components such as radar domes, rotor blades, propellers and access panels. In a range of tanks, weapons and space technology, composite materials are utilised.

The popularity of composite materials will continue to grow. As more engineers become more aware of composites, further opportunities for their use will develop. As the use of composites increases, further advances will be achieved in component materials, analysis, design and production. The advantages of composite materials are customizability, design flexibility and low-cost manufacture, with a low environmental effect. These features lead for composite materials to a bright future.

Many researchers have done extensively experimenting with various strengthening particles such as aluminium alloy B4C and SiC as parent metal and have produced the aluminium composite materials utilising a technology for liquid metallurgy. Based on B4C and SiC literature studies, the composite material B4C and SiC enhanced by metal alloy matrix 6061 alloy is attempted to sum up extremely good mechanical properties using various aluminium alloys. The B4C/SiC particle boosts wear resilience and also helps to improve mechanical characteristics at high temperatures, as demonstrated by the experiments carried out by many researchers. The presence of B4C/SiC would effectively prevent deformation of the matrix, transport load, and lock the micro fractures typically developing in the direction of friction. Pistons, connection rods etc are the most prominent applications of particulate aluminium reinforcing matrix. This research is therefore underway to explore the effects, such as B4C and SiC, on Aluminium Metal Matrix composites by varied compositions of reinforcement, and to draw on their mechanical qualities in the aim that Al-6061 can be replaced more widely in the automobile industry.

The MMCs were successfully produced using the liquid metallurgy process. Scanning electron microscopy was used to examine the morphology and microstructure of Al-B4C and Al-SiC composites. The addition of 2, 4 and 6 wt% B4C and SiC particles increased several mechanical parameters such as ultimate tensile strength and hardness. It was also discovered that the mechanical behaviour of B4C particulates AMC is superior to that of SiC particulates AMC.

II. EXPERIMENTATION

A. *Selection of Materials*

The selection of materials is a multi-layered, advanced and complex process that must take a number of elements into consideration, including:

- Material cost
- Production cost
- energy and raw materials demand (process intensity materials)
- Energy and demand for raw material (process intensity material)
- Potential environmental impact of selection of materials depending on production and consumption cycles.
- Material recycling accessibility.

1) *Aluminium Alloy:* Aluminium metal and alloys are used in almost all of the current industrial processes, given their wide availability and a wide range of applications. An alloy is a metal that was created to improve material qualities by mixing two or more metallic elements. Alloying means the addition of certain metallic alloying elements to a base metal, so that it has uniquely improved strength, resistance to corrosion, conductivity, toughness, and so on or the desired mix of these features. Worked alloys have low (approximately 4 percent) alloys, and are workable, while cast alloys are larger (up to 22 percent) and are generally fragile. A four-digit nomenclature system has been developed by the Aluminium Association (AA Inc.), the world leader in aluminium alloy, which differentiates various working alloys by its principal alloy constituents.

Figure 1: Aluminium 6061 alloy

2) *Silicon Carbide (SiC):* Silicon carbide is an extraordinarily hard, synthetically manufactured silicone and carbon crystalline mixture. It is constructed of carbide silicone (SiC). Since the late 1800s, silicon carbide has been a well-known material for sandpapers, mouldings and cutting tools. It has been employed in refractory forms and heating elements for industrial furnaces, wear-resistant pumps, rocket engine part and light-emitting diode semi-conducting substrate in recent years.

Figure 2: Silicon Carbide (SiC)

3) *Boron Carbide (B4C):* Boron Carbide (B4C) is the hardest material to rank 3rd following diamond and cubic nitride boron. It is the hardest substance to produce in huge numbers. Boron carbide was originally found as a by-product of the production of metal borides in the medium of the 19th century, but was not further explored until 1930. The boron carbide powder is produced by reacting with B2O3 in an electrical arch furnace, reducing carbotherms or reactions of gas phases. Before being used for commercial applications, B4C pulvers need generally be crushed and processed to eliminate metallic impurities. Boron carbide is difficult to sinter to the highest density, like other nonoxid materials, and requires hot pressing or sintering HIP to get a theoretical density of above 95%. In addition, even such techniques often require small amounts of dopants like fine carbon or silicon carbide to enable sintering at tolerable temperatures (e.g. from 1900 to 2200°C).

