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Investigation and Enhancement in Mechanical Properties of Aluminium 6063 by Silicon Carbide and Boron Carbide

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***Abstract*— The current study utilised the stir casting procedure to create four distinct samples of Al-6063/ SiC/ B4C hybrid MMCs. The samples included varying weight percentages of SiC (0%, 8%, 6%, and 4% wt) and B4C (0%, 2%, 4%, and 6% wt). Tests for the mechanical characteristics of Al-6063/SiC/B4C hybrid composites were conducted, including tensile, impact, hardness, and XRD analyses. Based on the results of the microstructural investigation performed using the X-ray Diffraction technique, the distribution of the reinforcing particles inside the aluminium matrix is rather uniform, and there is negligible porosity.**

Among the tested samples, sample-3 had the highest values for tensile strength (188.65 N/mm2), elongation (23.89 percent), impact energy (38 J), and hardness (62.1 HV). The mechanical tests showed that the Ultimate Tensile Strength (UTS) was 47% higher with 4% and 6% SiC and B4C reinforcement compared to the base alloy. & shortens the length. Results show that the created composite can replace heavier materials in high-friction parts like engine pistons and brake rotors.

***Keywords*— Composites, AMMC, Stir casting, XRD analysis, Reinforcements, Mechanical Properties, Silicon carbide, Boron carbide, Hardness and Tensile strength.**

I. INTRODUCTION

Composites are the materials made up of two or more physically and chemically distinct parts, which are arranged in suitable manner. Composites generally have better fatigue performance than metals. Low thermal expansion ensures dimensional stability.

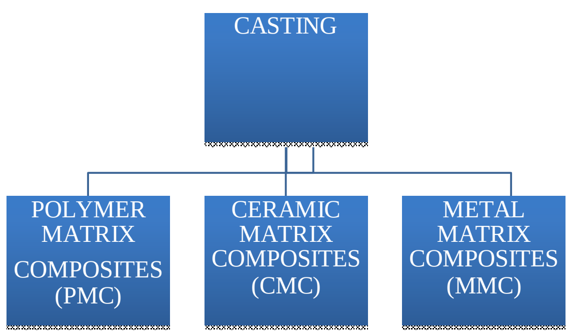

Fig. 1 Types of Composites

Among the many technical materials that have gained popularity in the last decade, aluminum-based metal matrix composites (MMCs) have stood out. Composite materials, made by mixing ceramic powder with a metal matrix, have desirable mechanical and physical characteristics. Aluminium matrix composites (AMCs) have been developed using a variety of reinforcements, including graphite, silicon carbide, titanium carbide, boron, al2o3, fly ash, Zr, and Tib2. Hard reinforcing, such silicon carbide, increase the composites' hardness, strength, and resistance to wear.[1]. Aluminium is a lightweight, corrosion-resistant, and highly versatile metal used extensively in aerospace, automotive, construction, packaging, electrical wiring, and consumer goods. Its strength-to-weight ratio, recyclability, and conductivity make it one of the most important industrial materials worldwide.

Stir casting method, an economical method for fabricating aluminium matrix composites, stir casting involves mechanically moving the molten matrix to distribute the reinforcing phases. In 1968, the process of creating metal matrix composites by stir casting was begun.

As S. Roy stirred the molten aluminium alloy containing the powdered ceramic particles, he added aluminium particles into the alloy. Part of the process involves using mechanical churning in the furnace. Casting, permanent mould casting, sand casting, and the subsequent molten alloy containing ceramic particles are all viable options; stir casting, in particular, is well-suited to the production of composites containing reinforcement volumes of up to 30%.[2]

II. LITERATURE REVIEW

Manas Kumar Parichha et al. (2026) reinforced Aluminium lithium alloy with alumina (Al_2O_3) particulates to form the aluminum metal matrix composite to improve the mechanical performace and microstructural stability by using controlled stir casting process.[3] Jignesh G. Parmar et al.(2025) reviews the effect of different production process of AMMCs on the behaviour and mechanical properitites of aluminium composite material.[4]

