Mechanical Properties of Al7075 Hybrid Metal Matrix Composites as a functionality of SiO2 % in the RHA

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Abstract: Hybrid metal matrix composites are wide in applications due to their improved mechanical properties. Where the optimum selection of reinforcements becomes necessary for determining the feasibility of producing high-performance metal matrix composites with low cost. Consequently, in Al7075, a hybrid metal matrix composite (MMC) with boron carbide and rice husk ash was reinforced. This current research determines the effect of heating temperature on the production of rice husk ash, and it was discovered that the temperature effect improved the SiO2 content of the rice husk ash (RHA). In addition, the deposition method of RHA into the AI7075 substrate was used as a variable, and the effects on the microhardness and tensile properties of the resultant were investigated. The introduced hybrid MMC was reinforced with 2% boron carbide particles and 5%, 10%, and 15% RHA respectively using the stir casting technique. Hence, mechanical performances like tensile strength, compressive strength, impact tests, and hardness tests were performed efficiently.

Keywords: Hybrid Metal Matrix Composite (HMMC), Stir casting, Mechanical Properties, Rice Husk Ash.
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1. Introduction

In recent years, the development of new materials and their properties has been most important in the field of manufacturing. In the last few decades, the improvement in the materials world has increased, and new materials with new characteristics have come into existence. The improvement in new materials has shifted the development and research towards the manufacturing of composite materials. Nowadays, researchers are very much interested on hybrid composite materials. Hybrid composites are made of two or more reinforcement materials with significant properties like physical and chemical to form a new material with better characteristics than the parent material. The selection of various reinforcement materials mainly depends on the type and application of the matrix material. Reinforcement materials play the main role in changing the physical and mechanical properties of the matrix in composites. Depending on the need and type of the application, the reinforcement material can be selected. The reinforcement materials can be metals, non-metals, ceramics. Nowadays, most researchers are focusing on the usage of industrial waste as reinforcement materials. The various handling methods for the manufacturing of composites by utilising by-products like fly ash, RHA, coconut shell, etc., produced by various industries, which can reduce pollution, wastage of the materials, and improve the properties of the matrix materials. The performance characteristics of the materials also depend on the chemical composition of the reinforcement materials and how the composite material is being processed so that there should be an effective bond between the parent material and the reinforcement material [1]. The uniform distribution of Mg in Al MMC is achieved by rolling, and it was observed that the effect of homogenization on the hardness of the sample is directly proportional [2]. The characterization of AA6061 with SiC. It was witnessed that the spread of the particles was clean without any reaction, and the increase in content of reinforcement material has changed the behaviour of the matrix material from ductile to brittle. Metal Matrix Composites (MMCs) can be processed using metal/metal alloys as matrix and any extra material as reinforcement material which may be metal, non-metal or ceramics [3]. The experiment was carried out on Al6061 matrix material. It was observed that with an increase in the addition of bamboo leaf ash has an inverse effect on the hardness of the material. The most common method for processing MMCs is the liquid processing method, wherein the matrix material is melted and the pre-heated reinforcement material is added to it to form the composite material. Different researchers have studied the behaviour of MMCs by adding various reinforcement materials [4]. has investigated on mechanical behaviour of HMMC with Al7075 as matrix material and Gr and B4C as reinforcement materials, with the rise in wt% of B4C reinforcement material there was major rise in hardness and tensile strength of the MMCs and decreased the malleability of the material [5]. The mechanical behaviour of HMMC with Al7075 as the matrix material and Gr and SiC as reinforcement materials has been inspected. The addition of SiC particles has improved the mechanical properties and decreased the percentage elongation of the prepared sample [6]. The researchers conducted a study on the mechanical and wear properties of Al7075/SiCp and Al6061/TiCp composites, and it was discovered that wear increased with the increase in particle size of SiC, and brittleness improved with the addition of Nano particles [7][8]. The AA6061/B4C/Gr composite is processed, which has resulted in an improvement in hardness [9]. The research carried out in the addition of SiC, B4C, Gr, and others as reinforcement materials has resulted in changes in the properties of the base material, where very few attempts have been made to use industrial waste as the reinforcement material. The studies made by using RHA as the reinforcement material have also shown an improvement in the mechanical and physical properties of the prepared composite, which is mainly due to the SiO_2 content in it. The current investigation is through describing the effect of SiO_2 content in RHA on the behaviour of Al Matrix Hybrid Composites [10-15]. Aluminium alloy composite materials have great strength,hardness, stiffness, thermal stability, corrosion and wear resistance, and fatigue life, making them the best choice for industrial applications [16-19]. The ability of a material to withstand load before fracture and elongation to fracture is determined by its tensile strength. The energy stored to fracture is measured by impact strength. Wear resistance is a measurement of the deterioration of a material over time.Hence, the presence of reinforcement, size, shape, volume percentage, and distribution all have an impact on the mechanical and tribological properties of hybrid composites[20-23]. As a result, there is a need to develop a composition that should achieve a higher % of SiO_2 in Al7075 Hybrid Metal Matrix composites.

