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Experimental investigation on mechanical properties of carbon fiber reinforced aluminum metal matrix composite

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A B S T R A C T

Many research works were carried out in the field of material science; these researches show that the composite materials are better than the conventional materials due to their enhanced mechanical properties. The recent manufacturing trends, aluminium based composite materials are popular in most of the application like automotive, aircraft, military, and others. The carbon fiber reinforced aluminum metal matrix composites are highly potential materials for aerospace and electronic industries. In the present work, an open die casting method is used to fabricate the AA 6061 based composite material. The AA 6061 is used as a base metal, and the uncoated continuous long spool-type pitch-based carbon fibers are used as reinforcement. The carbon fibers were placed in the format with two-levels of weight percentage 5% and 10%; the carbon fibers were reinforced with a certain distance with AA6061 aluminium alloy; the composite is fabricated with the help of an electric furnace. The composite's mechanical properties were studied by the various mechanical tests and they were compared with the base alloy of AA 6061. The morphological characteristic was studied by the SEM images, which exhibit the uniform distribution of carbon fibers in the composite material.

1. Introduction

The demand for current manufacturing trends needs a variety of materials; the researchers were focused to enrich material characteristics by the various new reinforcements. The Metal Matrix Composite's (MMC's) are composed of a metal or alloy as a continuous matrix and a reinforcement; that can be particulate, short fiber, or continuous fiber. In the MMCs, important metal matrices are Aluminium, Titanium, Copper, Magnesium alloys. In the case of lightweight metal matrix composites, most of the research works done so far, revolves around the Aluminium Metal Matrix Composite's (AMMC's) [1]. The AMMC's composites used for various applications include automobile, defense, transport, and aerospace sectors. AMMCs composites are used as thermal management materials in electronics industries. In this composite, the matrix phase is pure Aluminium, and can be various Al-Si alloys. The aluminum extrusions mostly 6xxx series alloy is predominantly used for most of the industrial applications. The alloys are used in end-use applications, which includes transportation applications with structural requirements to architectural projects with high surface finish requirements yet it is not a commonly used matrix for AMMCs [2]. In the AA5251 aluminium matrix composites reinforced with carbon having a volume fraction of 5–15% using the squeeze casting infiltration process. Due to the squeeze casting process, properties like tensile strength are decreased [3].

In the AA5251 aluminium matrix composites with reinforcement of carbon particle, there is a significant improvement in toughness and there is an increase in Brinell hardness number. Good wetting of the fibers results in improved mechanical properties. Due to this, the fibers are evenly distributed in the matrix [4,5]. The reinforcement of short carbon fibers coated with different metallic films used to control the interfacial reactivity of fibers with molten Al, copper, and Ni coatings are applied during composite manufacture which improves the mechanical properties of the material [6,7].

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2. Metal matrix composites

The availability of fibers, alloy matrices, fiber surface coatings, manufacturing processes, and their influence on the properties of composites is also studied [7,8]. The microstructure interface of C/Al composites review of aluminium matrix reinforced with continuous carbon fibers. The preparation of the AA 7075 aluminium metal matrix composite in squeeze casting for the fabrication of the reinforcement of SiC improves the mechanical properties [9,10]. The treated fibers are directly filtered by molten aluminium alloy in this process; the particulates are uniformly distributed with carbon fibers and the properties such as hardness and wear resistance are improved due to the addition of particulates. The result reveals that the increase in carbon fibers increases the strength [11,12]. The fabrication of CFRASL in the use of structural applications; the mechanical properties were studied such as tensile, flexural, and impact strength respectively are studied and the tests were conducted as per ASTM standards [10]. The structures of sandwich laminate composites were studied; in this study, the reinforcement of carbon fibers improves the mechanical characteristics of fiber [13].