Using stir casting, Jagannath Pattar et al. (2024) varied the volume percentages of TiO2 dispersoids added to an AA6063 matrix. After that, they looked into the process-structure correlation of the AMMCs that came out of it. The weight ratio of four separate samples was considered in this case: 99Al-1TiO2, 97Al-3TiO2, 95Al-5TiO2, and the as-received AA6063. They were tested for microhardness, tensile strength, and tribological behaviour. In addition, we looked at the microstructures of the samples. Adding 5% TiO2 particles to the AA6063 matrix increased its strain energy handling capacity and gave it the driving ability to develop substructures and dislocations. Stir casting route is being followed for processing the aluminium metal matrix composites due to its low cost. Addition of SiC reinforcement leads to increase in the tensile strength, hardness value. Powder metallurgy method has been used least as it is expensive method for preparation of composites. Powder metallurgy leads to fracture of reinforcement particles.[5]

More research has to done in comparing the mechanical property of composites when adding reinforcement particles at same percentages. Aluminium 6063 with 2% to 8% Silicon Carbide and 5% to 20% Al_2O_3 were the specimens utilised in the investigation conducted by Dr. M. Subramaniyan et. al. (2023). Compressive strength, microhardness, and microstructure of these composites were all measured. Further enhancement of the aforementioned properties is achieved by using 15% wt Al_2O_3 and 6% wt SiC [6]. Muhammad Yasir Khalid et.al. (2023) The growing demand for environmentally friendly, fuel-efficient automobiles has led to the development of lightweight materials. Aluminium is an excellent structural material due to its many desirable properties, including a high strength-to-weight ratio and generally better mechanical attributes in comparison to other metals and alloys.[7]

Boron carbide reinforced with an AL6063 alloy matrix has been studied in terms of mechanical and manufacturing qualities by M. Venkatesulu et al. (2019). Composites made of aluminium alloy matrix were created by him using the stir casting process. The AL6063 served as the foundational material, with B4C particles added at 2, 3, 5, and 6.5 weight percent serving as reinforcements. [8]

III. METHODOLOGY

A. Aluminum-6063

Al 6063 has a good surface finish, high corrosion resistance, is readily suited to welding and can be easily anodized. Most commonly available as T6 tempered. The chemical composition of aluminum alloy 6063 is shown in table I below.

TABLE I

TYPICAL CHEMICAL COMPOSITION FOR ALUMINUM ALLOY 6063 [9]

Element	% wt.
Si	0.2
Fe	0.5
Cu	0.1
Mn	0.1
Mg	0.45
Zn	0.1
Ti	0.1
Cr	0.1
Al	98.2

B. Boron Carbide

B_4C possesses a number of desirable properties, including low density, high hardness, young's modulus, resistance to impact and wear, and outstanding thermal and chemical stability. Particles of B4C ceramic were shown in Table 3.3 together with their physical and mechanical characteristics. Among the many applications for lightweight Al/B4C composites are bicycle frames, bullet proof jackets.

TABLE II

PHYSICAL AND MECHANICAL PROPERTIES OF BORON CARBIDE [10]

Density	2.52 g/cm3
Compressive Strength	3000 MPa
Modulus of Elasticity	460 GPa
Thermal Conductivity	29 W/m.K
Thermal expansion coefficient	5×10^{-6} /k

C. Silicon Carbide

Carbide of silicon is a chemical entity. The two major components of silicon carbide are carbon and silicon dioxide. The high-temperature electrochemical reaction between sand and carbon was responsible for its production. Silicon carbide has a crystal lattice structure that is made up of tetrahedra with carbon and silicon atoms bound together strongly. Because of this, silicon carbide grew into a robust and durable substance.

TABLE III

PHYSICAL AND MECHANICAL PROPERTIES OF SILICON CARBIDE [1]

Properties	Value
Melting point (c)	2200-2700
Limit of application	1400-1700
Mesh Size	220
Density	3.2

D. Material Requirement Calculation

The calculations of the material required for the casting of four sample compositions of metal matrix composites (MMCs) has been conducted.

As per the discussions with the testing agencies, four cylindrical rods of OD (Outer Diameter) = 2 cm and length 15 cm (total length 60 cm) for the tensile strength test and compressive test, hardness test.