The contribution of this paper involves the following,

- Al7075 with boron carbide and rice husk ash were used to reinforce a hybrid metal matrix composite (MMC).

- The stir casting technique has been used to develop a hybrid MMC with boron carbide particles.
- Evaluate the mechanical performance, as well as tensile strength, compressive strength, an impact test, and a hardness test.

The remainder of the paper has been organized as follows, out of which section 1 is the introduction: section 2 presents the recent literatures; section 3 depicts the detailed description of the proposed methodology; section 4 discusses the implementation results; finally, section 5 concludes the paper.

2. Literature Survey

Imran, et.al.[24] Aluminum-7075 series alloys are extensively used in transportation applications such as aerospace, aviation, marine, and automobiles due to their good mechanical qualities, low density, and high strength-to-density ratio. Where, the current review focuses on the mechanical characteristics, and corrosion behaviour of Al-7075 metal matrix composites (AMMCs) with desired reinforcements. Hence, the goal is to review the manufacture of aluminium metal matrix composite materials by mixing alloys and reinforcements.

Devaganesh, et.al. [25] The research focuses on the fabrication of Al7075 metal matrix composites (MMC) with silicon carbide ceramic particles and several other solid lubricants for use in piston development. The casted specimen is composed of 90 wt. percent Al7075 alloy and 5 wt. percent SiC, which must be kept constant, as well as modifying the kind of solid lubricants: graphite, hexagonal boron nitride (hBN), and molybdenum disulfide (MoS2) with 5 wt. percent. The stir casting technology is used to manufacture hybrid Al7075 composites.

Arunkumar,et.al. [26] Stir Casting was used to create a hybrid Aluminium (Al) metal matrix composites using Al 7075 (Aluminium alloy 7075) reinforced with Titanium Carbide (TiC), Graphite (Gr), and Alumina (Al2O3). A pin on disc device was used to perform a dry sliding wear test. The Pin-on-Disc test was performed in accordance with the ASTM G99 standard. The wear test was designed using Taguchi's L8 (2x4) orthogonal array and parameters such as 20 N and 40 N of applied load, reinforcements of 4 percent and 6 percent TiC, 6 percent and 9 percent Gr, and 7 percent and 8 percent Al2O3.

Subramaniam, et.al.[27] The current study describes the production and testing of hybrid aluminium matrix composites' mechanical characteristics (HAMC). Aluminium 7075 (Al7075) alloy was strengthened with boron carbide (B4C) and coconut shell fly ash particles (CSFA). Stir casting was used to create Al7075 matrix composites. The Al7075 HAMC samples were made with varying weight percentages of (0, 3, 6, 9, and 12wt. percent) B4C and 3wt. percent CSFA. Hardness, tensile strength, and elongation are the mechanical qualities mentioned in this study.

Khare, et.al. [28] The current study intends to evaluate the mechanical properties of an AA7075 hybrid composite reinforced with aluminium oxide (Al2O3) and boron carbide (B4C). In this study, composites are created in two stages: The Al2O3 composites were created and their mechanical properties were examined in the first stage. To evaluate the effect, the reinforcement weight percentage (wt%) of Al2O3 with the highest tensile strength, hardness, flexural strength, and impact energy is chosen and reinforced with a varied weight percentage of B4C.

Singh P,et.al.[29] The proposed study will examine the tribological behaviour of ZA-27 alloy augmented with low-cost eggshell ash (ESA) and boron carbide (B4C) particles using a stir casting process to create hybrid metal matrix composites. The percentage of ESA and B4C particles introduced ranges from 0 to 5 wt. Composites are being examined for density, porosity, and microhardness.