Figure 3: Boron carbide B_4C

B. Manufacturing Process

1) *Stir Casting Method:* Stir casting is a sort of casting method in which a mechanical stirrer is used to create a vortex in the matrix material to combine reinforcement. Due to its cost effectiveness, mass production suitability, simplicity, nearly net shaping, and easier control of composite structure, it is a good process for the manufacturing of metal matrix composites. A furnace, reinforcement feeder, and mechanical stirrer make up a stir casting apparatus. The furnace is used to heat materials and melt them. Because instant poring is required after stirring the mixed slurry to avoid solid particles settling in the bottom of the crucible, the bottom poring furnace is better suited for stir casting. The mechanical stirrer creates a vortex that aids in the mixing of the reinforcing materials delivered into the melt. The impeller blade and the stirring rod make up the stirrer. The impeller blade can have a variety of shapes and numbers of blades. Flat blades with three numbers are chosen because they provide an axial flow pattern in the crucible while consuming less energy. This stirrer is connected to variable-speed motors, and the stirrer's rotation speed is controlled by the motor's regulator. The feeder is also connected to the furnace and is used to feed reinforcing powder into the melt. Pour the blended slurry into a permanent mould, a sand mould, or a lost wax mould.

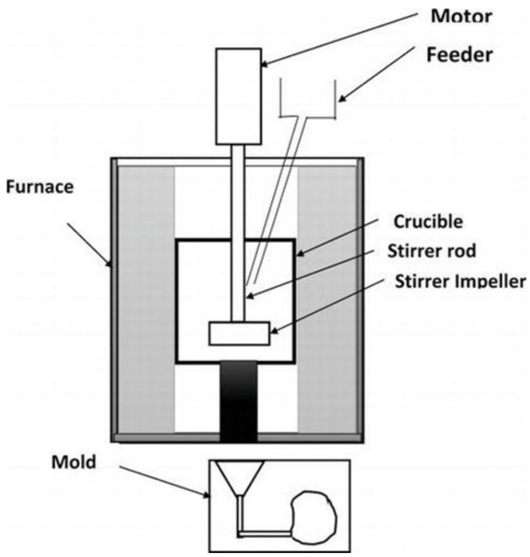


Figure 4: Stir Casting Setup

Figure 5: Stir casting Setup Used

Figure 6: Stir casting Setup Used

Figure 7: Casting the composite Material

2) *Specimen Preparation:* The crew of the SM ENGINEERING RAJGOPALNAGAR BANGALORE carried out the machining operations (560086). A CARBIDE was used to perform the entire machining operation on the late engine.