In the powder metallurgy, 6061 based aluminum alloy were fabricated and the characters were studied. The coated and uncoated carbon fibers were reinforced with AA 7075 which results that an improved mechanical strength was achieved [14,15]. The nickel-coated fibers were used in reinforcement in aluninium alloys were studied in different ratios the coated fibers improve the properties of the materials. The uncoated and Ni coated carbon fibers are mixed with AA6061 aluminium alloy powder and subsequently hot pressed [16,17]. The affected factors of mechanical properties like Tensile strength and Impact strength of Al matrix composites are reported in this literature review. The effect of uncoated continuous long mesh carbon fiber on aluminum metal matrix composites properties is studied. layer by layer mesh type reinforcement with the molten aluminium combination is not studied [18,19]. The AA 6061 material is selected for this experimental study because this material is most widely used in many industrial applications but it has to be improved for some special applications [17]. The literature review reveals that the reinforcement of carbon fibers improves the mechanical properties of the materials at the appreciatable level [18]. The preparation of aluminium metal matrix composite was made by several methods, among them squeeze casting method is one of the best and simple methods [19].

3. Experimental procedure

In an Electric furnace is used to achieve the high temperatures and the heating chamber with refractories is used to melt the aluminium alloy composites. The electricity operated furnaces produce heat energy by an induction coil, because of that there has no electrochemical effect on melting alloy metals. In the induction furnace, the container or chamber of metal is surrounded by a coil carrying alternating current, which develops the heat energy. Eddy currents are induced in metal and due this current it produces heat and therefore the metal melts. This melted aluminum is poured into a prepared steel sheet mould weaved with two carbon fiber meshes and the sheet box is placed in the sand mould to support thermal deformations of the box. This molten aluminium is air-cooled slowly. Fig. 1 shows the electric furnace and heating chamber which is used for the melt the alloy metals and refractories and the specifications of the electric furnace are depicted in Table 1.

Graphite Crucible is used for the preparation of AA 6061-carbon fiber composite, Graphite Crucible is used melting of the aluminium alloy because it can withstand at high temperatures while

Fig. 1. Electric furnace.

Table 1
Specifications of electric furnace.

Equipment	Electric furnace
Max capacity	5 kgs
Max temperature	1000 °C
Furnace type	Scooping type
Power consumption	10 kw to 50 kw

melting of an alloy. The crucible is used in several modern laboratory processes, metal, glass, and pigmentation production. Usually, crucibles are made of clay and now a day's crucibles are made with high-temperature resistant materials [20]. This aluminium alloy 6061 is placed in an electric furnace and heated at a controlled temperature of 700 °C, while melting the aluminium the sheet metal box is were used to prepare the two levels of meshes of carbon fiber (5 wt%,10 wt%). The boxes are placed in the middle of the drag box and the surrounding is rammed with green sand, which is prepared to support the thermal deformations of sheet metal boxes. The aluminum about 2.5 kgs is melted in a graphite crucible and the molten liquid of aluminium is poured in the drag mould box and the mould is kept to cool slowly in the air [21]. Fig. 2 shows the experimental procedure of the preparation of material in detail.

4. Results and discussion

In this research work, the aluminium alloy AA 6061 with the reinforcement of Carbon fiber matrix alloy has been prepared in different quantities. The various mechanical tests are performed to investigate the properties of carbon fiber in Aluminium metal matrix composites.

4.1. Torsion test

The torsion test was carried out by using a torsion testing machine, the AA6061 based MMCs specimens were prepared as per the ASTM standard of ASTM A938 used. A set of three samples were made by casting methods in the composition of as shown in Table 2. The Quantity of carbon fiber increased and it is varied in three stages as 0 wt%, 5 wt%, and 10 wt%. It is observed that as the concentration of Carbon fiber increased, the torque also

