Experimental Investigation on Mechanicalproperties of AL7075 reinforced with HBN and SiC

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Abstract. The pursuit of lightweight maetrials, materials with high-strength has led to significant advancements in the field of aluminum matrix composites (AMCs). Among these, aluminum alloy 7075 is notable for its exceptional mechanical properties, making it a popular choice in structural, automotive and aerospace, applications. However, in the direction of further enhancing its performance, the incorporation of ceramic reinforcements has become a focal point of research. Hexagonal boron nitride (hBN) and silicon carbide (SiC) are two such reinforcements that offer advantages such as improved wear resistance, thermal stability, and increased strength. Stir casting technique is a widely used fabrication technique for producing AMCs due to its simplicity, cost-effectiveness, and ability to achieve uniform scattering of reinforcements within the metal matrix. In this process, the metal is melted, and the reinforcing materials are added while stirring, promoting a homogeneous mixture. This method not only facilitates the integration of ceramic particles but also helps in minimizing issues like agglomeration, which can detract from the mechanical properties of the fabricated composite.

The objective of this study aims to explore the fabrication of Al7075 composites reinforced by the varying weight percentages of hBN and SiC using the stir casting process. The resulting composites undergone with various analysis including hardness testing, impact testing, scanning electron microscopy (SEM) and tensile testing. In comparison towards the base aluminum alloy, findings showed that the incorporation of hBN and SiC greatly enhanced the mechanical properties, such as tensile strength, impact strength, and hardness. Optimal reinforcement composition was identified, balancing the trade-off between strength enhancement and ductility. The micro structural analysis revealed a homogeneous distribution of these reinforcements, contributing to the composites overall performance. This study

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underscores potential of using hBN and SiC as reinforcements in aluminum alloys to develop advanced materials suitable for aerospace, automotive, and other high-performance applications. Further research is suggested to optimize processing parameters and explore additional reinforcement combinations for enhanced performance.

Keywords: AL7075, HBN, SiC, Stir Casting Process.

1. Introduction

The requirement for innovative engineering material advancements for a range of engineering applications is growing these days. Metal matrix composite is a dependable supply to satisfy such demands. One of the dependable options for meeting this need is composite material. A material with two or more different phases, both chemically and physically, is called a composite. In general, the composite exhibits better qualities than each of its constituent parts. The continuous or matrix component typically contains the reinforcing component. Materials are mixed together in composites to maximize the benefits of their parent materials while reducing the consequences of their shortcomings to some degree. Combining two or more materials to increase their qualities is indicated by the simple phrase "composites." The evolution of materials has changed in recent years from the monolithic age to composite materials in response to the global demand for structural materials with low weight, high performance, low cost, and good quality. In order to achieve specific qualities, the metal matrix composites (MMCs) are constructed with combinations of base metal (Matrix) and hard particles or ceramic (Reinforcement). Bicycles, cars, golf clubs, and many more devices are examples of MMCs. Aluminum-matrix composites belongs to a family of four materials, with adjustable density, strength, stiffness, good electrical properties and thermal properties, just like all other composites. To obtain the desired qualities, one can alter the reinforcement material, matrix alloy, shape of the reinforcement, volume of the reinforcement, the reinforcement's position, and the fabrication process. The objective of creating metal matrix composite materials is to combine the beneficial properties of metals and ceramics.A material having the mechanical properties halfway between the base matrix alloy and the ceramic reinforcements is created when high modulus refractory and high strength particles are added to ductile metal matrix. Metals can be beneficial because of their great strength, ductility, and tolerance to high temperatures, but they can also be less stiff than ceramics. While ceramics are strong and stiff yet brittle, metals comprise of desirable grouping of qualities including ductility, high temperature resistance and high strength. Yet they can also comprise poor stiffness. One of the components of aluminum metal composites (AMC) is aluminum, which is referred to as the matrix phase and forms a percolating network. The other component acts as reinforcement and is implanted in this aluminum. Reinforcements such as AL2O3, HBN, SiC, TiC, B4C, ZrO2, and others are frequently utilized.

Recent industries have recognized the value of aluminum-zinc alloys like AA7075 in several applications. Consequently, it can be utilized in all-terrain vehicles (ATVs) and bike frames. Worm gears, meter shafts, aircraft sprockets, gears and shafts, missiles, and keys for military, aerospace, and aviation uses. Scientists have tried to enhance the performance of such an alloy by adding one or more special reinforcing particles to metals, which greatly improves the manufactured metal matrix composite, because of the limitations of some of its features [1,2]. In recent years, aluminum matrix composites (AMMCs) have garnered a lot of interest in engineering applications due to their lightweight nature and distinctive mechanical properties[3, 5].

