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Development of Aluminum Alloys 6061(AA6061) Silicon Carbide (SiC)-Graphite (GR) and Hybrid Composite for Automotive Applications

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Abstract:- The microstructure and mechanical properties of composite materials made of Silicon carbide (SiC) and Graphite (GR) reinforcement, known as Aluminum Alloy 6061(AA6061) Matrix were developed. Using the stir casting method, the hybrid composites were prepared with 6 weight percent of the reinforcements in the ratio of 0:1,1:3,1:1,3:1,and 1:0. It was determined how the reinforcement particles affected the microstructures and mechanical characteristics of these materials. The microstructure displays a uniformly distributed fine particles of α-Al grains and Mg2Si phase with in the matrix alloy. The microstructure amply demonstrates the presence of the reinforcing particles (SiC and GR) and dendritic development was noted. There are very few indications of particles clusters, and the particles are very dispersed throughout the matrix. Sample A2 (AA6061 25% SiC/ 75% GR) had the highest recorded hardness value of 123.34 HRB4.8,9.33, while the base alloy had the lowest value of 70.36 HRB when compared to the base alloy, the developed hybrid composites showed improved tensile strength. In contrast to the base alloy, which displayed a strength of 115.67N/mm², Sample A3 demonstrated a maximum strength of 143.88 N/mm² as compared to the base alloy which showed strength of 115.67 N/mm2. The hard reinforcement particles sharp edges serve as a nucleation site, which is why the strength of samples A4 and A5 decreased when SiC reinforcement is added, the materials extension decreases when the developed hybrid composite materials with samples were compared with the base alloy. In comparison to the created hybrid composite materials, the base alloy displayed a maximum extension of 2.4mm, with sample A5 showing the lowest extension value of 1.23mm. Sample A2 displayed the highest structures rate of 0.060, while sample A5 displayed the lowest strain rate of 0.031. The impact strength values increases from 2.76 (Base alloy) to 4.77j (Sample A5) with the addition of the reinforcement particles. The obtained mechanical properties indicate that the reinforced alloy performed favorably well but not significantly better than the ones in the literature.

Keywords:- *Stir Casting; Reinforcement Particles; Hybrid Composites, Mechanical Behavior; AA6061 Alloy.*

I. INTRODUCTION

Metal matrix composite (MMC) are metal reinforced with other metal, ceramics or organic compounds. They are made by dispersing the reinforcement in the metal matrix. Reinforcement is usually done to improve the properties of the base metal like strength, stiffness, conductivity [1].

In-service performance demands for many modern engineering systems require materials with broad spectrum of properties, which are quite difficult to meet using monolithic material systems [2]. Metal matrix composites (MMCs) have been noted to offer such tailored property combinations required in a wide range of engineering applications [2], [3]. Some of these property combinations include: high specific strength, low coefficient thermal expansion and high thermal resistance, good damping capacities, superior wear resistance, high specific stiffness and satisfactory levels of corrosion resistance [3], [4], [5].

A large number of manufacturer's methods are used to place reinforcement into matrix alloy. Stir casting technique has remained the most investigated technique for fabricating AMCs owing to its simplicity, flexibility and commercial viability [6], [7].

The use of Aluminum Matrix Composites (AMCs) has attracted interest in aerospace, defense and automotive applications owing to its high strength to weight ratio, improved stiffness, moderately high temperature properties, controlled thermal expansion coefficient, enhanced and tailored electrical performance, improved abrasion and wear resistance as compared to the monolithic alloys [8], [9], [10], [11].

Hybrid materials are composites consisting of two constituents at the nanometer or molecular level. Commonly one of these compound is inorganic and the other one organic in nature. Thus, they differ from traditional composites where the consistent are at the macroscopic (micrometer to millimeter) level. Silicon carbide (SiC), alumina (Al_20_3), boron carbide (B_4C), tungsten carbide (WC), graphite (GR), carbon nanotubes(CNT) and silica (siO_2) are some of the synthetic ceramic particulate that has been studied but silicon carbide and alumina are mostly utilized compared to other synthetic reinforcing particulates [12]. Conventional AMCs reinforced with SiC or Al_2O_3 have shown improved strength

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and specific stiffness over the monolithic alloys but this occurs at the expense of ductility and fracture toughness [13]. Ductility and fracture toughness are important material properties that are necessary for preventing failures under in-service stress or shock load application.