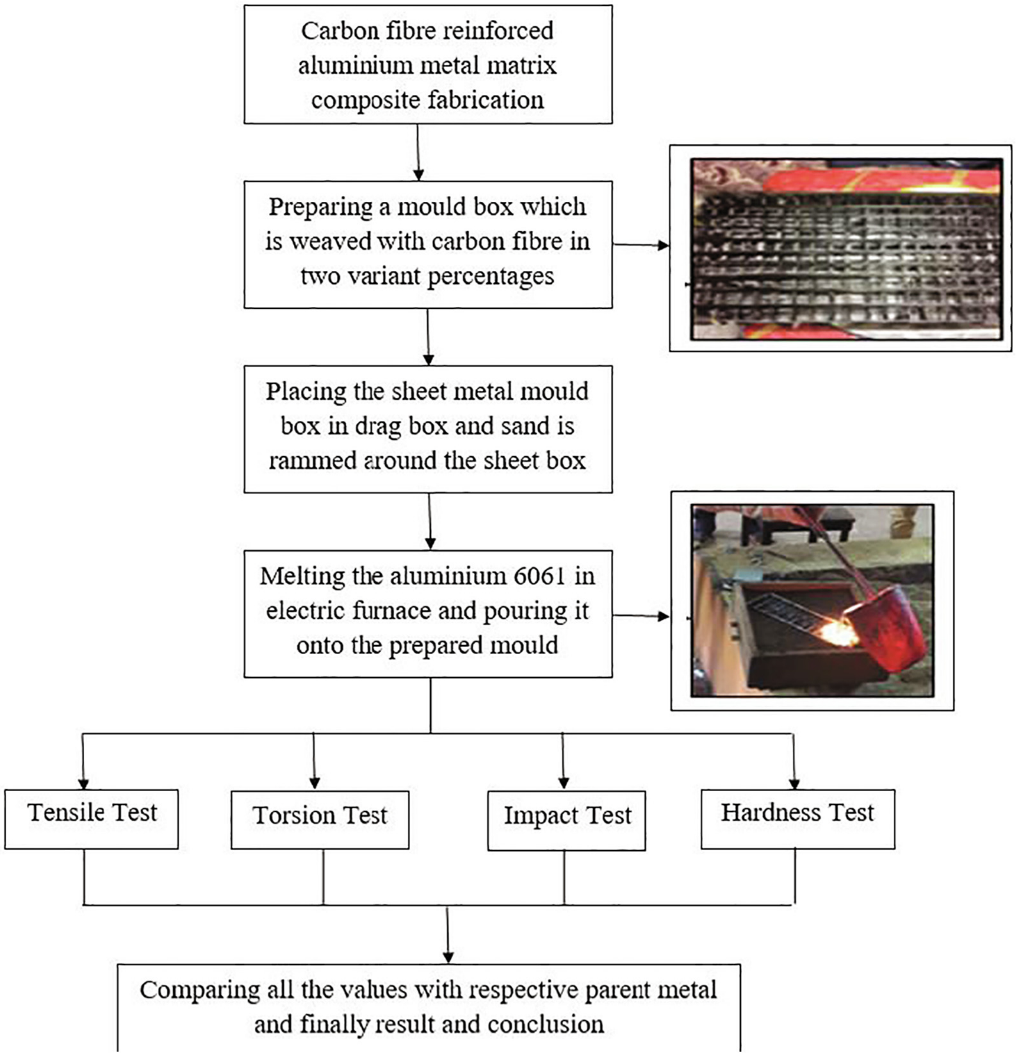

Fig. 2. Experimental Procedure.

Table 2
Result of the torsion test.

Sample Number	Carbon fiber wt.%	Torsion (N-m)
1	0	24.6
2	5	32.9
3	10	52

increased from 24.5 N-m to 52 N-m. When we increased the wt.% of Carbon fiber in such a caseload is increased. In this torsion test, the 10 wt% of Carbon fiber has high torque values are represented in Fig. 3.

4.2. Hardness test

In the Brinell micro hardness machine used to find the hardness value, the hardness test is carried out on the AA6061-carbon fiber reinforced aluminium metal matrix composite with a load of 150 g as tabulated in Table 3. Three samples were made by the casting methods. From Fig. 4, it can be observed that as the content of Carbon fiber is increased then the hardness value of the material is also increased. Three readings are considered for each of the samples. Finally, the average of all the three readings is calculated to minimize the error in the hardness for each of the samples considered as per ASTM E92. The highest value of hardness is 92 BHN is observed for the 10 wt% of Carbon fiber-reinforced composite is shown in Fig. 4. The lowest value of hardness is 74 BHN and the corresponding value of matrix material Al-6061 respectively. By adding carbon fiber the hardness value of AA6061 metal matrix composite is increases.

4.3. Tensile test

The universal testing machine is used for the tensile test value of the Al 6061–Carbon fiber reinforced composite material the tests were carried out per ASTM standard (ASTM E8) and which is shown in Table 4. Three sets of samples were prepared and the quantity of carbon fiber increased and it is varied from 0 wt% to 10 wt% as shown in Table 4. The test results show that the increasing concentration of carbon fiber increases the tensile strength as shown in Fig. 5. The increased wt.% of Carbon fiber in such a caseload is increased, the 10 wt% of Carbon has high Tensile strength of 315.5 Mpa.