2. Literature Work

The study "Influence of Graphite on Mechanical Properties of Al6061-hBN-Gr Hybrid MMC's" was conducted by Nagesh D. and Manjunath S.H. (2016) [1]. The creation and mechanical analysis of hybrid metal matrix composites made of graphite (Gr), aluminum 6061, and hexaboron nitride (HBN) are the subjects of this work. In order to determine the composition (6% BN and 2% Gr), They added 2%, 4%, and 6% graphite to three composite samples of Al6061/6% hBN. It was found that the micrographs had less porosity because of the good particle bonding and uniform distribution of the particles. Because of the higher percentage of particles added, the composition (6% BN and 6% Gr) reinforcement has higher grain boundaries and porosity, which results in more flaws in the composite. Up to 6% more boron nitride has improved the composite's mechanical and wear characteristics. Overall test results indicate increased characteristics with 4% graphite.

Sridhar Atla et al. (2019) [2] demonstrated smart mechanical properties of a metal matrix composites when reinforced with Silicon Carbide (SiC) ceramic material. However, advancements are needed in the tribological and friction properties of metal-based composites. In this work-study, graphite, a solid lubricant, is added in an attempt to build a whole new material using the metallurgical process. This study looked into how graphite affected the hybrid metal matrix composite Al 7075/5 weight percent Si_3N_4 / X weight percent graphite (X=10, 5, and 0) in terms of its tribological behavior. By adding graphite to the composite, the study validates the wear characteristics' performance. The aluminum alloy 7075 reinforced with Si_3N_4 and graphite was examined. Optical microscopy, scanning electron microscopy, pin-on-disc equipment and XRD are used to examine the material combination, wear and wear resistance characteristics. According to these experiments, adding an additional 10% Gr to the hybrid composite does not improve its wear characteristics. The experimental investigations then confirm that a minimal loss of wear of 0.01062 grams and a coefficient of friction of 0.1278 are produced with a sliding distance of 1,000 meters, an applied load of 5 N, and a sliding velocity of 1.5 meters per second.

Prasad Reddy, A., et al. (2019) [3] investigated the tribological characteristics of AA6061 alloy reinforced with 2% Si_3N_4 and X weight percent Gr (x=0, 0.5, 1, 1.5, 2, and 3) nanoparticles. The procedure of creating AlMMCs reinforced with alumina (Al_2O_3) and evaluating their mechanical and tribological characteristics using the powder metallurgy method are described in this research. despite the fact that Al 22 has superior strength, hardness, wear resistance, and corrosion prevention at high temperatures. To increase its use and application, it is imperative that the qualities be further improved. Al2O3 particles were added to an AMMC in varying weight percentages of (10%, 15%, 20%, and 25%) to create sintered compacts they used. Then, in order to evaluate the efficacy of the chosen fabrication procedure, the tribological and mechanical properties of the fabricated compacts was thoroughly examined. This technique works well for altering the materials' characteristics in various directions as needed. AMMCs are effectively produced with varying weight fractions of alumina (Al2O3). Composites have demonstrated effective compression strength, and the matrix's composition is being investigated. The amount of Al2O3 in the material continues to increase its hardness. In the composite materials, density and hardness both decrease as GR increases. Additionally, they investigated the wear coefficient of friction using the Gr content.

Aluminum 6061 was made and described by Jims John Wessley, G., et al. (2019) [4] using reinforcements like fly ash and alumina oxide in varying volume fractions of 5%, 10%, 15%, 9%, and 11%. Stir casting is employed to create these composites, while SEM and EDAX are used for microstructural investigation. The mechanical and microstructural behavior of six manufactured examples was examined, and conclusions were drawn. Then, in comparison to the original material, the fabricated composite containing Al 6061, Fly Ash 3%, Al2O3-6%, and Magnesium 1% by the volume fraction have demonstrated an improvement in mechanical properties (tensile strength, wear resistance, and hardness). Stir casting and analysis are performed on a metal matrix composite that contains AA6061 as the matrix material, alumina and fly ash for reinforcing, and trace amounts of magnesium for wetting. Following that, mechanical characteristics and micro-level examination are carried out, yielding the following outcomes. Using alumina and fly ash with a composition of 90% AA 6061, 3% FA, 6% Al2O3, and 1% Mg, they found that specimen 3's tensile strength increased by 3%. SEM and EDAX micro level analyses demonstrate a strong connection between the base metal and reinforcement. Mechanical qualities like tensile strength and hardness could be enhanced by strengthening this with fly ash and alumina oxide reinforcement.

Rink, Yadav, and colleagues (2018) [5] Sheet metal, construction, automotive, aerospace, and the military are just a few of the companies that depend heavily on aluminum metal matrix composites, or MMCs. The properties of aluminum composites, which include their exceptional wear resistance, high strength to weight ratio and affordability are driving up demand for them. There are numerous methods of manufacture viable to produce such composites. One popular technique for making aluminum composites in liquid phase processes is stir casting. The present investigation investigates the effect of these reinforcements on the mechanical and tribological characteristics of aluminum alloys. Numerous reinforcements, including Si3N4, Al2O3, TiC, MoS2, and others, are used to create composites[32]. A composite material can be made from a single reinforcement or by combining more than one reinforcements. Furthermore, surface properties of AlMMCs can be enhanced by the application of alumina coatings, calcia-stabilized zirconia coatings, plasma electrolyte oxidation layers, and additional materials. These coatings are commonly used when a continuous rubbing motion between two surfaces is desired. In this study, we investigated how various reinforced AlMMCs affected the wear and mechanical properties of aluminum composites. It is clear from the literature review above that the kind of reinforcement greatly affects the properties of the composites, which also vary according to the reinforcement's composition. Incorporating graphite particles increases the fabricated composites' tribological efficiency while decreasing their hardness.