Jayendra, et.al.[30] Aluminium-based metal matrix composites have a wide range of applications in aerospace, defence, automobiles, sports equipment, and electronics. Al 7075 is a lightweight castable alloy with intermediate hardness and strength that is used in automotive and aerospace. In general, adding refractory reinforcement improves the material's hardness, tensile strength, and high-temperature qualities.

Raju, et.al.[31] Aluminium is the matrix metal in Al-based MMC, and it has qualities that are important to the automobile industry. Some of these characteristics are a high strength-to-weight ratio and lightweight. In this paper, we attempt to develop an aluminium-based metal matrix composite (MMC) reinforced with natural fibre ashes. We use fine ashes of sugarcane (bagasse), groundnut shell ash (GSA), rice husk ash (RHA), and coconut shell (Jute), and different effects are investigated for different percentages of reinforcing material produced by burning in a free atmosphere.

Muni, et.al.[32] Metal matrix composites (MMC) are gaining popularity for use in the defence, and automotive industries. Materials used in these applications must be lighter in weight and more resistant to wear than conventional materials. Aluminium hybrid composites are a new category of metal matrix composites that meet the latest requirements of modern technological applications. These needs are a result of increased mechanical features such as lightweight and high wear resistance, adaptability to traditional processing techniques, and the possibility of lowering production costs.

Sharma, et.al.[33] Because of its vast range of uses, the demand for and consumption of metal matrix composites (MMCs) is growing all over the world. There is a constant need in businesses to develop stronger lightweight materials with high efficiency and performance across a wide range of industries. Aluminium metal matrix composites (AlMMCs) are an asset for product producers who require lightweight, medium strength, and low-cost materials.

Sharma, et.al [34] To investigate the influence of graphite particle addition on the characteristics of AA6082 metal matrix composites made using the traditional stir casting method. The percentage of reinforcement was increased by 3% steps from 0% to 12%. The results showed that the inclusion of graphite particles reduced the micro-and macro-hardness by 11.11 % and 10.44 %, respectively.

Pitchayyapillai, et.al [35] Due to its appealing properties such as high ductility, high conductivity, light weight, and high strength to weight ratio, aluminium Hybrid Reinforcement Technology is a response to the dynamic ever-increasing service requirements of industries such as transportation, aerospace, automobile, and marine. An attempt has been made in this evolution to explore the wear rate of Al6061 hybrid metal matrix composite reinforced with hard ceramic alumina (4, 8, and 12 wt. % of Al2O3) and soft solid lubricant of molybdenum disulphide (2, 4, and 6 wt. % of MoS2).

Nallusamy,et.al [36] The stir casting procedure was used to create the composites.All three composites were hardness and wear tested using a Brinell hardness testing machine and a pin on disc wear test device, respectively.Consequently, the specimens were also examined using an inverted microscope to evaluate their microstructures, and it was determined that the reinforcement was uniformly distributed in the primary matrix without agglomeration.

Ashwath,et.al[37] The effects of reinforcement materials such as SiC and Al2O3 on the mechanical characteristics of composites produced using traditional methods and powder metallurgy are compared and described. The researchers findings on the effect of reinforcement material % on the overall properties of MMCs are provided.

Arora,et.al[38] The use of industrial-agro wastes as reinforcements in the development of composites is a recent trend in the world of material research. The current study comprises the creation of AA6351 mono-composites with various weight percentages (2wt.%, 4wt.%, 6wt.%, and 8wt.%) of silicon carbide (SiC) and rice husk ash (RHA) as reinforcement utilising the stir casting technique.

Nayak,et.al [39] aluminium matrix reinforced with varying percentages of SiCp, Graphite, and Zirconia. These reinforcement materials were chosen for their superior mechanical and tribological qualities.Where the densities of graphite and silicon carbide are low. Silicon carbide offers high strength, hardness, and thermal shock resistance.

Reddy, et. al[40]To improve mechanical characteristics and wear resistance, ceramic particles were amalgamated with an aluminium alloy. Al-7075/Al2O3/SiC hybrid MMCs were created by reinforcing 2%, 3%, 4%, and 5% Al2O3 particles and 3%, 5%, and 7% SiC particles. The uniform dispersion of reinforcing particles inside the base matrix was evaluated using microstructural analysis. The results show that increasing the wt.% of ceramic particles improves the mechanical characteristics of hybrid MMC.