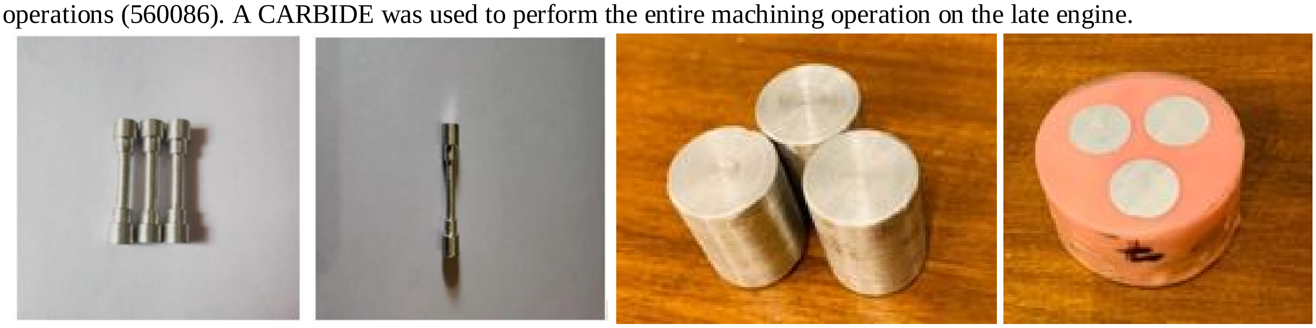


Figure 8: Specimen Preparation as per ASTM standard dimensions

III.EXAMINATIONS AND TESTING

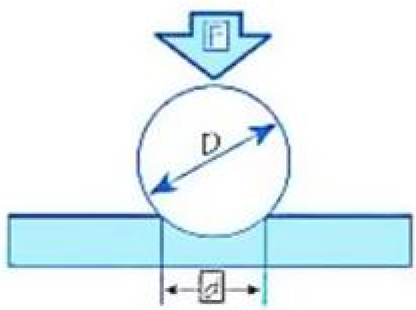
A. Hardness Test

Hardness, rather than basic physical property, is a characteristic of a substance. It is defined as indentation resistance and is determined by measurement of the permanent indentation depth.

Simply said, the smaller the indentation, the harder the material when employing a fixed force (load) and a certain indenter. Indentation hardness value is achieved using one of 12 different test methods, measuring either the depth or the indentation area.

ASTM E10 defines the Brinell hardness test technique for Brinell hardness. It is most usually used to test materials which have a too gross structure or have a surface which is too rough for testing, e.g. casting and forging using another method of testing. Brinell tests commonly use a very high test load (3000 kgf) and an indenter diameter in 10 mm, such that most surface and subsurface irregularities are measured by average.

The Brinell method uses a specified test load (F) to hold and then remove a fixed diameter carbide ball (D). A properly built Brinell Microscope or optical system measures the resulting imprint in at least two diameters – usually at the appropriate angles, and the findings are averaged (d). Whilst the following equation can be used to obtain the Brinell number, a chart is commonly employed to turn the average measurement diameter into a Brinell hardness number.



$$HB = \frac{2F}{\pi D\left(D - \sqrt{D^2 - d^2}\right)}$$

B. Microstructure Examination

An optical microscopy was used for the microstructure exam of the composites Al/SiC and Al/B4C, before the microstructure was examined, the specimens were cut and machined with the lattice and then melted with emery paper (500 and 1000) µm in the size of the particle. The specimens were polished with a diamond paste at size of 0,7 µm for 30 minutes after grinding to get surfaces like a mirror. Finally, the composite specimens were being etched with a 1% basement reagent for 30 secs before being washed with water before the microstructure inspection.

C. Tensile Testing

Tensile testing is a destructive testing procedure that informs on metallic material strength, output strength and ductility. It evaluates how much force a composite or plastic specimen is required to break down and in the measurement to which the specimen extends or extends. The composite tensile tests are usually performed in the way of basic tensioning or flat-sandwich tension testing, which complies with ISO 527-4, ISO 527-5, ASTM D 638, ASTM D 3039 or ASTM C 297 standards. These tests generate tensile module stress-strain diagrams.

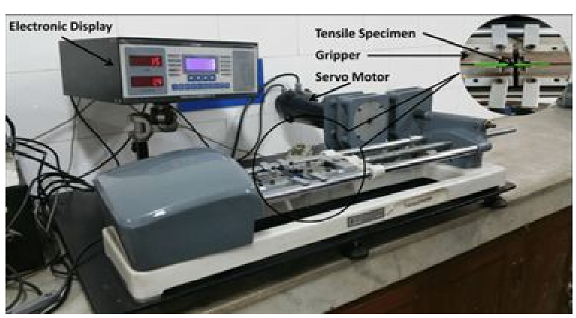


Figure 9: Tensile Testing Equipment

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IV. RESULTS

Aluminium 6061 reinforced with B4C and SiC composites are cast, machined according to ASTM standard and tested to investigate its novel mechanical properties. The obtained values are tabulated and plotted. Results are justified with theoretical backgrounds.