[14] studied the influence of mica on the mechanical and wear properties of aluminum matrix composite reinforced with 10 wt% silicon carbide. The percentage of mica added to the 10wt% SiC reinforced Aluminum composites was 6% in step of 3. It was reported that hybrid composites containing mica and SiC as reinforcement have superior hardness, tensile strength and wear resistance than the single reinforced silicon carbide aluminum composites. The superior wear resistance observed was ascribe to the formation of a stable mechanically mixed layer (MML) formed on the composites which reduces the wear loss. The hybrid composites with 3wt% mica have the highest wear resistance, strength and hardness. The properties dropped as the mica content was increased to 6wt%. The reason for this was not reported and still need further studies.

The objective of this research is to study the influence of silicon carbide and graphite particles on microstructure and mechanical properties when they are reinforced with AA6061using stir casting method.

II. MATERIALS AND TECHNIQUES

➢ *Materials used*

The following Materials were used in this study: AA6061 ingot, Silicon carbide (SiC), Graphite (GR), Magnesium (Mg), Charcoal, emery papers.

➢ *Equipment used*

A charcoal fired crucible furnace, stirring rod, crucible pot, split metal mold, slag scooper, pair of tongs, sensitive weighing machine, lathe machine, Computer controlled Hardness Testing Machine, Izod Impact Testing Machine, Polishing Machine, Monsanto Tensometer, EDXRF Machine and Metallurgical microscope are some of the equipment used.

➢ *Fabrication of the Hybrid Composites*

The stir casting technique was used to create the hybrid composites. Charge calculations were performed in advance of the stir casting procedure to ascertain the quantity of silicon carbide (SiC) and graphite (GR) needed to prepare the six weight percent reinforcements in the suggested hybrid composite based on Al 6061. The weight mix ratios of SiC and GR, which are 0:1, 1:3, 1:1, 3:1, and 1:0, were utilized to produce different grades of reinforced composites with a weight percentage of 6%.

The Al-6061 alloy was melted at a temperature of approximately 700°C ± 30°C (above the alloy's liquid temperature) in a crucible furnace fired by charcoal. After that, the liquid alloy was allowed to cool to a semi-solid state, or roughly 650°C. After that, the liquid alloy was allowed to cool to a semi-solid state, or roughly 600°C. After that, the melt was mixed with reinforcement particles made of SiC and GR that had first been preheated to 250°C. In addition, 0.1 weight percent magnesium (Mg) was added to enhance wettability. The molten metal was poured into a prepared cylindrical mold cavity measuring 35 cm in length and 20 cm in diameter. The composite slurry was manually stirred for 10 minutes before being superheated to a temperature of 800°C ± 50°C for improved fluidity. Inside the mold, the molten metal was left to solidify. After that, the cast was taken out and samples were machined for testing mechanical properties. The following are the hybrid composite grades generated using the matching sample designations Table 1.

Table 1 Designation of Al-6061 – SiC/GR Composite Samples

6 wt %		
Sample	**Mixture Ratio SiC/GR**	**% SIC/ GR**
A1	0:1	0:1
A2	1:3	25:75
A3	1:1	50:50
A4	3:1	75:25
A5	1:0	100:0

➢ *Chemical Composition Determination*

Using x-ray fluorescence (XRF) on the cast sample, as per [15], the true chemical composition of the cast aluminum alloy 6061 (control) was ascertained. The findings are shown in Table 2.

Table 2 Cast Aluminum Alloy 6061's Elemental Composition

S/N	Elements	wt. %	Elements	Wt. %
1	Al	89.74	Ni	0.128
2	Si	4.34	Fe	0.821
3	Mg	2.26	Zn	0.59
4	Ca	0.14	Cu	1.54
5	Sc	0.005	Mo	0.005
6	Ti	0.025	Ru	0.16

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7	Cr	0.008	Te	0.05
8	Mn	0.186	Pb	0.17

➢ *Mechanical Test Procedure*

- *Test for Hardness*

Using a standard computerized Vickers Hardness Testing Machine, Model MV1-PC, with a load of 0.3 kgf and a maximum/minimum limit of 500/300HV, a hardness test was performed on the samples in accordance with [16].