From the survey, [24] Aluminum-7075 series alloys are widely employed in transportation applications due to their mechanical properties, low density [25], and development and testing of hybrid aluminium matrix composites. [26] Composites are also being tested for density, porosity, and microhardness. [27] The composite's properties are determined not only by the reinforcement materials utilized [28-35]. As a result, intelligent techniques are proposed to develop mechanical properties in metal matrix composites. The material and processing of the rice husk ash are discussed in the following section.

3. Material and Processing of RHA

The base material is (Al 7075), the composition of which is described in Table 1, and the filler material is boron carbide and rice husk ash. Where, the aluminium alloy composites were created using a high vacuum casting process with varying wt % particulate filler. Consequently, rice ash is warmed at 450^0C before being added to 7075 Alloy in this method. Preheating filler materials is required to avoid moisture infiltration into the sample; otherwise, particle agglomeration is enhanced. Also, the aluminium metal matrix was melted in graphite using a vacuum casting furnace at 150-200 degree Celsius. Whereas, the selection of the material for the preparation of the composite is based on the type and application of the composite prepared. The current work is aimed at improving the behaviour of the Al-7075 as a matrix material with B4C as shown in fig. 1, and RHA as reinforcement material.

Table 1 provides the detailed elements in Al7075.

Table 1: Elements in Al7075

Element	Zn	Cr	Cu	Fe	Mn	Si	Ti	Mg	Al
%	6	0.2	1.9	0.5	0.3	0.2	0.4	2.9	bal

Figure 1: B4C Particles/Powder

Rice Husk Ash (RHA) is prepared by obtaining rice husk from a local rice mill and cleaning it with normal water to remove all undesired elements and soluble matter. It is then allowed to dry at room temperature for 2-3 days. RHA is obtained when heating the dried husk. Therefore, the proposed research analyses the processing of RHA, which has resulted in the development of a change in the composition of SiO2 content in RHA.

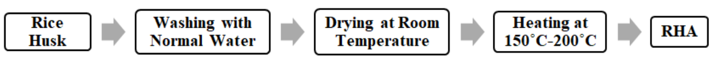

Figure 2: Flow Chart for processing RHA for sample (RHA)

Fig. 2. represents the flow chart for processing of RHA for sample (RHA) at different temperatures.

Table 2: Composition of RHA for Sample (RHA)

Element	LOI	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	K_2O	CaO	TiO_2	V_2O_5	MnO	Fe_2O_3
%	62.56	0.214	0.267	0.054	34.44	0.201	1.643	0.132	0.006	0.001	0.056	0.045

Table 2 give the composition of RHA processed as discussed in the flow chart respectively.

Figure 3: RHA Sample

Fig.3. shows the rice husk ash sample. The preparation of composite specimens is shown in the below section.

3.1. Preparation of Composite Specimens:

The preparation of HMMC is carried out using a stir casting setup which uses a liquid metallurgy route technique. Primarily, aluminium alloy is charged into the crucible and heated up to 800^0c till the complete aluminium alloy present in the invessel changes its phase. A stirrer made of stainless steel is dipped in the molten metal and it is stirred at 500 rpm. Now the reinforcement materials are added slowly into the vessel containing molten metal at a constant rate as per the weight percent discussed in table 3, and gradually the stirring speed is increased to 700 rpm. The mixing is done by using a stirrer and continues for 5 minutes after the addition of reinforcement material. The mixture is poured into a preheated mould and allowed for solidification. A similar procedure is carried out for the remaining weight percentage of reinforcements.

(a) **(b)**

Figure 4: (a) Stir Casting and (b) Electrical Furnace Equipment

Stir casting was used to make the Al7075 aluminium alloy reinforced with 5%, 10% and 15% RHA and 2% boron carbide particles. Initially, 3 kg of Aluminium 7075 was placed into a graphite crucible and melted in a pit furnace at 750^0c. As the aluminium metal is heated, 2 g of Mg was added to the melt as a wetting agent to reduce casting fluidity and molten aluminium surface tension. Rice husk ash particles were roasted to 200^0c for 1 hour to remove moisture. Therefore, the graphite stirrer was lowered, and the preheated RHA at 600^0c was slowly charged into the melt for uniform distribution. Hence, the stir casting manufacturing setup is depicted in Fig.4.