A. Microstructure Examination

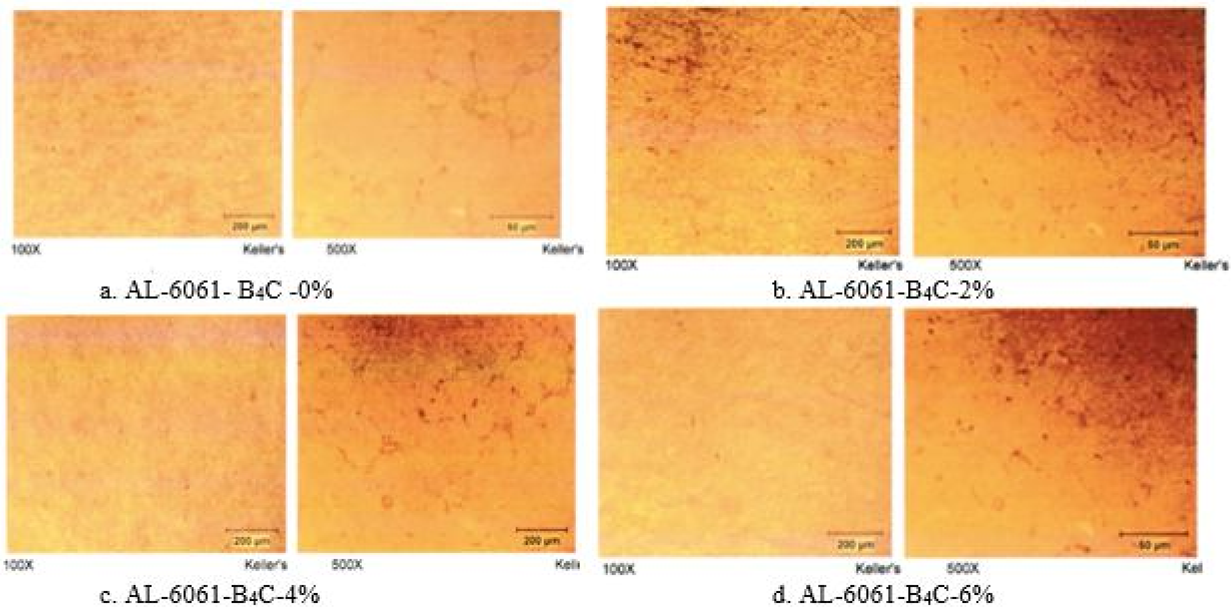

Figure 10: Microstructure Analysis of Al-6061-B_4C Composite.