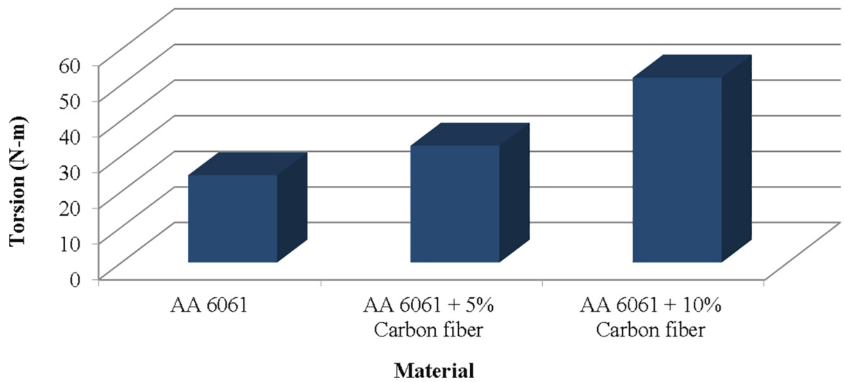

Fig. 3. Variation of torsional load.

Table 3
Results of Vickers Micro Hardness.

Sample No.	Carbon fiber wt.%	BHN	Avg. BHN
1	0	77,74,73	74
2	5	87,83,85	85
3	10	93,99,92	92

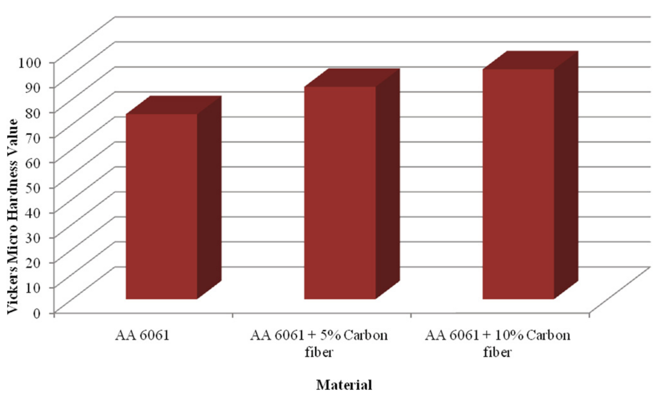

Fig. 4. Variation of Brinell hardness Number (BHN).

Table 4
Result of the tensile test.

Sample Number	Carbon fiber wt.%	Tensile strength (Mpa)
1	0	283
2	5	304
3	10	315.5

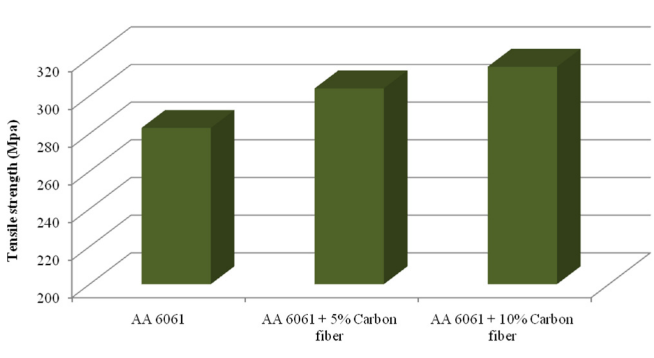

Fig. 5. Variation of Tensile strength.

Table 5
Result of Impact test.

Sample Number	Carbon fiber wt.%	Energy (joules)
1	0	9.4
2	5	10
3	10	12.2

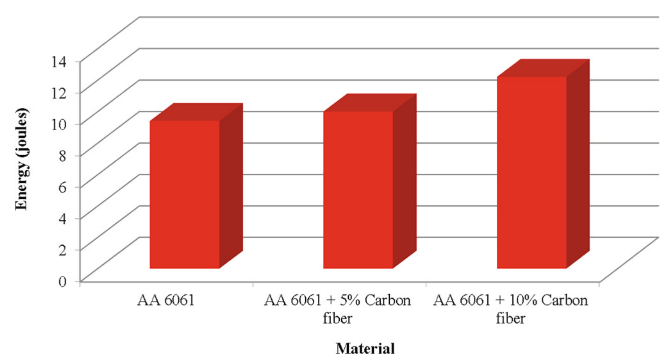

Fig. 6. Energy and reinforcement distribution.