Mohammed Imran and colleagues (2017) [6] concentrated on creating aluminum alloy (7075) using reinforcements, such as bagasse ash, Si3N4, Al2O3, Gr, and TiO2. Reviewing the literature on the creation of AlMMC materials through the combination of alloys and reinforcements is the goal. The stir casting incorporates these particulate reinforcements. The mechanical qualities have significantly improved, according to the data. AlMMCs are made via liquid and powder metallurgical processes. This review discusses the stir casting method, often known as the vortex method, for liquid metallurgy. AMMCs were successfully manufactured using this casting method, which had the intended impact of various ceramic reinforcing particles on aluminum alloys' tribological and mechanical characteristics.. The mechanical behavior was enhanced by them. By adding different weight percentages, they were able to see enhanced mechanical behavior. When alumina, barium chloride and silicon carbide were added to aluminum-based matrixes, the composites' tensile strength, hardness, yield strength, and compressive strength all rose while their ductility dropped. Additionally, adding graphite increases the material's tensile strength, ductility, and elastic modulus while decreasing its hardness. Greater wear and corrosion resistance, and a lower coefficient of thermal expansion than base alloys.

The study report by Darshan et al. (2018) [7] examines the microstructure, mechanical, and tribological characteristics of four distinct weight percentages of aluminum alloy (7000 series) with graphene nanopowder composites. Liquid stir casting process is used to fabricate AlMMCs with nanographene. EDS and morphology “scanning electron microscopy (SEM)” were used to study the composites' microstructure. Additionally, the mechanical behavior of composite materials was examined. According to ASTM guidelines, tensile characteristics such as wear, ultimate tensile strength, hardness and yield strength were assessed. Though the study reveals that the ultimate tensile strength, hardness and yield strength of composites rise as grapheme percentage increases. Results of wear test indicate that their rate of wear decreases as graphene % increases. Reinforced graphene made of aluminum alloy was successfully manufactured using the liquid metallurgical approach. According to the microstructure examinations, the reinforcement (graphene) is distributed uniformly, while some specimens have porosity and voids due to incorrect casting. As the weight percentage of graphene grows, so do the composites' yield strength, wear resistance, and ultimate tensile strength. An increase in the amount of graphene in the composites results in an improvement in the hardness of the AlMMCs.

3. Materials & Methodology

SiC and hBN particles were selected as the reinforcement in this work, whereas Al7075 alloy was selected as the matrix. SiC was selected to provide the composite additional hardness, and hBN was selected to enhance the lubricating qualities of the composites. The utilized Al7075 alloy's chemical makeup is displayed in Table 1.

Table 1. Chemical composition of Al7075.

S.No	Element	Percentage
1.	Manganese	0.3
2.	Silicon	0.4
3.	Magnesium	2.5
4.	Copper	1.6
5.	Iron	0.5
6.	Zinc	5.5
7.	Titanium	0.2
8.	Chromium	0.15
9.	Others Elements	0.05 each 0.15 in total
10.	Aluminium	Remaining

The mechanical properties of AL-7075 alloy are shown in table .2

Table 2. Mechanical properties of AL-7075 Alloys

S. No	Properties	Metric	Imperial
1	Shear strength	150.00 MPa	21756 psi
2	Tensile strength	220.00 MPa	31909 psi
3	Yield strength	95.00 MPa	13779 psi
4	Elastic modulus	70-80.00 GPa	0.33
5	Fatigue strength	160.00MPa	10153-11603 psi
6	Hardness	60.00	60
7	Poisson's ratio	17%	17%

Carborundum, also referred to as silicon carbide (SiC), a durable compound consisting of carbon and silicon atoms. While it occurs naturally as the rare mineral moissanite, this semiconducting material has been synthetically manufactured as both powder and crystal for use as an abrasive since 1893. The molecular structure of silicon carbide features tetrahedra of carbon and silicon atoms, forming robust bond within the crystal lattice. This arrangement results in an exceptionally tough and resilient substance. Notably, silicon carbide remains impervious to acids, alkalis, and molten salts at temperatures up to 800°C. The process of sintering silicon carbide particles produces extremely rigid ceramics, which are commonly employed in the applications requiring elevated durability. These include automotive brakes, clutches, and the ceramic components of bulletproof vests.