Four square bar of cross-section 1 × 1 cm2 and length 10 cm (total length 40cm) for the impact strength tests and XRD test were prepared.

For the calculations, density of Aluminium is taken as 2.719 gm/cm3.

Approx. Weight of Al-6063, SiC (220 Mesh) and B4C (220 Mesh) is calculated as follow:

Weight of Aluminium cylindrical rod for tensile test = Volume of cylindrical Rod × Density

= 0.204 Kg

Weight of Aluminium square bar required for impact test = Volume of square bar × Density

= (1 × 1 × 20) × 2.719 = 0.054 Kg

Weight of Aluminium per sample = 0.204 + 0.054 = 0.258 Kg

To account for the losses in casting like solidification shrinkage, riser and top gating etc. allowance of 30% was taken.

So, net weight of aluminium after adding allowance = 1.30 × 0.258 = 0.335 Kg

But for 90% wt% , weight of aluminium required =0.90 x 0.335 =0.301 kg

Total weight of aluminium for all 4 samples = net weight of aluminium after adding allowance per sample × 4

= 0.301 × 4 = 1.206 Kg.

Total weight of SiC for all 4 samples = (0% +8% +6% +4%) of wt. of aluminium per sample

$$W_{SiC} = (0+0.08+0.06+0.04) \times 0.301$$

$$W_{SiC} = 54.2 \text{ gm}$$

Total weight of B4C for all 4 samples = (0% +2% +4% +6%) of wt. of aluminium per sample

$$W_{B4C} = (0+0.02+0.04+0.06) \times 0.0.301 \quad W_{B4C} = 36 \text{ gm (approx.)}$$

Total weight of Mg for all 4 samples = (1%) of wt. of aluminium per sample = 0.01 x 0.301 = 3 gm

E. Process Parameter of Stir Casting

TABLE IV

PROCESS PARAMETERS OF STIR CASTING[11]

S.NO.	Process parameter	Value
1	Stirring temperature	900^{o}C
2	Stirring Speed	200 rpm
3	Stirring time	10 min
4	Preheat temperature of reinforced particles	500^{o}C

F. Stir Casting Apparatus

1) Prepare the Crucible: A cylindrical graphite crucible is selected for its high thermal resistance and non-reactivity with Aluminium. Use a graphite crucible capable of withstanding >900˚C. Ensure crucible is clean and free of contaminants. Place crucible inside a ceramic-lined muffle furnace.

Fig. 2 Crucible

2) Heat the Furnace: Gradually increase furnace temperature to melt aluminium alloy efficiently. Set initial heater temperature to 500˚C. Raise temperature slowly up to 900˚C. Maintain high heat to reduce oxidation and improve particle bonding.

Fig.3 Furnace

3) Prepare Aluminium Alloy: Cut and clean Aluminium alloy pieces before melting. Cut alloy into rectangular pieces of required weight. Clean thoroughly to remove dust and impurities. Weigh accurately before loading.

Fig.4 Weighting Al-6063

4) Melt the Matrix Material : Load Aluminium alloy into the crucible for melting. Place cleaned alloy pieces into crucible. Allow alloy to melt completely at target temperature.

Fig.5 Weighting Al-6063

5) Add Reinforcement Powders: Introduce SiC and B4C powders into the molten Aluminium. Measure required quantities of SiC and B4C according to the Table V. Add powders gradually to molten Aluminium. Stir thoroughly to ensure uniform dispersion. For good wettability 1% of Mg to increase wettability of reinforced particles.[12]

Fig.6 Weighting B4C

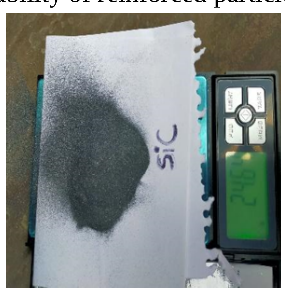

Fig.7 Weighting Sic

Fig.8 Weighting Mg

TABLE V
WEIGHT RATIOS OF FOUR DIFFERENT SAMPLES

Sample No.	Matrix AA6063 (wt%)	Reinforcement materials (wt%)	
		B_4C	SiC
S1	100%	-	-
S2	90%	2%	8%
S3	90%	4%	6%
S4	90%	6%	4%