4.4. Impact test

The impact testing values of the composites are shown in Table 5, the three sets of samples were fabricated by casting technique and the test was carried out as per the ASTM standard (ASTM E23). The Quantity of carbon fiber was varied from 0 wt% to 10 wt %, From the test results, it was observed that the concentration of Carbon fiber is increased then the tensile strength also increased. The tensile strength from 9.4 J to 12.2 J for the 0 wt% to 10 wt% of the carbon fibers respectively. The increased weight percentage of carbon fiber in such a caseload is also increased as shown in Fig. 6. The highest impact strength achieved for the 10 wt% of Carbon of 12.2 J.

4.5. SEM analysis

The SEM images of the AA 6061-carbon composite 5 wt% and 10 wt are shown in Fig. 7, it is evidenced that the AA 6061 and carbon fibers were uniformly distributed in the matrix form and the interfacial adhesion is also present up to a nominal level. When compared with Fig. 7a; it is evidenced that carbon fibers are deposited before the aluminium which eventually leads to the composite. The arrangement of fibers in the composite is shown in Fig. 7b; the top portion of the image shows the carbon fibers flow

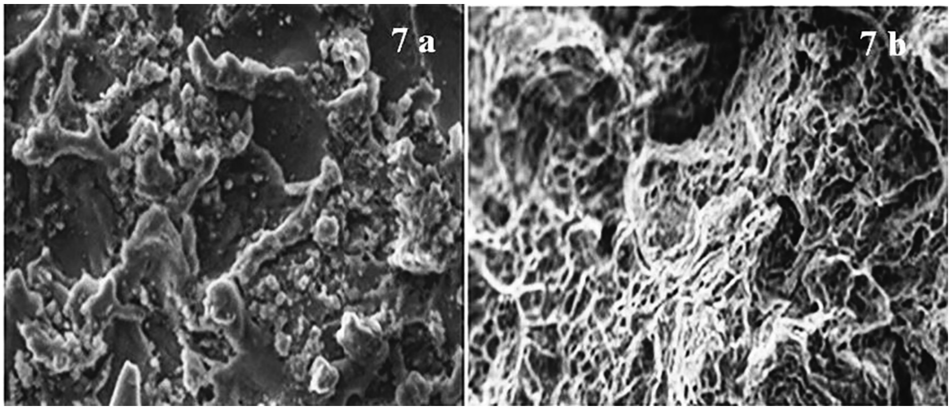

Fig. 7. SEM Image for Al 6061 – Carbon Composite.

in the horizontal direction and the center part shows the fiber in a vertical direction.

5. Conclusion

The present investigation deals with aluminum metal matrix composite of AA 6061 alloy with reinforcement of carbon fiber, in this work the carbon fiber weight percentage varies from 0 to 10% in three combinations and which is prepared in casting technique. The three compositions of AA 6061 composite compositions mechanical properties were studied, the SEM analysis confirms that the carbon fibers uniformly distributed in the composite and the flowing conclusion drawn from the present work:

- The hardness of Al alloy 6061-carbon fiber composites have increased with an increase in the addition of carbon fiber. There is a decrease in elongation with an increase of particle weight percentage due to the silicon carbide and alumina; there is an increase in brittleness.
- The Ultimate tensile strength has improved with an increase in carbon fiber content, whereas ductility has decreased.
- The addition of carbon fiber particles in the matrix increases the Hardness and the addition of carbon fiber mesh type layers the impact strength increased.

CRediT authorship contribution statement

N. Mahaviradhan: Conception and design of study, Acquisition of data. **N. Padma Sravya:** Analysis and / or interpretation of data. **S. Sivaganesan:** Drafting the manuscript. **A. Parthiban:** Revising the manuscript critically for important intellectual content. Approval of the version of the manuscript to be published.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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