Table 3. Properties of Silicon Carbide

S. No	Properties	Metric
1	Molecular Weight	40.11g/mol
2	Solubility in H2O	insoluble
3	Appearance	Powder form
4	Density	3.21g/cm3
5	Boiling Point	N/A
6	Exact Mass	39.976927
7	Melting Point	2830°C, 3100K, 5130°F

Hexagonal boron nitride (hBN) is a unique ceramic material that exhibits remarkable properties, making it a subject of interest across various fields, including materials science, electronics, and lubricants. Structurally analogous to graphite, hBN consists of boron and nitrogen atoms arranged in a hexagonal lattice. One of the most significant advantages of hBN is its chemical inertness. It is resistant to oxidation and corrosion, which broadens its applicability in harsh environments. In the context of aluminum matrix composites, hBN serves as a reinforcement that not only enhances mechanical properties such as strength and hardness but also improves thermal stability and wear resistance. White graphite is another name for hexagonal boron nitride (HBN), shares a similar structure as of graphite. The properties of Hexagonal Boron nitride is represented in table 4.

Table 4. Properties of Hexagonal Boron Nitride

S. No	Properties	Metric
1	Molecular weight	24.82 g/mol
2	Appearance	Colourless Crystals
3	Density	2.1 g/cm^3
4	Melting Point	2973°C, 3246K,5383°C.
5	Solubility in molten liquids	Insoluble
6	Refractive Index(nD)	2.1308
7	Molecular weight	24.82 g/mol

Stir casting technique is used for fabricating AMCs. The composite specimens are prepared by varying the weight percentage of base metal (Al7075) and adding the reinforcements. The prepared specimens are shown in table 5.

Table 5. Prepared specimens by varying weight percentage of basemetal and reinforcements.

Specimen No	Al7075 (Wt%)	HBN (Wt%)	SIC (Wt%)
A1	96	2	2
A2	92	4	4
A3	88	6	6
A4	84	8	8
A5	80	10	10

Using a stir casting machine, the necessary quantities of Aluminium 7075 alloy were calculated by weight percentages and melted in an Inconel crucible, as shown in Fig. 1. The alloy reached complete liquefaction at 800°C. A hexachloroethane tablet was introduced to eliminate the slag that formed on the molten metal's surface. After the alloy had fully melted, preheated ceramic particles, including silicon carbide (SiC) and hexagonal boron nitride, were incorporated into the molten Al7075 alloy in the Inconel crucible in specific amounts based on weight percentages. Prior to addition, the reinforcements were heated to 250°C in a muffle furnace, as illustrated in Fig. 2. The mixture underwent mechanical stirring at 300 rpm for 12 minutes. Subsequently, molten composite is transferred in to a cast iron mold that had been preheated to 400°C. The resulting composite specimens were fabricated as round bars measuring 25 mm in diameter and 150 mm in length, as shown in Fig. 3.

Fig. 1. Stir Casting machine

Fig. 2. Furnace

Fig.3. Casted Specimens

Tests using the Universal testing machine, Charpy impact testing machine, scanning electron microscopy and Rockwell hardness testing machine are used to examine the mechanical characteristics and microstructure behavior.

4. EXPERIMENTAL RESULTS

Using a scanning electron microscope (SEM) at different magnifications, the microstructures of the composites were investigated. The dispersion of SiC and h-BN inside the aluminum matrix, as well as the properties of the interface between the reinforcements and the matrix, were the main subjects of this investigation. Fig. 4 to 8 shown below represents the microstructure of the specimens with 2%, 4%, 6%, 8% and 10% of each reinforcements respectively.