6) Pouring the liquid metal into the Mould : The liquid metal is poured into the mould box. After the AMMC get solidified then it was removed from the mould box. The casted AMMC were machined to get required test specimen.[11]

Fig.9 Pouring the liquid metal into mould

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G. Standard Test Specimen Dimension

For tensile strength testing Dumble shape specimens were machined. ASTM E8/E8M:22 standard codes were used for testing specimens. The dimensional plot of tensile test specimens is shown in Fig.10 . The dimensional plot of Compressive test specimens is shown in Fig.11. For hardness testing cylindrical disc shaped specimens were machined. Hardness is measured on Micro Vickers Scale. The dimensional plot of hardness test specimens are shown in Fig.12 . For impact strength testing, square bar shape specimens were machined. IS 1757 (Part 1): 2020 standard code was used for testing specimens. The dimensional plot of impact test specimens are shown in Fig.13.

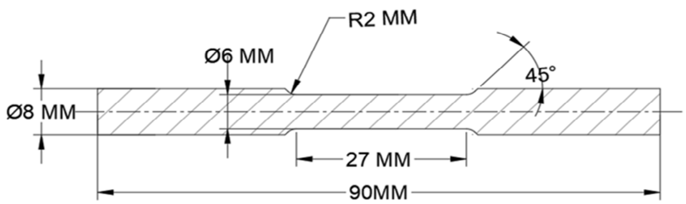
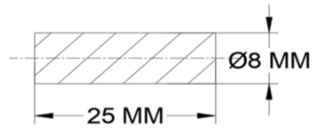


Fig.10 Tensile test specimen dimension.



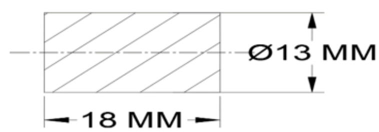


Fig.11 Compressive test specimen dimension. Fig.12 Hardness test specimen dimension.

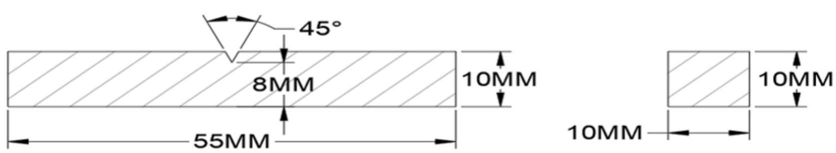


Fig.13 Impact test specimen dimension.

IV. RESULTS AND DISCUSSION

Several tests were conducted to forecast the samples' mechanical characteristics Here we discuss the findings that came from analysing several specimens that made up the sample. Using an INSTRON-made computerised 20 KN Universal Testing Machine, we subjected aluminium specimens as shown in Fig.14 and 15 to tensile tests in order to investigate the impact of SiC and B_4C on the composite material. Circular specimens machined to a 6 mm gauge diameter and 90 mm length were used for tensile testing in accordance with ASTM E-8 standards. A computer records the data from tensile tests that were performed under ambient circumstances with a strain rate of 0.001/sec.

To measure the impact strength of composites, Charpy impact tests were carried out using an ASI-made AMT-8 model standard impact pendulum testing machine with a 184 J capability. In accordance with ASTM requirements, the impact specimens were ground to have a 10×10 mm^2 cross section.

The Vickers hardness tests were carried out using a 200 kgf force and a 5mm ball diameter in a hardness tester. In order to get an accurate hardness measurement, the surfaces of the test specimens were polished using emery paper.[13]

1) Effect on the Tensile Strength of Composites

Tensile strength is the ability of material to withstand a maximum amount of tensile stress without failure.[14] The stress occurs when the material is being pulled or stretched. It is the point when a material goes from elastic to plastic deformation. The tensile test provided the tensile strength for different sample compositions specimens. Value of the tensile strength in N/mm^2 for the two specimens was used for the analysis as shown in Table VI