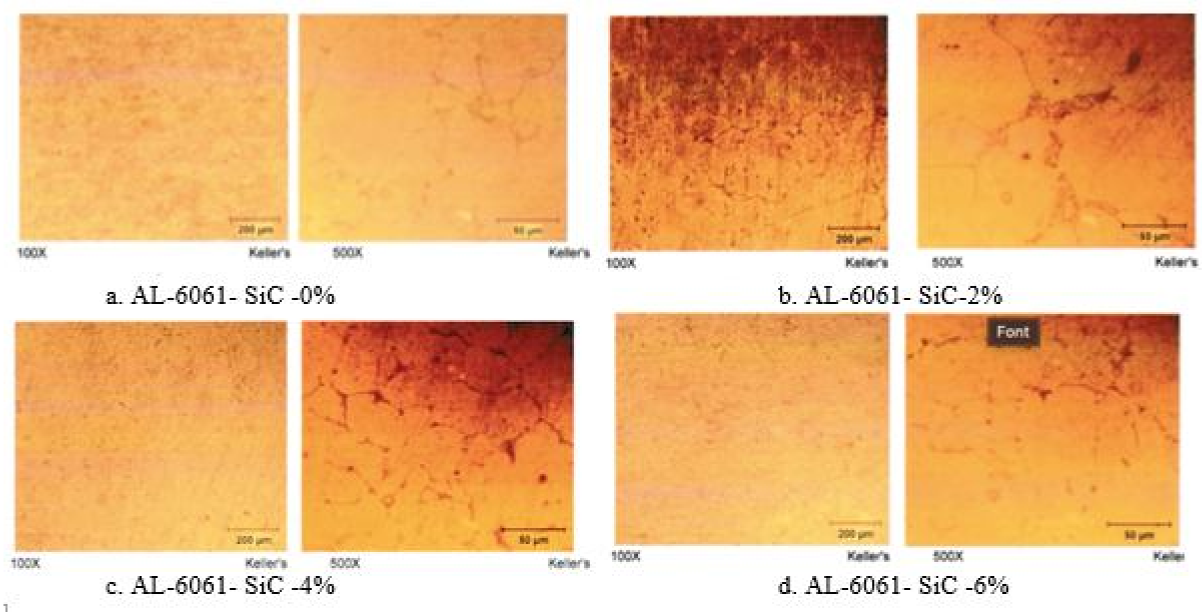

Figure 11: Microstructure Analysis of Al-6061-SiC Composite.

Optical metallurgical microscopy examines the distribution of silicone carbide and boron carbide within the aluminium matrix. The basic metal (Al) microstructure is shown in Figure 1. The manufactured composite Al-B4C and Al-SiC were employed. The sample surface was polished such that the metal matrix could be observed to see any other part other than the basic metal. The photograph of the optical microscope (Figure 2and 3 demonstrates that the aluminium matrix has uniform distribution between ceramic particles and the matrix. This consistency was achieved by agitating for 10 minutes. In the background, the ceramic particles look black.

B. Hardness Test

Table 4.1: Brinell hardness number of AL-6061- B_4C Composite

Specimen	Ball Diameter: 5mm Applied load: 250KG	
	Avg Dia of Indentation	Brinell Hardness (BHN)
AL-6061- B_4C - 0%	2.405	48.1
AL-6061- B_4C - 2%	2.485	48.3
AL-6061- B_4C - 4%	2.480	51.6
AL-6061- B_4C - 6%	2.350	54.3

Table 4.2: Brinell hardness number of AL-6061- SiC Composite

Specimen	Ball Diameter: 5mm Applied load: 250KG	
	Avg Dia of Indentation	Brinell Hardness (BHN)
AL-6061-SiC - 0%	2.405	48.1
AL-6061- SiC - 2%	2.490	49.9
AL-6061- SiC - 4%	2.360	50.1
AL-6061- SiC - 6%	2.440	53.8

The Brinell hardness number of base metal Al-6061 was 48.1 BHW, but the hardness of AL- B4C 2%, 4%, 6% was found to be 48.3 BHW, 51.6 BHW,54.3 BHW respectively, which indicates towards the increase in hardness of Al-SiC Composite from the that of base metal. The Hardness of Al-SiC 2%,4%,6% was hence found out to be 49.9 BHW, 50.1 BHW, 53.8 BHW respectively.
These results hence confirm that the hardness value of the composites have increased due to uniform dispersion of both boron carbide and silicon carbide.

C. Tensile Test

Table 4.3: Tensile test results of AL-6061-SiC Composite

Specimen	Peak Load (N)	Load at Break (N)	Max. Displacement (mm)	Tensile Strength (N/mm^2)
AL-6061-SiC - 0%	519.8	107.9	3.69	41.3
AL-6061- SiC - 2%	774.8	156.49	1.14	61.6
AL-6061- SiC - 4%	1598.5	823.8	2.86	127.2
AL-6061- SiC - 6%	1951.6	1588.7	2.49	155.2