Fig. 4. Morphology of A1

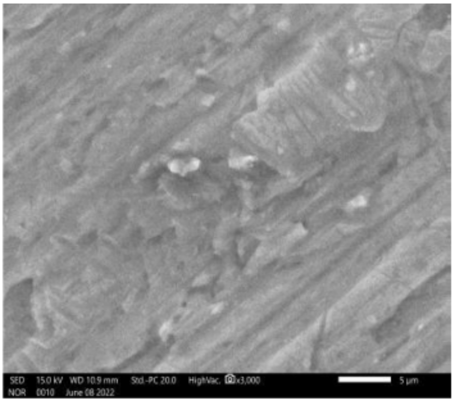


Fig.5. Morphology of A2

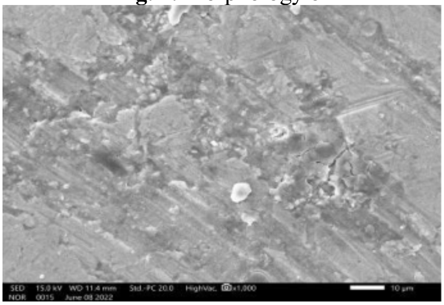


Fig. 6. Morphology of A3

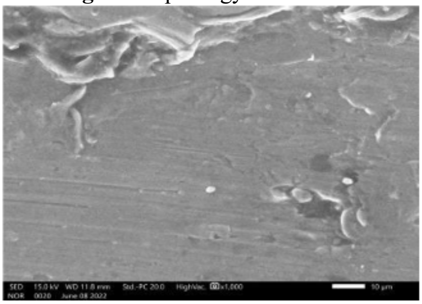


Fig. 7. Morphology of A4

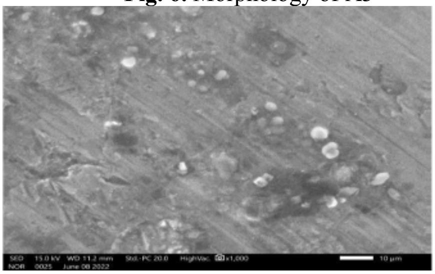
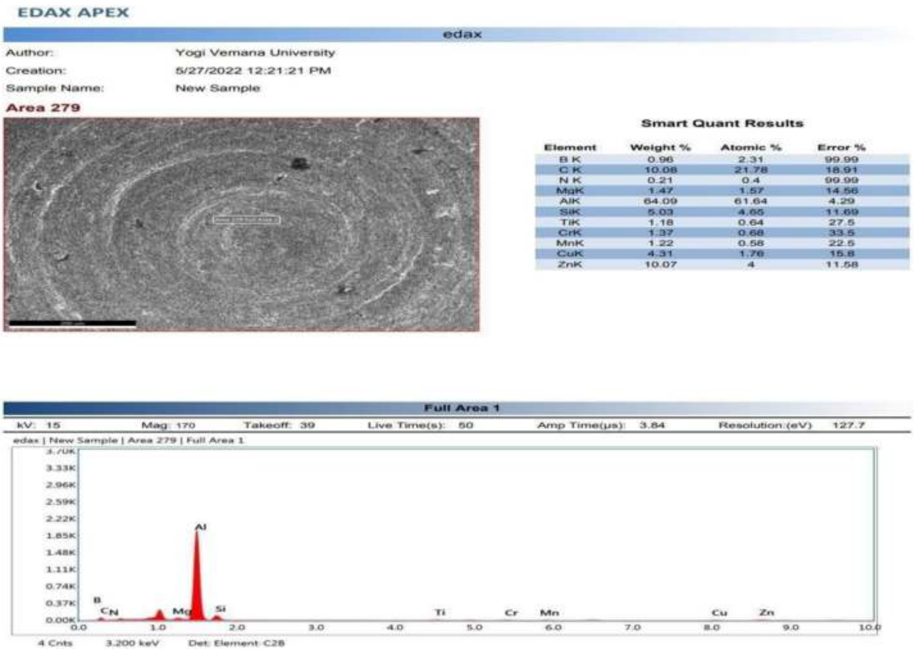


Fig. 8. Morphology of A5

The morphology images reveal a uniform dispursion of h-BN and SiC particles throughout the AL7075 matrix. h-BN particles appear as elongated platelets. SiC particles, which are more angular, are dispersed throughout the matrix and appear to form a network structure. These reinforcements contribute potentially improving the composite's mechanical properties.

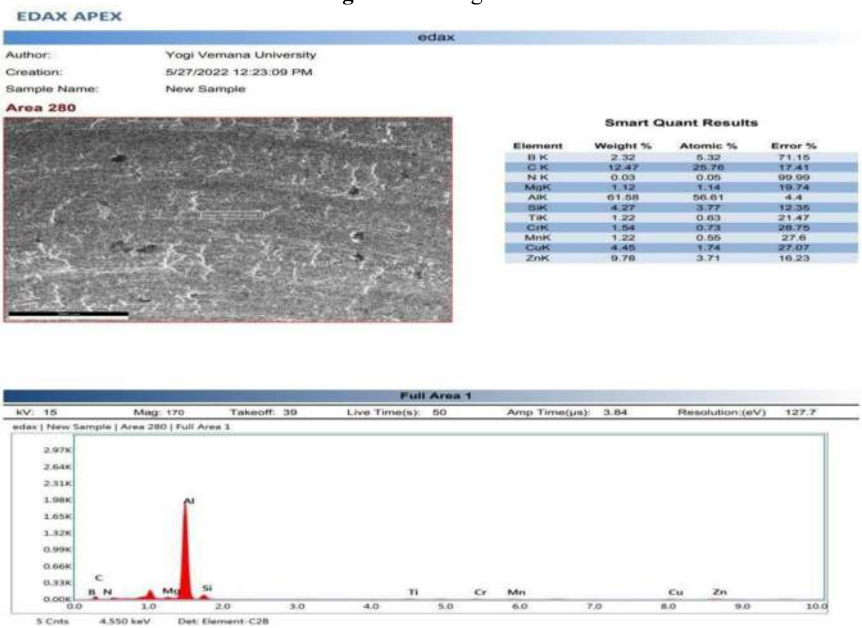
The EDS spectra confirm the presence of aluminum (Al), zinc (Zn), and copper (Cu) from the AL7075 matrix, along with distinct peaks for boron (B), nitrogen (N), and silicon (Si) from the h-BN and SiC reinforcements. The EDS images of the composites are shown in Fig. 9 to 13 with 2%, 4%, 6%, 8% and 10% of each reinforcements respectively.



