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Experimental investigation on mechanical and morphological properties of AA 6061 reinforced with silicon carbide

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ABSTRACT

This research investigation work is aimed to identify the mechanical and morphological properties of the aluminium alloy AA 6061 with Silicon carbide particle (SiC) composites with varying reinforcement. The mechanical properties of tensile strength, hardness, young's modulus, and buckling strength of the composite material are determined based on the impact of the har ceramic particles Sic in 5%, 10%, and 15% reinforcement with the AA 6061 and compared with the base metal of AA6061. And identified the effective method of casting the AA 6061/Sic composite material in the liquid stir casting method, which helps to decrease the porosity and increase the mechanical properties of the composite. The uniform structural dissemination of AA 6061 with Sic in various weight percentages was investigated by the morphological analysis with the help of Optical Microscope image (OM), EDEX, and XRD. The increasing weight percentage of SiC in AA 6061 is increasing the hardness of the composite and decreases the ductility of the material.

Selection and peer-review under responsibility of the scientific committee of the International Conference on Newer Trends and Innovation in Mechanical Engineering: Materials Science.

1. Introduction

The modern rapidly developing world always perforce a good quality of material with lower in the cost; the material to be easy to machine but its posse's high hardness these can be achieved by composite materials. The "composite" is an enriched material, which forms by combining two or more different materials together to obtain the superior and unique properties of it (Sanjay & Mazumdar 2010). This definition holds good and true for all composites. The biggest advantage of such new materials (composites) may be preferred for many reasons: they are light as well as strong. The application requirements can be met by choosing an appropriate combination of matrix and reinforcement material. Composites offer design flexibility so that they can be molded into complex shapes. For example, the world's largest passenger airliner (Airbus A380) made up of composite materials (more than 20%). The design primarily used glass-fiber-reinforced aluminium, a newly developed composite that is 25% stronger as well as 20% lighter than conventional airframe aluminium (Rajeev and Maheshwar, 2014). According to Surappa & Mater (1997), the composites can be classified as follows.

1. Particle-reinforced (large-particle and dispersion-strengthened) -These are composed of a particle of one or more material that is suspended in a matrix of another material to make the material stronger.
2. Fiber-reinforced (continuous (aligned) and short fibers (aligned or random) - these are the long fiber of one material that is embedded in the matrix of other material which turns out to be extremely strong.
3. Structures (laminates and sandwich panels) - these are layers of two or more different materials that are bonded together by sandwiching two layers of strong.

Metal Matrix Composite (MMC) and Aluminium Metal Matrix Composite (AMMC) are the most widely used materials in the engineering applications. MMC is a composite material which has at least two constituent parts, the one being metal and the other may be a different metal or other material, such as a ceramic or organic compound. The MMC synthesized with more than two or at least three materials known as a hybrid composite. According to reinforcement materials, the MMCs are classified as the Graphi-

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tic type and Ceramic type. Aluminum Metal Matrix Composite (AMMC) based material is preferred because aluminium is low-density material. Aluminium has very good corrosion resistance in most environments. Its properties can be increased by alloying it with other materials. Aluminium applications are wide, In transportation (automobiles, aircraft, trucks, railway cars, marine vessels, bicycles, spacecraft, etc.) as a sheet, tube, and castings.

The aluminium alloys are classified in 4-digit serial numbers by the IADS (International Alloy Designation System) and are accepted worldwide. The first four-digit shows the major alloying elements of the particular alloy. In every series of aluminium alloys have a separate material composition based on the composition of the material had different applications; among the eight aluminium series the 6000 series alloy is selected for this research work. It is very popularly used in the automobile industries because of this 6000 series aluminium alloy can be easily machined as well as it can be easily precipitation hardened with the reinforcement of silicon carbide (SiC) and magnesium (mg). The 6000 aluminium alloy series had high strength with a low density which is the main reason this series is most widely used in the automobile industry. Usually, 6000 series aluminium alloy mechanical and surface properties were improved by the reinforcement of ceramic particles like Si3N4, A12O3, B4C, TiC, etc.