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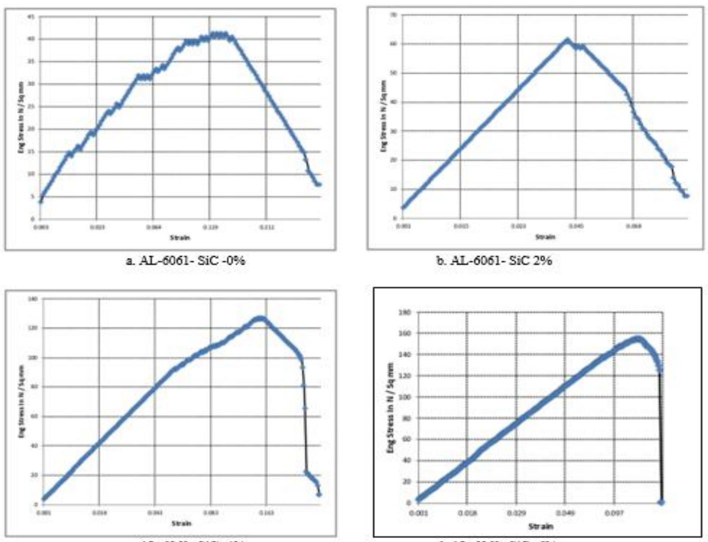
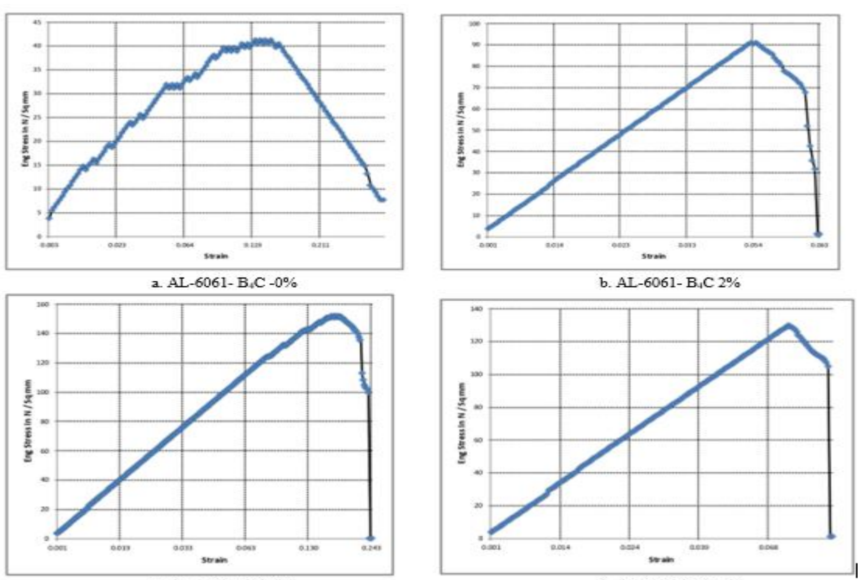
Table 4.4: Tensile test results of AL-6061-B_4C Composite

Specimen	Peak Load (N)	Load at Break (N)	Max. Displacement (mm)	Tensile Strength (N/mm²)
AL-6061- B_4C -0%	519.8	107.9	3.69	41.3
AL-6061- B_4C -2%	1147.4	402.1	1.00	91.3
AL-6061- B_4C -4%	1912.4	1255.3	3.87	152.1
AL-6061- B_4C -6%	1637.8	1323.9	1.42	130.3



a. AL-6061- SiC -0% b. AL-6061- SiC 2% c. AL-6061- SiC -4% d. AL-6061- SiC -6%

Figure 12: Tensile Test of Al-6061-SiC Composite



a. AL-6061- B_4C -0% b. AL-6061- B_4C 2% c. AL-6061- B_4C -4% d. AL-6061- B_4C -6%

Figure 13: Tensile Test of Al-6061-B_4C Composite

The tensile test was conducted on the specimens cut according to dimensions and the results indicated that there was in increase in ultimate tensile strength of the Al-SiC and Al-B4C composite compared to that of parent metal Al-6061.