Smart Quant Results

Element	Weight %	Atomic %	Error %
B K	0.96	2.31	99.99
C K	10.08	21.78	18.91
N K	0.21	0.4	99.99
MgK	1.47	1.57	14.56
AlK	64.09	61.64	4.29
SiK	5.03	4.65	11.69
TiK	1.18	0.64	27.5
CrK	1.37	0.68	33.5
MnK	1.22	0.58	22.5
CuK	4.31	1.76	15.8
ZnK	10.07	4	11.58

Fig. 9 EDS image of A1



Smart Quant Results

Element	Weight %	Atomic %	Error %
B K	2.32	5.32	71.15
C K	12.47	25.76	17.41
N K	0.03	0.05	99.99
MgK	1.12	1.14	19.74
AlK	61.58	56.61	4.4
SiK	4.27	3.77	12.35
TiK	1.22	0.63	21.47
CrK	1.54	0.73	28.75
MnK	1.22	0.55	27.6
CuK	4.45	1.74	27.07
ZnK	9.78	3.71	16.23

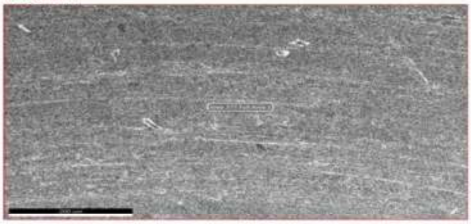
Fig. 10. EDS image of A2

EDAX APEX

edax

Author: Yogi Vemana University
Creation: 5/27/2022 12:17:03 PM
Sample Name: New Sample

Area 277



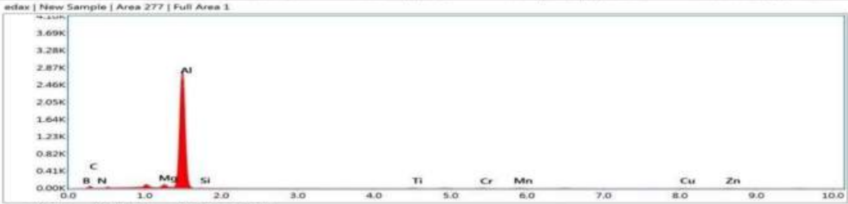
Smart Quant Results

Element	Weight %	Atomic %	Error %
B K	0.17	0.41	99.99
C K	8.55	18.27	19.79
N K	0.02	0.04	99.99
MgK	2.14	2.26	9.67
AlK	77.8	73.99	3.41
SiK	0.29	0.26	71.97
TiK	1.04	0.56	20.46
CrK	1.51	0.74	23.23
MnK	1.49	0.7	19.95
CuK	2.44	0.99	29.33
ZnK	4.55	1.78	16.56

Full Area 1

kV: 15 Mag: 170 Takeoff: 39 Live Time(s): 50 Amp Time(µs): 3.84 Resolution:(eV) 127.7

edax | New Sample | Area 277 | Full Area 1



30 Cnts 0.770 keV Det: Element-C2B

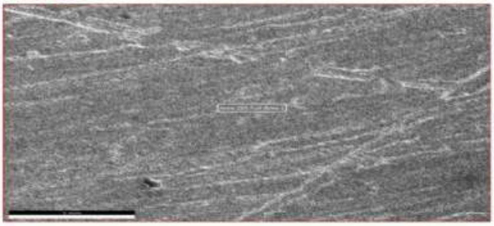
Fig..11 EDS image of A3

EDAX APEX

edax

Author: Yogi Vemana University
Creation: 5/27/2022 4:45:02 PM
Sample Name: New Sample

Area 285



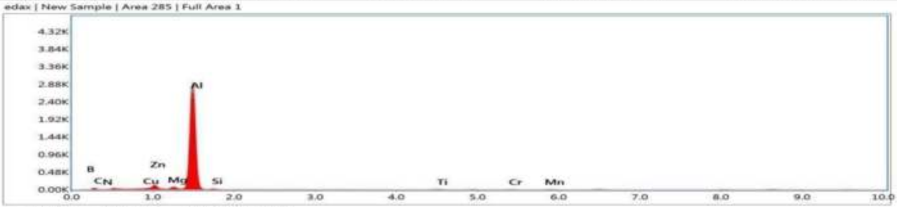
Smart Quant Results

Element	Weight %	Atomic %	Error %
B K	0.69	1.72	99.99
C K	3.83	8.65	20.3
N K	0.02	0.04	99.99
CuL	0.53	0.23	42.48
ZnL	3.76	1.56	12.56
MgK	1.61	1.8	12.15
AlK	80.25	80.8	3.45
SiK	0.77	0.75	26.16
TiK	2.1	1.19	27.63
CrK	2.64	1.38	42.26
MnK	3.8	1.88	26.57