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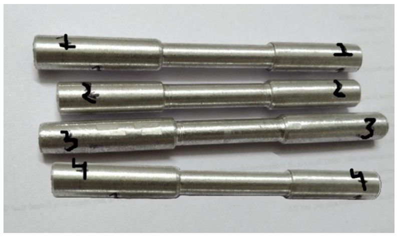

Fig.14 Tensile test machined specimen

Fig.15 Samples after Tensile test

TABLE VI
TENSILE STRENGTH OF DIFFERENT SAMPLES

S.NO.	SAMPLE	COMPOSITE (VOL%)	$\sigma_T$max(MPA)	ELONGATION (MM)
1	S-1	AA6063 (100%) +SiC (0%) +B_4C (0%)	127.79	0.08
2	S-2	AA6063 (90%) +SiC (8%) +B_4C (2%)	130.23	0.05
3	S-3	AA6063 (90%) +SiC (6%) +B_4C (4%)	188.65	0.02
4	S-4	AA6063 (90%) +SiC (4%) +B_4C (6%)	171.72	0.11

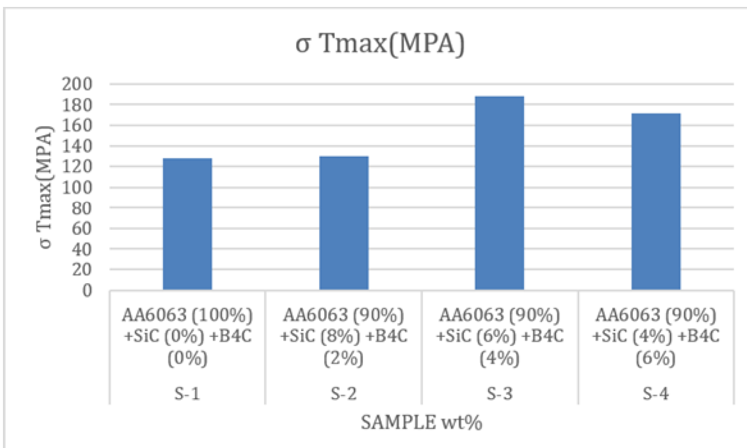

Fig.16 Plot for value of tensile strength for different samples

2) Effect on the Compressive Strength of Composites

A compressive test is a mechanical test used to determine how a material behaves under a compressive load — essentially, how much force it can withstand before deforming or failing.

TABLE VII
COMPRESSIVE STRENGTH OF DIFFERENT SAMPLES

S.NO.	SAMPLE	COMPOSITE (VOL%)	σ C(MPA)	ELONGATION (%)
1	S-1	AA6063 (100%) +SiC (0%) +B_4C (0%)	172.4	14.39%
2	S-2	AA6063 (90%) +SiC (8%) +B_4C (2%)	181.5	6.73%
3	S-3	AA6063 (90%) +SiC (6%) +B_4C (4%)	198.95	9.15%
4	S-4	AA6063 (90%) +SiC (4%) +B_4C (6%)	191.7	7.05%