- *Tensile Strength Test*

The Monsanto Tensometer, type W Serial No. 9875, was used to perform the ultimate tensile strength test in compliance with [17]. The samples were held firmly in the Tensometer's chucks, and load was applied using the load handle until the samples broke.

- *Impact Test*

The [18] Standard Method and Definitions for Mechanical Testing of Steel Products were followed in conducting the impact test. The samples were each given V-notches 0.5 mm deep, and the Izod Impact Testing Machine (Joules) was used to measure the impact strength.

- *Analysis of Microstructure*

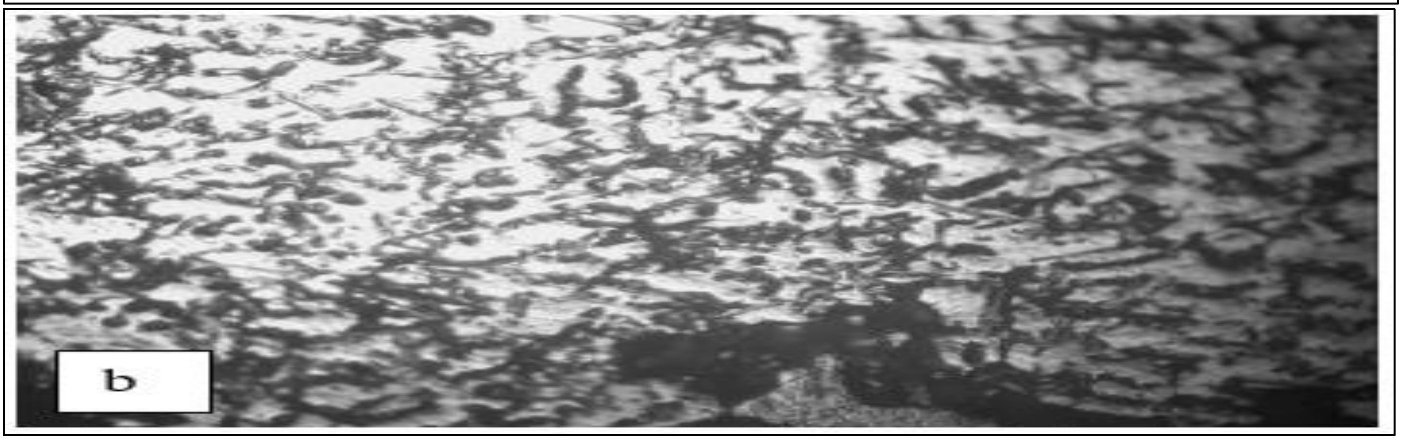
Before the samples' surfaces were examined for metallography and surface morphology, they were successively ground using grit papers of various grades, including 120C, 180C, 320C, 400C, 600C, 800C, and 1200C. Grinding aluminum involves moving from 400C grit paper to 1200C grit paper while applying lubricant sporadically to avoid overheating and to provide a rinsing action that removes particles removed from the surface. After that, the scratches from grinding were removed by polishing them with the help of a polishing machine and alumina. The polished surface was then etched using Keller's reagent, which is a solution of one milliliter distilled water, five milliliters nitric acid, and two milliliters hydrofluoric acid.

To view the microstructures of the polished samples, a computer control photographic visual metallurgical microscope (model NJF-120A, rating 230V-5V/60Hz) was used.

III. RESULTS AND DISCUSSION

➢ *Analysis of Microstructure*

Figures 1a through f show the microstructure of the developed hybrid composites and the base alloy (AA 6061) as observed under a metallurgical microscope.