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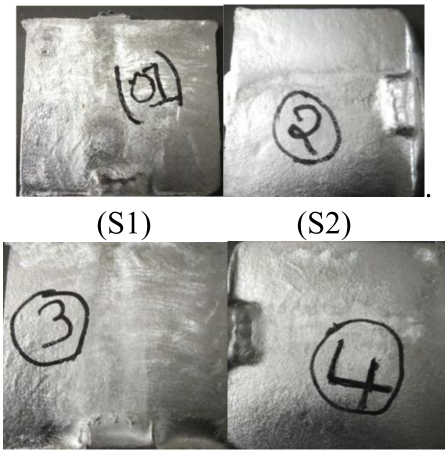

(S1) (S2)

(S3) (S4)

Figure 5: Samples Prepared using Stir Casting

The samples (S1), (S2), (S3), and (S4) are manufactured utilising a stir casting manufacturing technique, as shown in Fig.5.

Table 3: Wt % of Reinforcement Material

Designation	Composition
S0	Al7075
S1	Al7075 + 2% B4C
S2	Al7075 + 2% B4C + 5% RHA
S3	Al7075 + 2% B4C + 10% RHA
S4	Al7075 + 2% B4C + 15% RHA

Table 3 shows the Wt% of Reinforcement Material with various compositions and designations. The hardness analysis results demonstrate that Al7075+2% B4C+15% RHA has a greater hardness value and thus a superior hardness attribute. The increase in hardness was attributed to an increase in the fraction of hard and brittle phases of rice husk ash particles in the aluminium alloy.

4. Results and Discussion

The results of the proposed framework are presented in this section. The performance was assessed using mechanical properties such as tensile property, percentage elongation, impact test, hardness (BHN), and compressive strength.

4.1. Tensile Property:

The variation of tensile properties of the prepared composite with different wt% of reinforcement material is shown in fig.6.

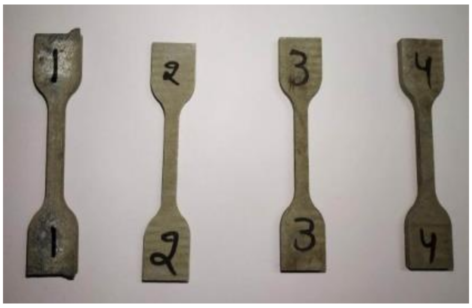

Figure 6: Tensile test specimens as per ASTM E8M04 standards.

The tensile strength with varied weight percentages of reinforcement material is shown in table.4.

Table 4: Tensile strength with different wt. % of Reinforcement Material

Designation	Tensile Test (N/mm2)
S0	86.826
S1	102.882
S2	186.209
S3	178.411
S4	191.212

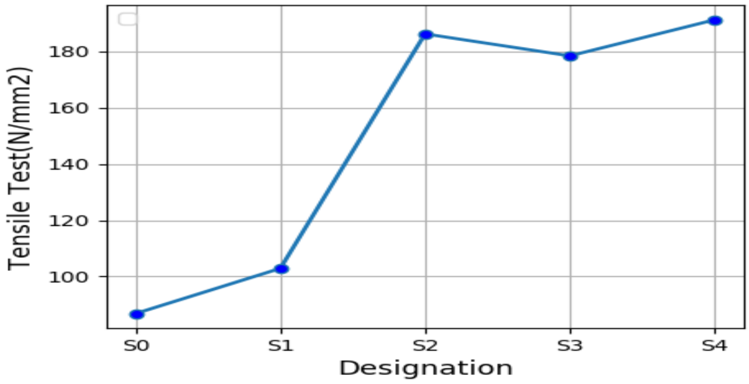

Figure 7: Tensile Test

From Table 4, the above graph is plotted for various designations S0, S1, S2, S3 and S4. As shown in fig.7, increasing the sample size increases the tensile values.

4.2 Percentage Elongation:

The difference in percent elongation of the prepared composite with varying weight percentage of reinforcement material is shown in Table 5. The percent elongation increased with an increase in the weight percentage of RHA.