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D. SEM Analysis

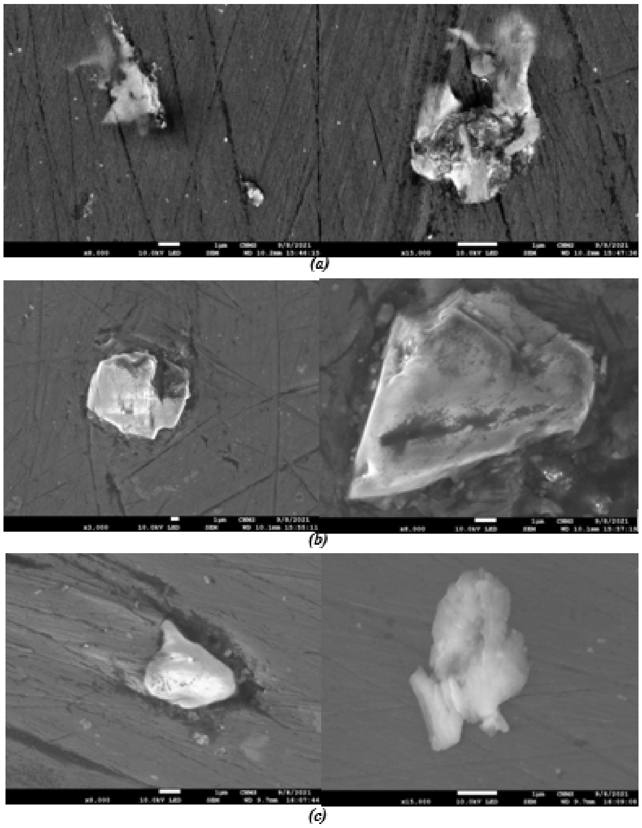

Figure 14 (a) SEM analysis of Al-6061-B4C (2%), (b) SEM analysis of Al-6061-B4C(4%), (c) SEM analysis of Al-6061-B4C(6%)

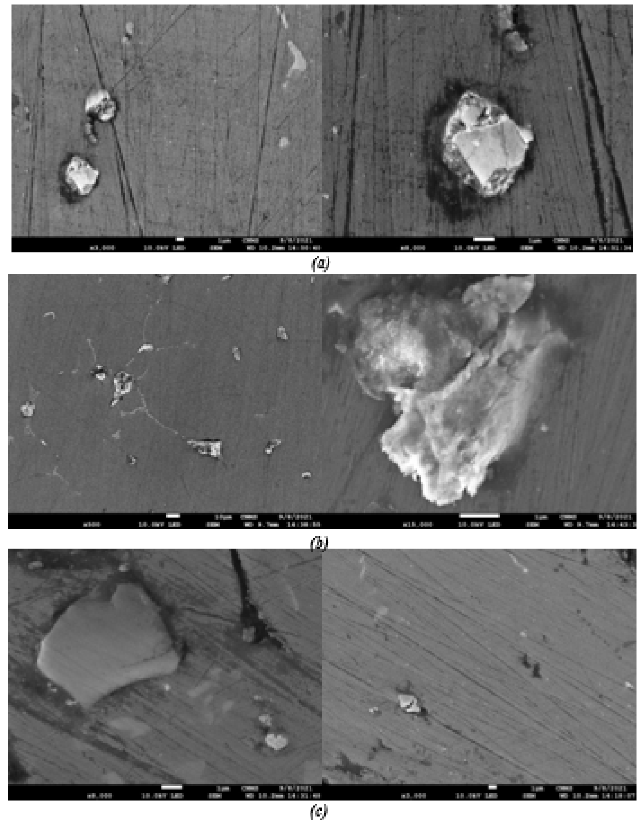

Figure 15 (a) SEM analysis of Al-6061-SiC (2%), (b) SEM analysis of Al-6061-SiC(4%), (c) SEM analysis of Al-6061-SiC(6%)

V. CONCLUSIONS

Boron carbide particles with the size of 30 microns and Silicon Carbide particles of 1000 grits where used to reinforce Aluminium 6061 parent metal in 2,4,6 wt% and the study conclude as follows:

1) Successful fabrication of Al-B4C and Al-SiC made by liquid metallurgy route with minimum porosity
2) The results of tests conducted are much closer to the literature survey conducted.
3) The microstructure analysis is carried out to understand the distribution of the reinforcement
4) The mechanical properties like Hardness and Tensile have been impacted with the addition of boron carbide and silicon carbide.
5) SEM analysis clarifies the uniform distribution of the reinforcement within the parent metal.
6) The tensile property and hardness increases with increase in wt% of reinforcements in the case of both Al-B4C and Al-SiC composites.
7) A comparative study shows that Al-B4C exhibits higher tensile and hardness properties compared to Al-SiC of the same concentration of reinforcements.