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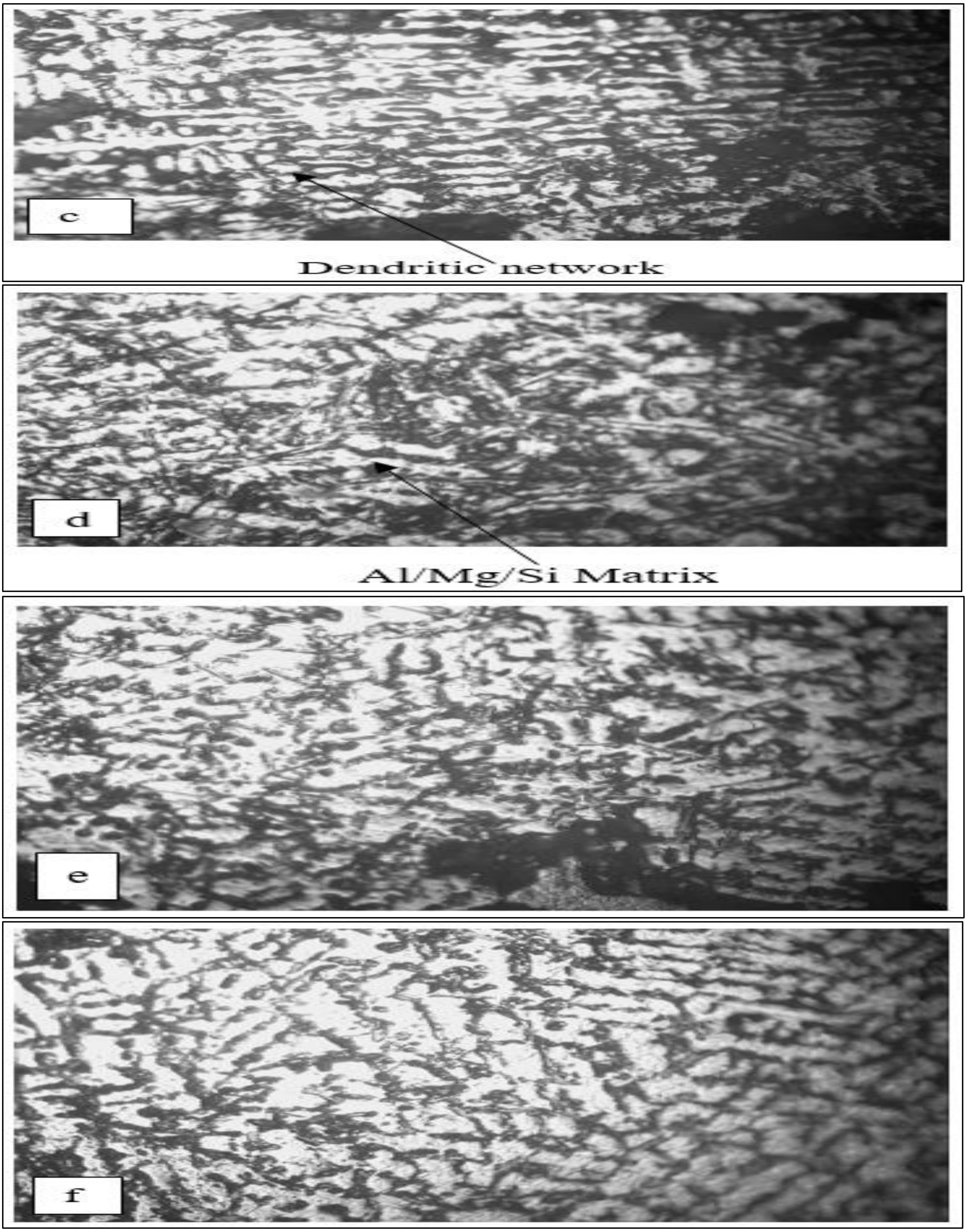

Fig 1: An Optical Micrograph of the Aluminum Alloy 6061/SiC/GR that has been Developed, Displaying the Intermetallic Phase (Black) and α-Al (White), Mag X100: Regulate (a), The following are the AA6061values: 0% SiC/100% GR (b), 25% SiC/75 GR (c), 50% SiC/50 GR (d), AA606175% SiC/ 25% GR (e), AA6061 100% SiC/ 0% GR (f).

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- *Mechanical Properties*

Figures 2 to 6 shows graphs of the results the Hardness, Tensile and Impact tests of the developed hybrid composites.