Table 5: % elongation with different wt. % of Reinforcement Material

Designation	% Elongation
S0	1.16
S1	2.52
S2	1.8
S3	4.04
S4	4.6

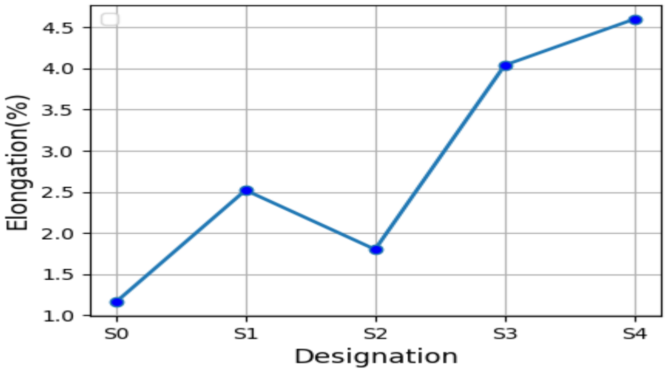

Figure 8: Elongation

From Table 5, the above graph is plotted for various designations S0, S1, S3 and S4. As shown in fig.8, increasing the sample size increases the elongation (%). At S4 the influence of SiO_2 occurs 4.5%,which is 0.5% higher than S3,which is 2% higher than S1.

4.3. Impact Test:

The toughness of the material can be observed by performing an impact test. Usually, the notch type of specimen is used to carry out impact tests. The notch assists as a stress concentrator. In the present study, the Izod impact testing machine and v-notch made only on one side of the specimens were used to study the impact energy of the prepared composites. This study describes the energy that materials can absorb. The impact stress of aluminium hybrid composite is shown in fig.9.

Figure 9: Impact test specimens as per ASTM E8M04 standards.

The impact energy with varied weight percentages of reinforcement material is shown in table.6

Table 6: Impact energy of different wt. % of Reinforcement Material

Designation	Impact Test (J)
S0	4.00
S1	4.00
S2	4.00
S3	6.00
S4	6.50

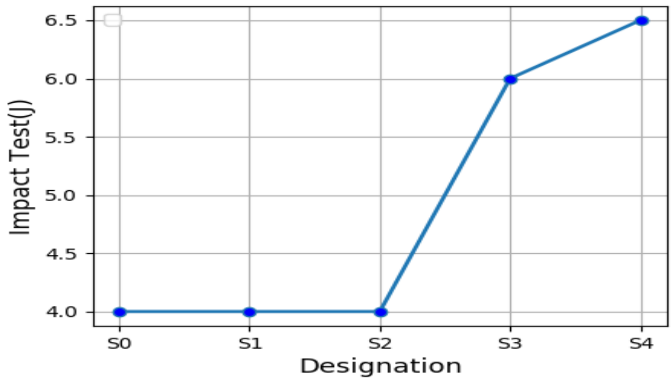

Figure 10: Impact Test

From Table 6, the above graph is plotted for various designations S0, S1, S3 and S4. As shown in fig.10, increasing the sample size increases the impact test. At S4 the influence of SiO_2 occurs 6.5J,which is 0.5J higher than S3,which is 2.5J higher than S1.

4.4 Hardness Test:

The deviation in hardness of the unlike combination of Al-HMMC was evaluated and shown in figure11. Specimens are tested on a Brinell hardness testing machine, which usually consists of a diamond ball indenter. It was observed that the hardness values of the HMMC were reduced due to the presence of porosity in the specimens.

To analyse the strength of the material the below equation follows,

$$BHN = \frac{2R}{\pi E(E-\sqrt{E^2-e^2}} \quad (1)$$

Where R be the load in kgf.
E be the steel ball diameter in mm.
e be the depression diameter in mm.

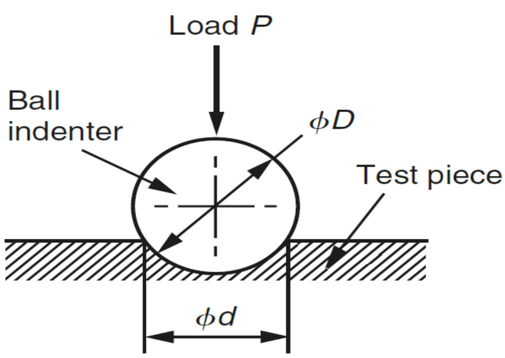

Figure 11: Brinell Hardness Test

The Hardness value with varying weight percentages of reinforcement material is shown in table.7.