Full Area 1

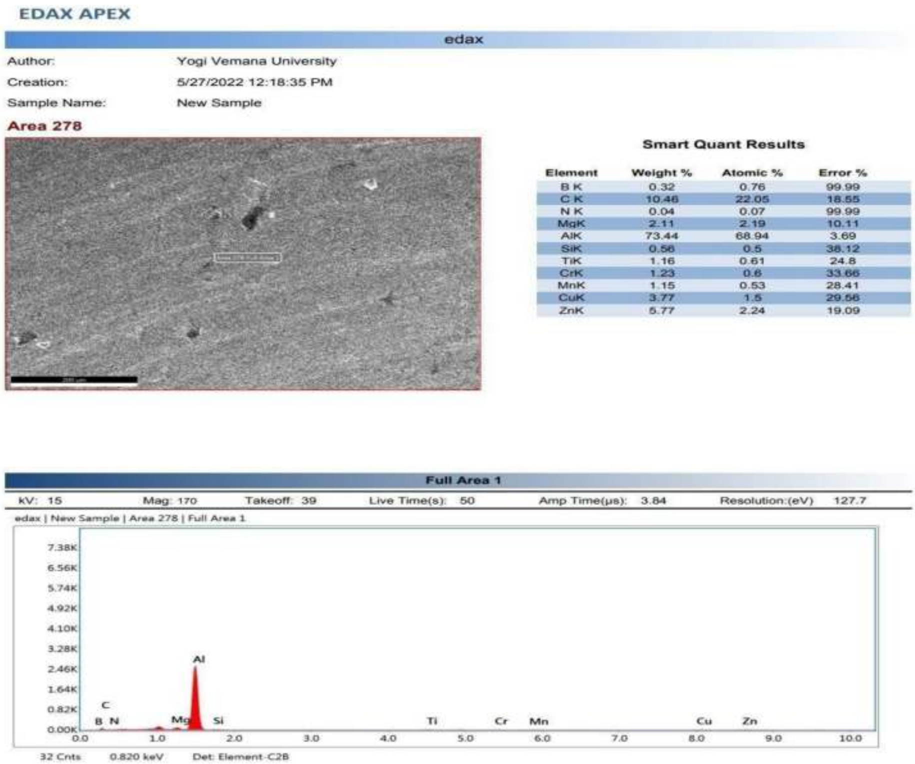
kV: 10 Mag: 33 Takeoff: 34 Live Time(s): 50 Amp Time(µs): 3.84 Resolution:(eV) 127.7

edax | New Sample | Area 285 | Full Area 1



26 Cnts 0.830 keV Det: Element-C2B

Fig. 12. EDS image of A4



Element	Weight %	Atomic %	Error %
B K	0.32	0.76	99.99
C K	10.46	22.05	18.55
N K	0.04	0.07	99.99
MgK	2.11	2.19	10.11
AlK	73.44	68.94	3.69
SiK	0.56	0.5	38.12
TiK	1.16	0.61	24.8
CrK	1.23	0.6	33.66
MnK	1.15	0.53	28.41
CuK	3.77	1.5	29.56
ZnK	5.77	2.24	19.09

Fig. 13. EDS image of A5

Quantitative analysis indicates:

- **Elemental Composition:**
    - AL7075: Predominantly Al, with Zn and Cu contributions.
    - h-BN: Detected B and N in expected stoichiometric ratios.
    - SiC: Detected Si and C in line with the expected composition.

The EDS results also reveal that the overall composition remains consistent with the intended ratios of the components, indicating successful fabrication.

Fig. 14. shows the variations in the ultimate tensile strength of the fabricated composites. The results signify that addition of reinforcements to Al7075 matrix by stir casting process contributes to a positive improvement in the elastic moduli of the composite samples.

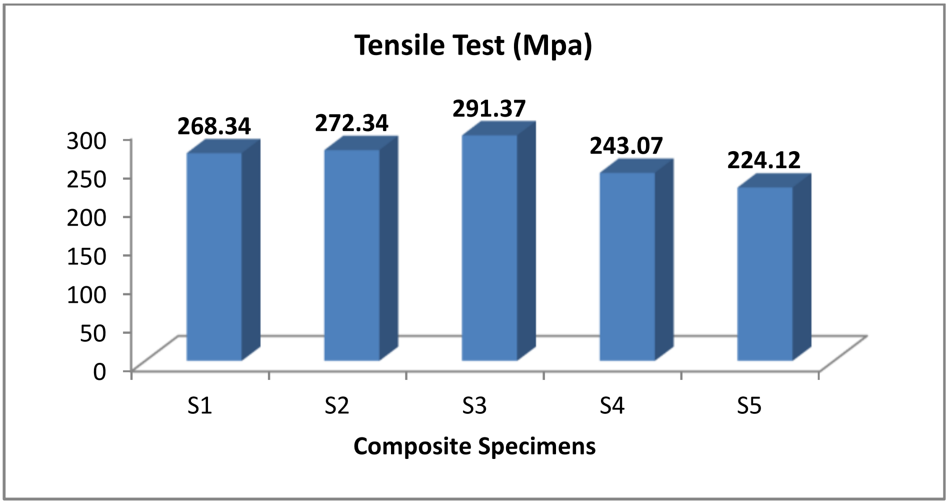


Fig. 14. Ultimate tensile strength of the composites

From Fig. 15 it is evident that, the composites incorporated with silicon carbide (Sic) and hexagonal boron nitride (hBN) has more hardness compared to Al7075.