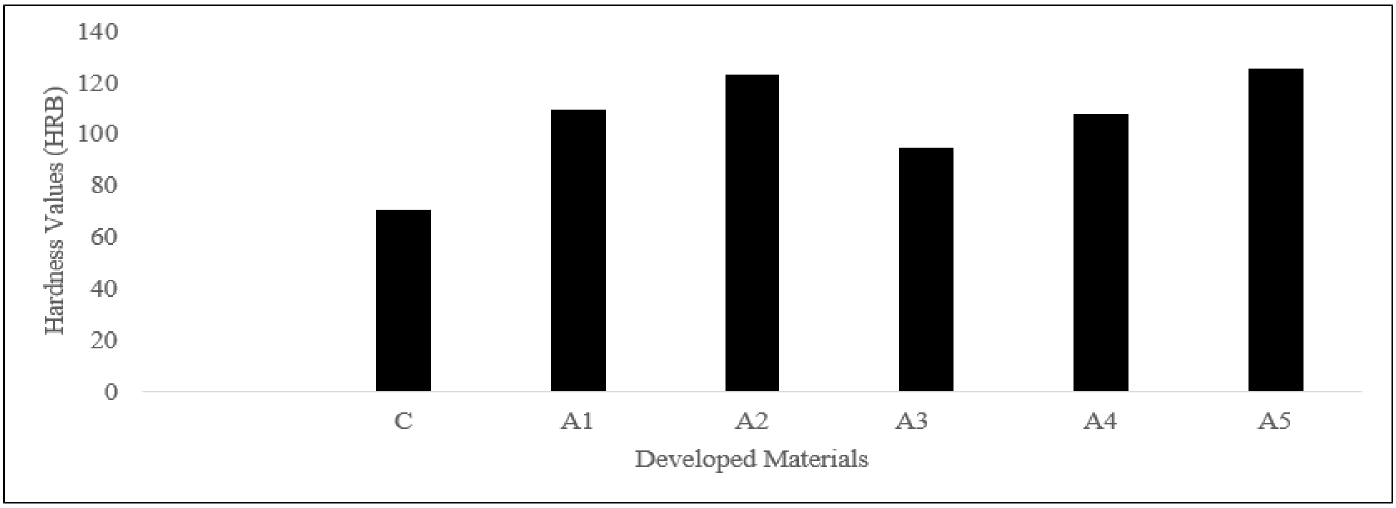

Fig 2 Variation in Developed Hybrid Materials Hardness Values.