Table 7: Hardness value of different wt. % of Reinforcement Material

Designation	Hardness (BHN)
S0	125.33
S1	121.33
S2	108.33
S3	107.67
S4	105.8

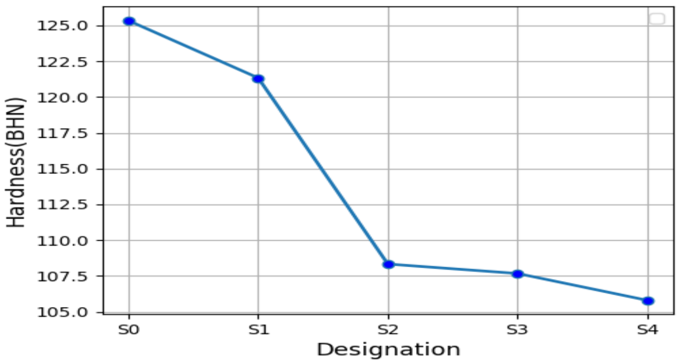

Figure 12: Hardness

From Table 7, the above graph is plotted for various designations S0, S1, S3 and S4. As shown in fig.12, increasing the sample size increases the hardness(BHN). At S0 the influence of SiO_2 occurs 125.33(BHN), which is 3.5(BHN) higher than S1.

The variation of compression strength by adding RHA is displayed in fig 13. After the investigation, the results showed that the compressive strength was increased with a rise in the weight% of RHA particles. The maximum compressive strength was found to be 15% of RHA in the hybrid composite, which is due to the higher percentage of silica content in the MMC.

4.5 Compression Behaviour:

Figure 13: Impact test specimens as per ASTM E8M04 standards.

The Compressive test with varied designation of reinforcement material is shown in table.8.

Table 8: Compressive strength of different wt. % of Reinforcement Material

Designation	Compression Test (Mpa)
S0	420.192
S1	514.128
S2	547.824
S3	625.536
S4	650.69

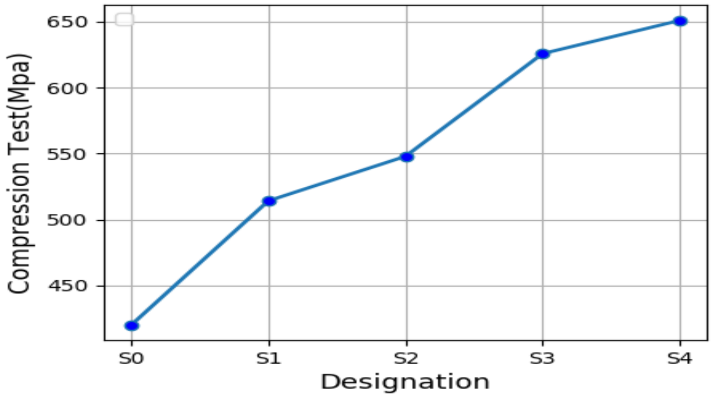

Figure 14: Compression Test

From Table 8, the above graph is plotted for various designations S0, S1, S3 and S4. As shown in fig.14, increasing the sample size increases the compression test. At S4 the influence of SiO_2 occurs 650(Mpa),which is 10(Mpa) higher than S3.

This section compares the performance of the proposed work with existing works based on the mechanical properties of AI7075 to ensure the effectiveness of the proposed methodology.

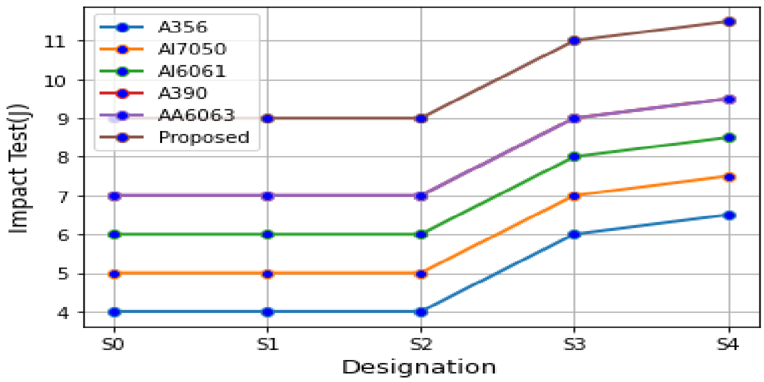

Figure 15: Comparison of Impact Test.

Fig.15. shows the comparison of the impact test with known approaches such as Al7050, Al6061, Al390, AA6063, and A356. The proposed technique's impact test yields better results than the other. At Al7075 the influence of SiO_2 occurs 11J, AA6063which is 1.8J lower than Al7075.