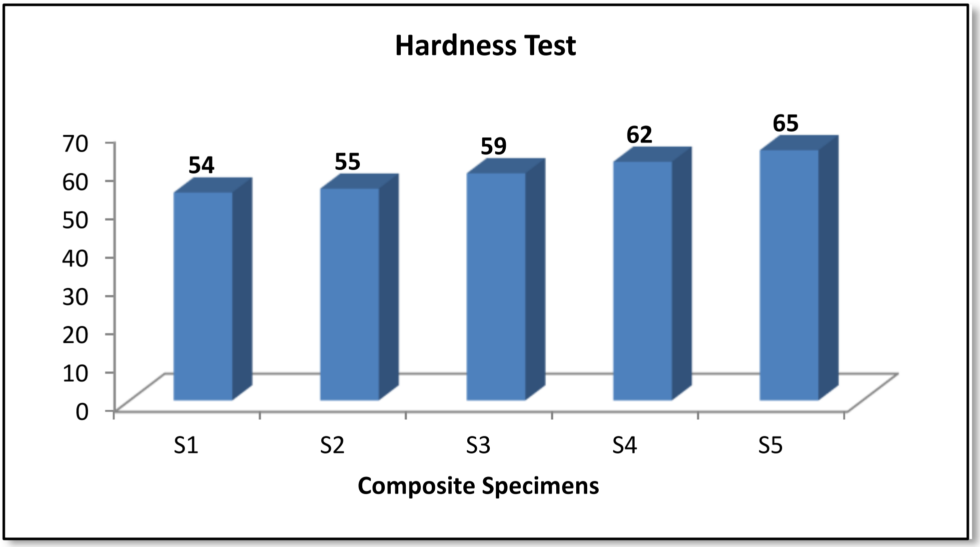


Fig. 15. Hardness of the composites

When reinforced with ceramic particles, metal matrix composites exhibits greater impact resistance strength than the underlying Al7075 alloy, as shown in Fig.16.

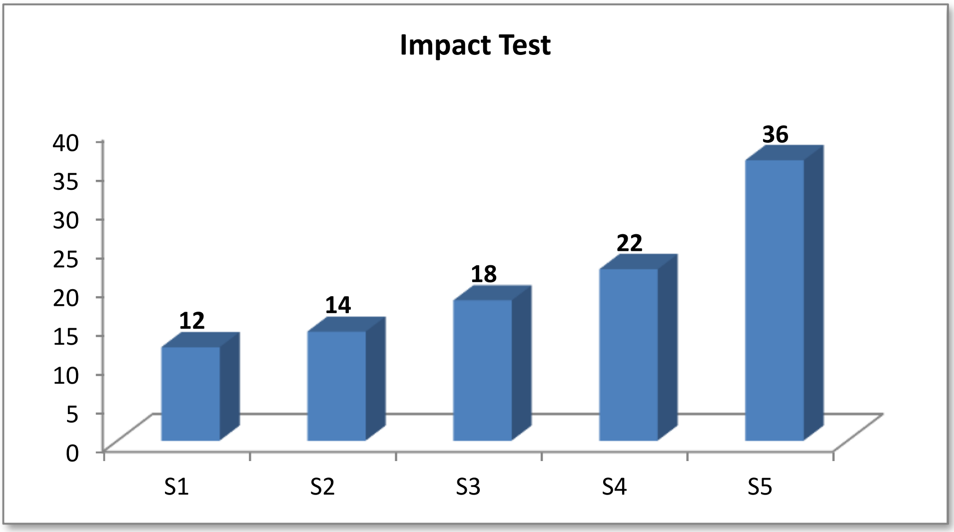


Fig. 16. Impact strength of the composites

5. CONCLUSIONS

The experimental investigation has drawn the following conclusions:

- ✓ The good dispersibility of SiC and hBN powder particles in the aluminum matrix improved the composite's tensile performance and the matrix material's hardness.
- ✓ The weight percentage of reinforcement was the most significant element affecting the hardness of fabricated composites utilizing the stir-casting technique.
- ✓ The most important factor influencing the hardness of composites made using the stir-casting technique was the weight percentage of reinforcement.
- ✓ The SEM and EDS analyses of AL7075 composites reinforced with h-BN and SiC demonstrate good interfacial bonding and uniform distribution of reinforcements within the aluminum matrix.
- ✓ The ultimate tensile strength is increased by incorporation of hBN and SiC found to be maximum [291.37 Mpa] at 6% addition of each reinforcements to the AL7075.
- ✓ The addition of hBN and SiC to the base metal increased the hardness value to [65 RHN] which was obtained at 10% of addition of each reinforcements to AL7075.

- ✓ The addition of hBN and SiC to AL7075 Increased the toughness value (36J) was obtained at 10% addition of each reinforcements to AL7075.

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