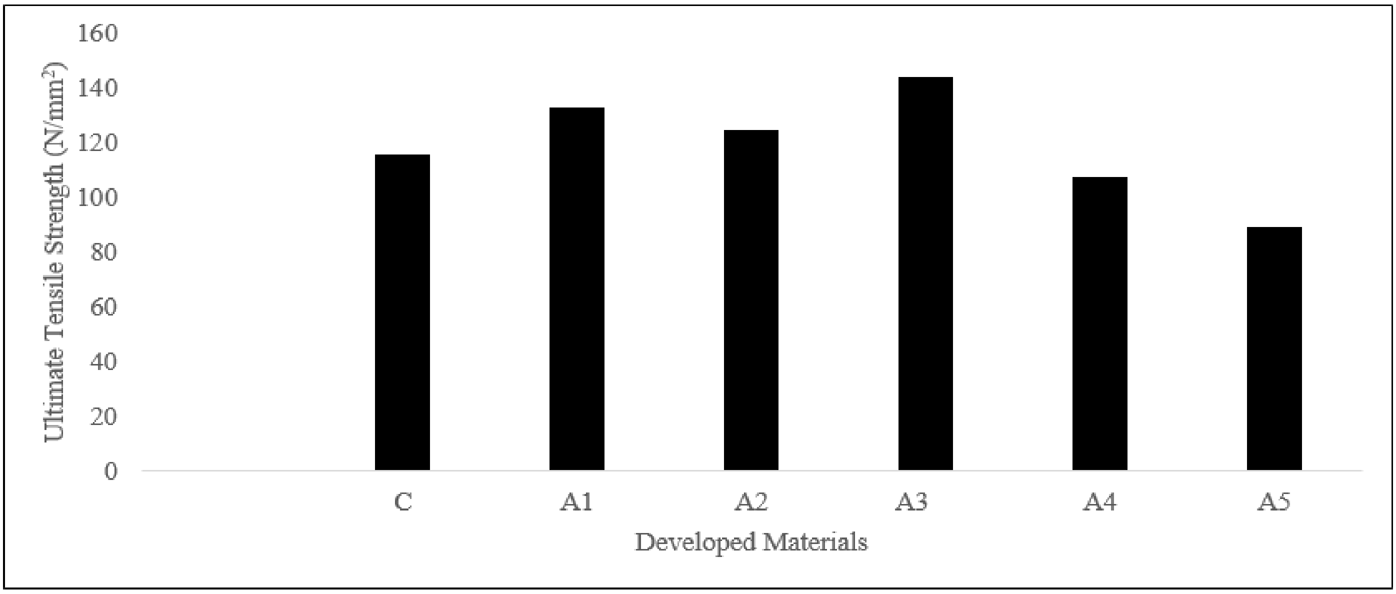

Fig 3 Tensile Strength Variation Compared to Developed Hybrid Materials

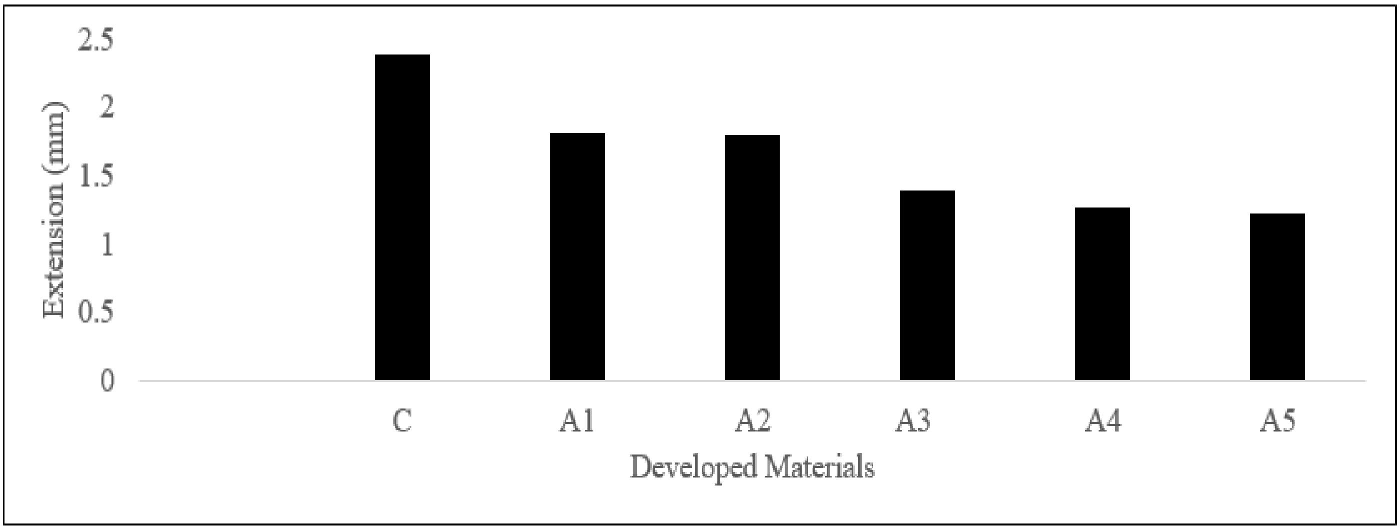

Fig 4 Extension Variation in Opposition to Developed Hybrid Materials.