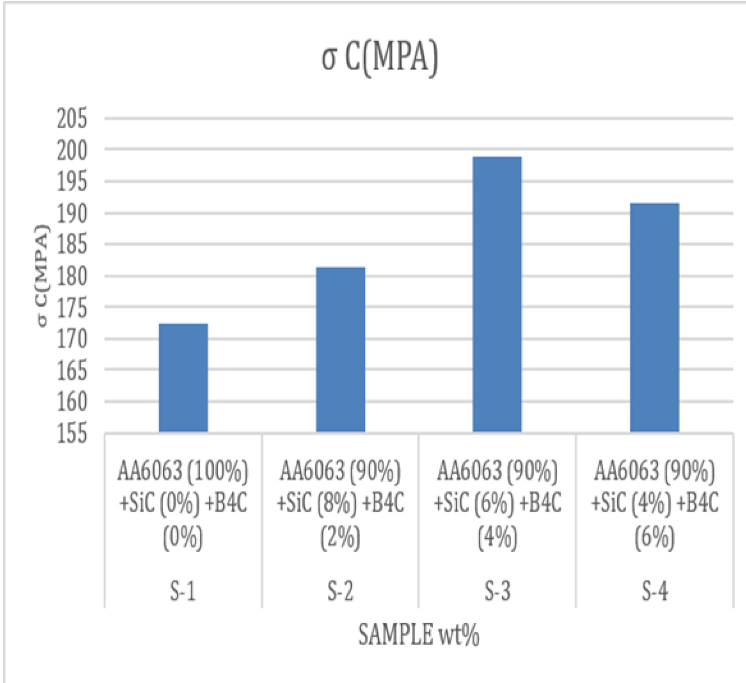

Fig.17 Plot for compressive for different samples

3) *Effect on the Hardness of Composites*

Testing the micro hardness of several samples on the HV scale yielded the results shown in Table VIII. Fig.18 shows the range of average hardness (HV) values for various samples. The data showed that the hardness increased from sample 1 to sample 3, peaked at 62.1 HV in sample 3, and subsequently decreased to sample 4. Fig. 17 displays various specimens that were subjected to the hardness test. `

Fig.18 Machined specimen for hardness test

TABLE VIII
HARDNESS OF DIFFERENT SAMPLES

S.NO.	SAMPLE	COMPOSITE (VOL%)	HARDNESS (HV)
1	S-1	AA6063 (100%) +SiC (0%) +B_4C (0%)	53.4
2	S-2	AA6063 (90%) +SiC (8%) +B_4C (2%)	58.3
3	S-3	AA6063 (90%) +SiC (6%) +B_4C (4%)	62.1
4	S-4	AA6063 (90%) +SiC (4%) +B_4C (6%)	57.3

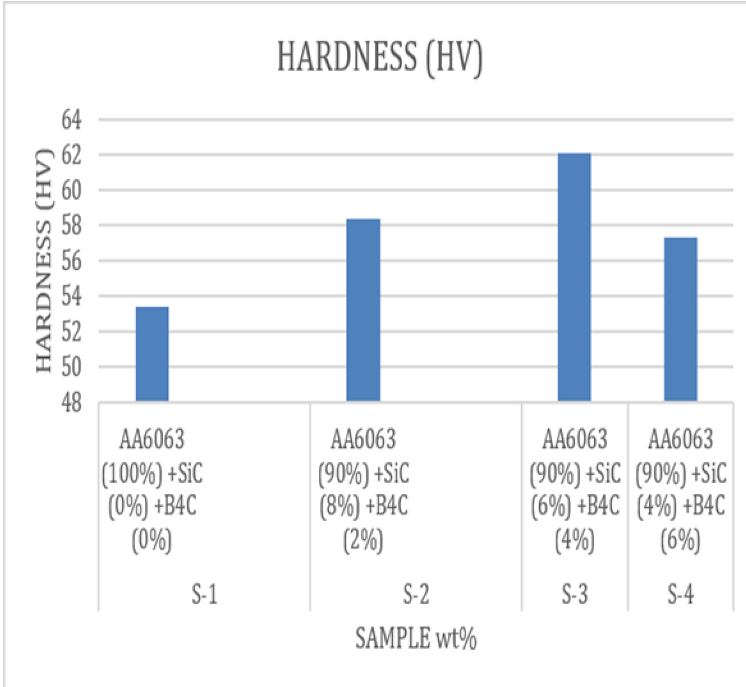

Fig.19 Plot for value of Micro Vickers hardness for different samples

4) Effect on the Impact Strength of Composites

The specimen support is used to clamp the test specimen in such a way that the pendulum's striking edge meets the specimen at its notched end. Fig.20 shows a test specimen that is correctly positioned.

Fig.20 Positioned test specimen.