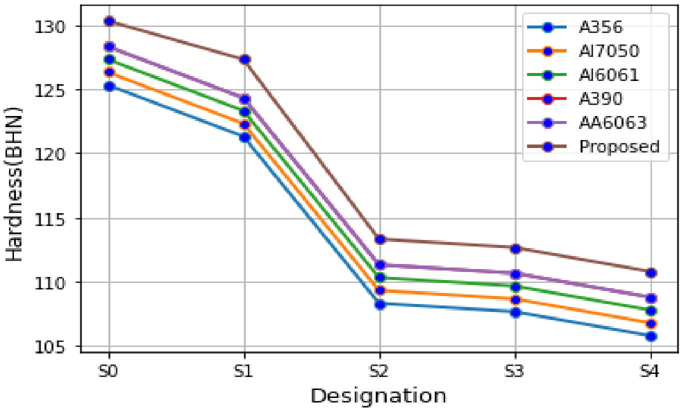

Figure 16: Comparison of Hardness(BHN)

Fig.16.depicts the comparative analysis of the Hardness(BHN) with the existing techniques such as Al7050, Al6061, Al390, AA6063, and A356. The hardness of the proposed technique achieves 130 BHN, which is 2BHN higher than AA6063.

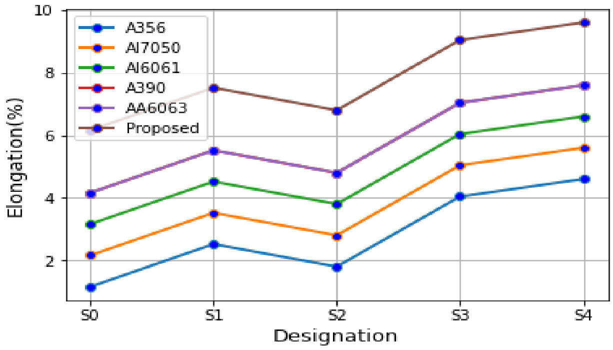

Figure 17: Comparison of Elongation(%)

Fig.17.depicts the comparative analysis of the Elongation (%) with the existing techniques such as Al7050, Al6061, Al390, AA6063, and A356. The elongation of the proposed technique achieves 9.9%, which is 5.4% higher than AI7050, which is 3.2% higher than AI6061, which is 2.1% higher than AA6063.

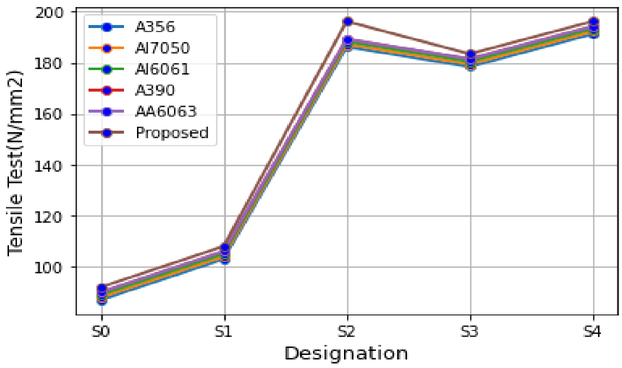

Figure 18: Comparison of Tensile Test(N/mm2)

Fig.18.depicts the comparative analysis of the Tensile Test (N/mm2) with the existing techniques such as Al7050, Al6061, Al390, AA6063, and A356. The tensile test of the proposed technique achieves 198 (N/mm2) which is 4(N/mm2) higher than A390.

5. Conclusion

This research proposed a technique for determining the mechanical properties of Al7075-B4C–RHA hybrid metal matrix composite. The manufacturing of low-cost hybrid aluminium matrix composites with rice husk ash as a complementing reinforcement with boron carbide showed a significant advantage due to the enhanced mechanical properties of the generated hybrid composites. The hardness of composites increased as the matrix reinforcement content increased by 125.33 BHN. The addition of reinforcing particles B4C and RHA to aluminium7075 boosts the tensile strength of composites. Also, the matrix reinforcement content of composites is increased to achieve a 6.5 J impact energy. B4C and rice husk ash both exhibit 4.6 % composite elongation. According to the experimental results, the proposed framework outperforms the others in terms of impact testing, tensile testing, hardness, and elongation.

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