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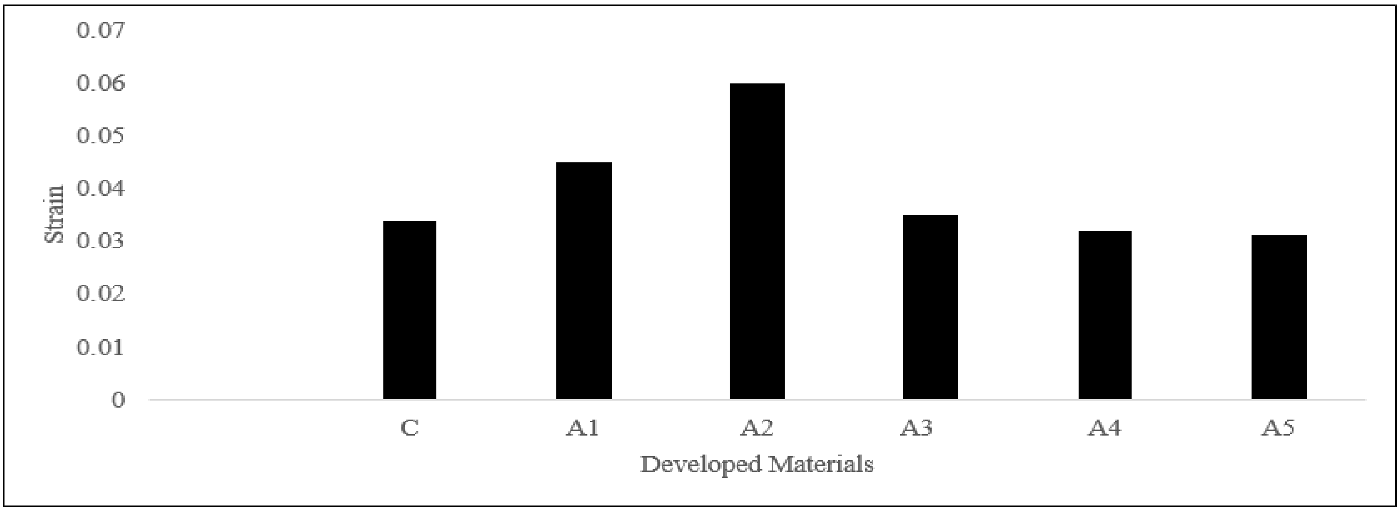

Fig 5 Stress Variation against Developed Hybrid Materials.

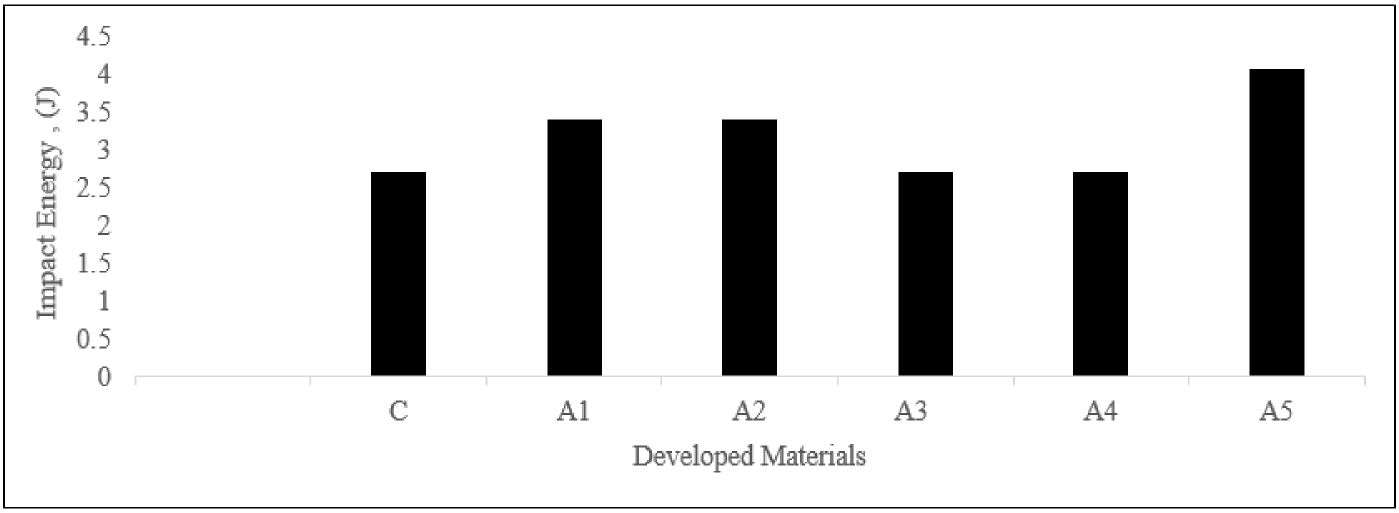

Fig 6 Impact Energy Variation against Developed Hybrid Materials.