Fig.21 Samples after performing Charpy Impact test

TABLE IX

IMPACT STRENGTH OF DIFFERENT SAMPLES

S.NO.	SAMPLE	COMPOSITE (VOL%)	IMPACT ENERGY (J)
1	S-1	AA6063 (100%) +SiC (0%) +B_4C (0%)	31
2	S-2	AA6063 (90%) +SiC (8%) +B_4C (2%)	33
3	S-3	AA6063 (90%) +SiC (6%) +B_4C (4%)	38
4	S-4	AA6063 (90%) +SiC (4%) +B_4C (6%)	36

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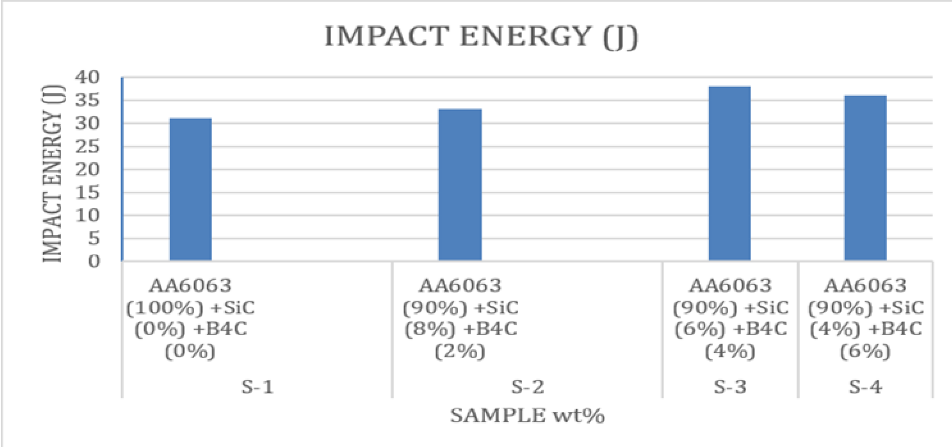

Fig.22 Plot for value of Izod Impact energy for different samples

5) XRD Result

In order to assess the distribution of particles and phases in the composites, X-ray diffraction (XRD) experiments were performed on the samples.Fig.21 and 22 show that the composites include SiC and B_4C in a rather consistent distribution.

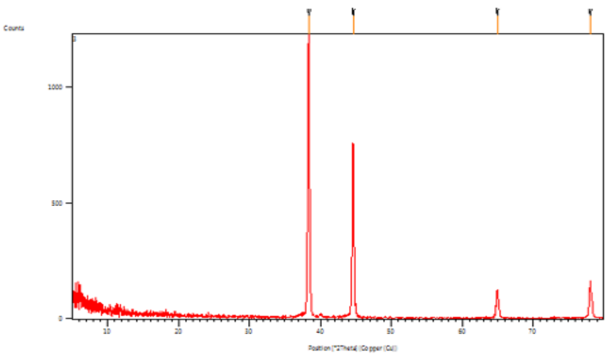

Fig.23 Graph of XRD for sample 2

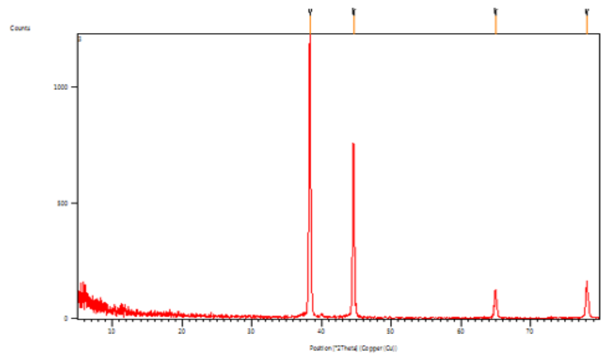

Fig.24 Graph of XRD for sample 3

V. CONCLUSIONS

Following conclusions are derived from the results: -

1) Aluminium metal matrix composite successfully produced by liquid stir casting technique by adding SiC (0%, 8%, 6%, and 4% wt) and B4C (0%, 2%, 4%, and 6% wt).
2) From the tensile test it was concluded that tensile strength is maximum at reinforcement of SiC (6%) & B_4C (4%) added with the maximum tensile strength of 188.65 N/mm2 for sample-3.
3) The results from Table 5.1 shows that percentage elongation nearly increases with increase in percentage of reinforcement of B_4C added and hence ductility also increases in the same manner.
4) Impact energy absorbed by the samples initially showed the increasing trend from sample-1 to sample-3 and then decreased for sample-3. Therefore, sample-3 and sample-1 have the maximum and minimum toughness respectively.
5) Hardness increases with the addition of reinforcement particles. Thus sample-3 was the hardest one having a hardness of 62.1 HV.
6) Results of the XRD test for the investigation of elements present in the different samples was satisfactory. The presence of reinforcements is found in the samples.