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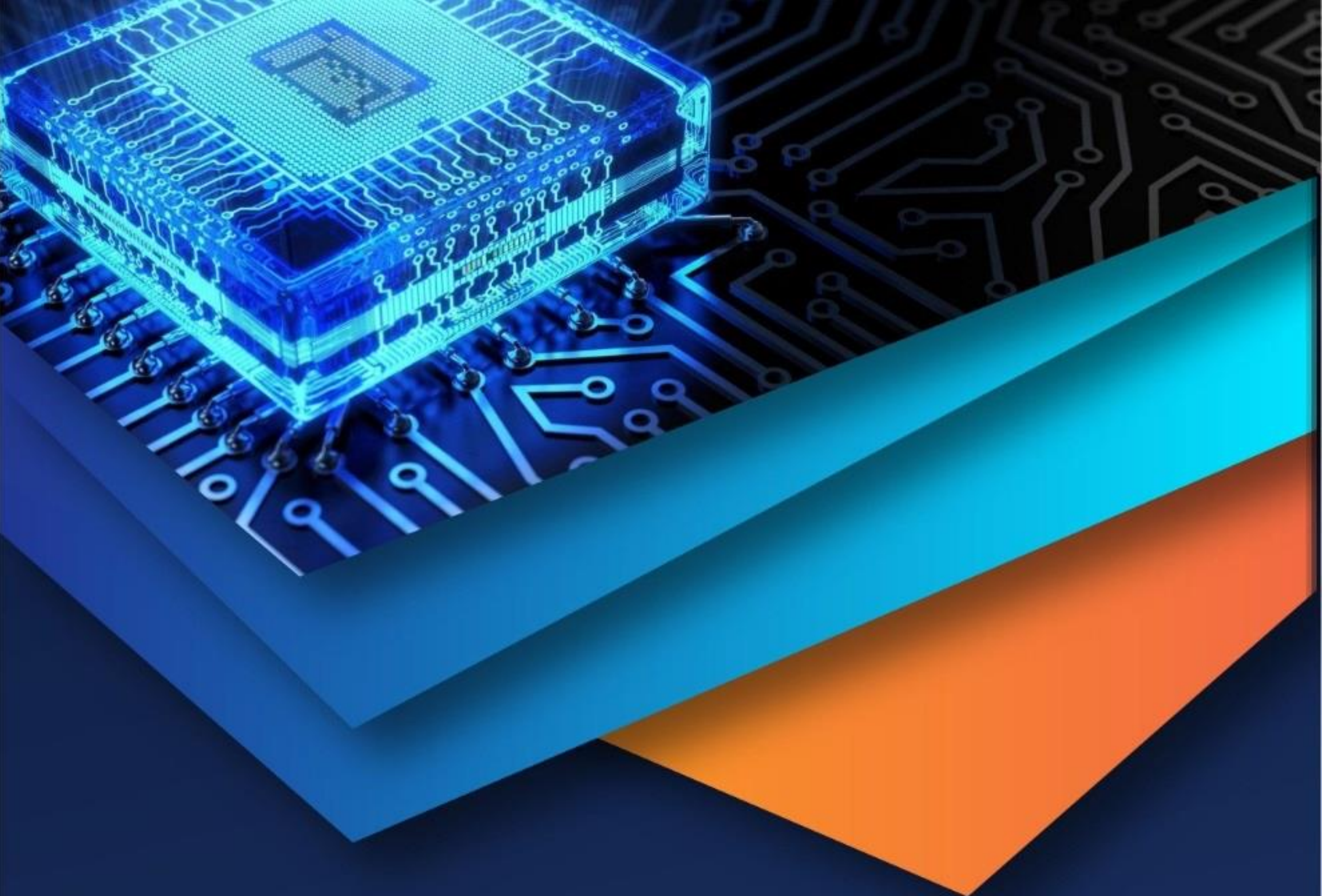

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