- *The Developed Hybrid Composites' Microstructure*

Figures 1a through f show the microstructure of the created hybrid composites. The uniform distribution of α-Al grains and fine particles of phase Mg2Si in the matrix alloy of (Al-Mg-Si) is evident in the microstructure of AA6061 (Figure 1a). Figures 1b to f shows the microstructures of AA6061- 0% SiC/ 100% GR, AA6061 25% SiC/ 75% GR, AA6061 50% SiC/ 50% GR, AA6061 75% SiC/ 25% GR and AA6061 100% SiC/ 0% GR hybrid composites respectively. The reinforcing particles in the matrix alloy are fairly distributed. Additionally, the micrographs show a strong bond between the reinforcement particles and matrix alloy. This is caused by the presence of magnesium in the Al-alloy's chemical composition, which raises the percentage of SiC particles that are retained in the matrix and enhances the wettability of ceramic particles with matrix alloy [19].

The microstructure shows the visible and distinct delineation of the reinforcing particles (SiC and GR) and the formation of dendrites. There are very few indications of particle clusters and the particles are evenly dispersed throughout the Al-Mg-Si matrix. The geometrical arrangement of the phases and grains in the material agrees with the results of [20].

- *Mechanical Properties*

The plots of the results of mechanical properties test of the developed hybrid composite materials are presented in Figures 2 – 6. In Figure 2 the developed hybrid materials shows improved hardness values as compared to the base alloy (matrix). This is due to the addition of the reinforcement materials (SiC and GR) into the microstructure of the alloy. Sample A_2 (AA6061 25% SiC/ 75% GR) showed the maximum hardness value of 123.33 HRB compared to the base alloy C (AA6061 matrix) which showed lowest hardness value of 70.33 HRB. Similar observations were put forward by [20].

The plot of tensile properties of the developed hybrid materials are presented in Figures 3 to 5.

The tensile strength values of the SiC and GR-reinforced developed AA6061 hybrid metal matrix composites are displayed in Figure 3. The tensile strength of the created hybrid composites is higher than that of the base alloy. Hard reinforcement particles are what give the composites their strengthening effect [21]. Because the reinforcement particles (SiC and GR) in aluminum alloy composite are uniformly distributed, they function as a blocker against the matrix alloy's dislocation motion. The primary way that the addition of reinforcement particles increases the composite's tensile strength is through the transfer of stress from the ductile aluminum matrix to the reinforced, brittle particles. In contrast to the base alloy, which displayed a strength of 115.67 N/mm2, sample A3 demonstrated a maximum strength of 143.88 N/mm2. The hard reinforcement particles' sharp edges serve as a nucleation site, which is why the strength of samples A4 and A5 decreased. Fracture will result from the concentration of stress at the nucleation site [22].

As shown in Figure 4, the addition of SiC reinforcement results in a decrease in the materials' extension. In comparison to the created hybrid composite materials, the base alloy displayed a maximum extension of 2.3 mm, with sample A5 showing the lowest extension value of 1.22 mm. This is also consistent with the strain rate result displayed in Figure 4.4, where sample A2 has the greatest strain rate (0.060) and sample A5 has the lowest (0.031).

The impact strength variation of the developed hybrid composite materials is displayed in Figure 6. The impact strength values increase from 2.71 J (base alloy) to 4.07 J (sample A5) with the addition of reinforcement particles.

Mechanical properties obtained shows clearly that the reinforced alloy performed favorably well but the results obtained are not much better than the ones reported in literature.

Furthermore, the mechanical properties of the produced hybrid composite materials are better than the alloy which is agreement with some of the research reported in literature.

Sample A_5 with 100% SiC/0% GR - AA6061 shows better mechanical properties amongst the developed hybrid composite materials tested.

IV. CONCLUSIONS

Stir casting was the method used to successfully develop AA6061/Sic/GR and hybrid composite with GR and SiC reinforcements at weight percentages of 0:1,1:3,1:1,3;1 and 1:0 has been studied. The findings indicate that:

- The SiC/GR particles were evenly dispersed throughout the aluminum matrix. Most of the distribution was within individual grains.
- The Mechanical characteristics of the AMCs were improved by the addition of SiC/GR particles. Sample A5 had the highest hardness value and impact energy, measuring 12.65 HBR and 4.77J, respectively. Sample A3 exhibited the highest tensile strength of 143.88N/mm².
- Highest extension of 2.4mm was. observed by the alloy compared with the reinforced materials, with the material having 100%GR reinforcement recording 1.81 mm and 1.23mm for material having 100%SiC.

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