VI. ACKNOWLEDGMENT

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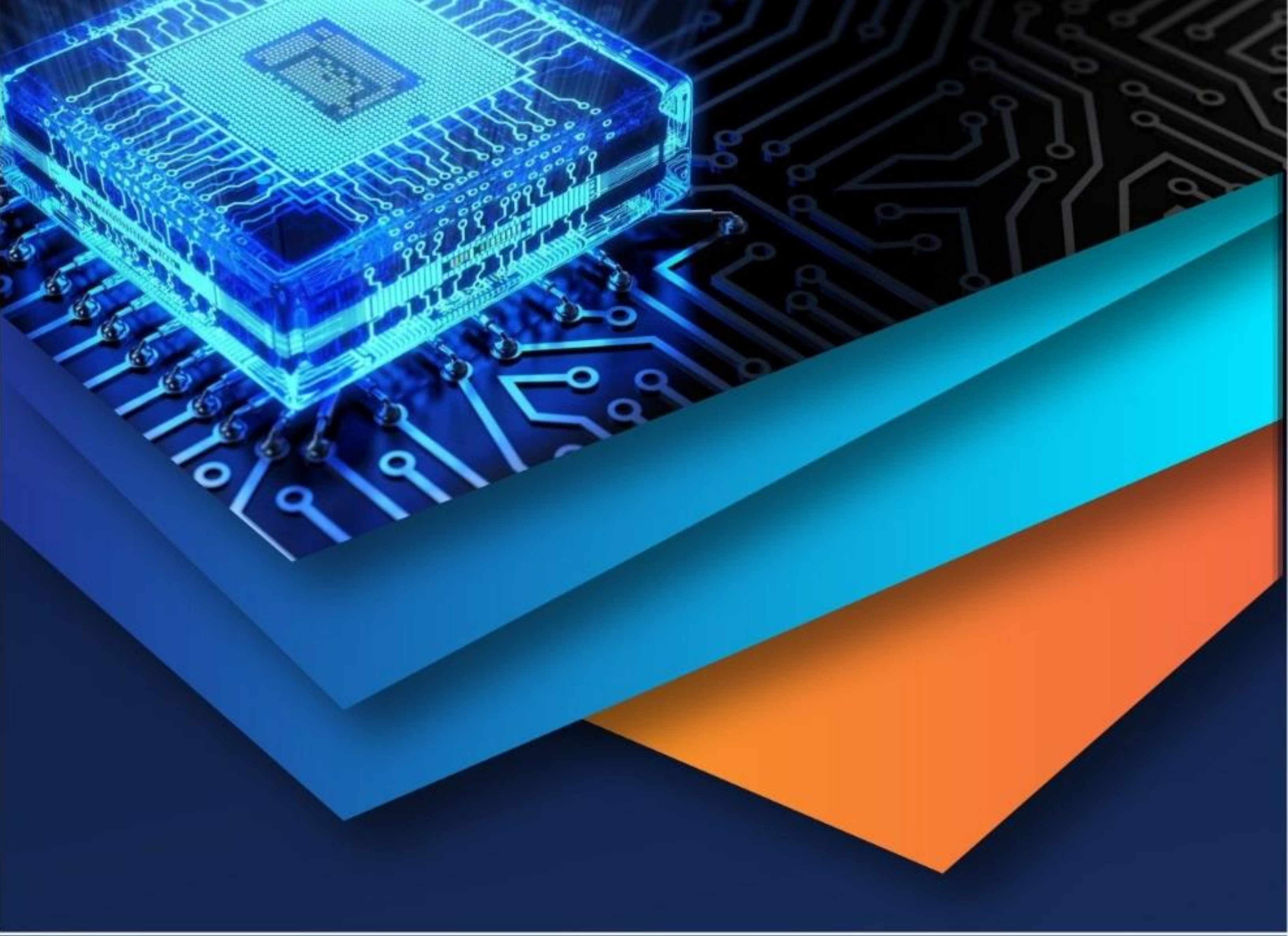

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