2. Literature review

The Metal matrix composites are a new class of material with lower density and are increased in the use of the automobile and marine industries for weight reduction purposes. Owing to its low density, tremendous corrosion resistance, castability, and mechanical properties the exploitation of aluminium and its alloys have become an attractive material for manufacturing low-density metal matrix composites [1]. The metal matrix composites are primarily utilized for buoyancy applications these composites are made of aluminium, steel, titanium, and magnesium alloys [2]. The AMMC alloys are paying more attention majorly due to its lightest structural metal with a density, which is extensively lesser than steel. It is also inferred that the synthesizing of silicon carbide is very tedious even though it has a low density compared with aluminum. Also, it possesses a lower ductility compared with aluminium alloy. This significantly considers that it can replace aluminum in existing applications for further weight savings [3]. However, the application of aluminium and its alloy is inadequate due to accelerated loss of strength with escalating the temperature, low elastic modulus, and lower wear resistance at elevated temperatures [4]. By adding suitable ceramic reinforcement particles can compensate for the above inadequacy. The ceramics of varying particle sizes such as SiC, Al2O3, Y2O3, SiO2, and carbon nanotubes had been utilized for synthesizing metal matrix composites [5]. In addition to that, the processing method such as solid-state method (powder metallurgy, mechanical alloying and diffusion bonding) and liquid state method (pressure infiltration, stir casting, and spray deposition and in situ processing) has been used to develop such composites [6,7]. The synthesizing using solid particle reinforcement provides less optimal properties owing to the inadequate filling of interstitial spaces between the matrix and the reinforcement, reaction between the matrix and reinforcement, the formation of detrimental inter metallic's originates decrease in mechanical properties [8,9]. Despite these challenges, the liquid state method has been utilized for the present study. However, achieving uniform distribution of reinforcement particles within the matrix is more significant which directly impacts the mechanical property [10,11]. Hence it is imperative to manipulate the process factors to achieve consistent distribution of reinforcement in the aluminium matrix and by using this the mechanical property of aluminium matrix composites has to be characterized [12].

3. Experimental procedure

3.1. Aluminium alloy (AA 6061)

The aluminium alloy AA 6061 is already comprising the Silicon (0.6%) in the material composition the other alloying elements are Magnesium (0.89%), Iron (0.25%), Chromium (0.25%), Copper (0.21%), Titanium (0.1%), Zinc (0.11%), and Manganese (0.04). To improve the strength of the material the SiC is adding into the material in various percentages and their mechanical properties were analyzed.

AA 6061 is one of the most commonly using multipurpose alloy which has good mechanical characteristics, the strength the material depends on the heat treatment of the material. The material of AA 6061-in the T6 temperature condition which has 69GPa temper of young's modulus value, 300–310 MPa of ultimate tensile strength and 241–275 MPa of yield strength. The aluminium metal matrix composite is widely used for automobile, aircraft and military aircraft because of corrosion-resistant characteristics (See Fig. 1).

3.2. Silicon carbide (SiC)

The Silicon carbide (SiC) is one of the most popularly used ceramic components which is the compound of silicon and carbon. SiC is a natural ceramic particle, it is used as an abrasive and sintering to form very hard ceramics. It has high strength, low density, high hardness, low thermal expansion, high thermal conductivity, high thermal shock resistance, and superior chemical inertness. In this work 37μ grain size SiC was used a photographic view is shown in Fig. 2 and properties are tabulated in Table 1.

3.3. Preparation of Al/SiC composites

The stir casting method being the most popular and effective method to prepare the alloys materials especially the AMMC; it is effective in fabricating the materials. It is also a modest, more cost-effective method, and an effective blending of material can be achieved [13]. Only in the state of the liquid form of material the composite material can blend properly, which forms the good dispersed phase like ceramic particles and short fibers, etc. The stir casting experimental set up is shown in Fig. 3.

The aluminium alloy 6061 of the quantity of 1000 g was supplied to the crucible of the furnace (stir casting) and it is heated to 850 °C. The SiC particles were preheated in the furnace and it was passed to the stir caster when the AA 6061 in liquid state and stirring process was done, which was maintained at approximately 150 °C above the liquidus temperature. The degreaser

Fig. 1. Photograph of AA 6061.

Fig. 2. Photograph of SiC powder.

Fig. 3. Experimental work setup of stir casting furnace with electric preheating furnace set up.

was added to avoid the oxidation after the complete dispersion of the SiC particle in the AA 6061. The molten metal was poured into the permanent steel mould and solidified after reach the molten AMMC in a proper state of mixing. The AMMC's were made for the required mixture of SiC particle weight percentages of 5, 10 and 15. The test specimens were prepared in the T6 heat-treated condition, Photographic view of the fabricated AA 6061/SiC casted samples were shown in Fig. 4.

4. Metallographically characterization of Al/SiC composites

The synthesis of AMCs (Al/SiC) by reinforcing Aluminium 6061 alloys with SiC in weight percentages like 5%, 10%, and 15% by use of stir casting. The produced AMCs characterized by OM. EDS and XRD. The aluminum alloy of AA 6061/SiC was prepared in the T6 heat treated condition and for preparation of metallographic samples was made by using grinders. The NIKON MM (400/800) inverted metallurgical microscope was used to get the distributed reinforcement of the AMMC's microstructure characterization. The JEOL-MODEL 6390 Scanning electron microscope was used to record the worn surface's Electron Dispersion Spectrum (EDS). The X- RAY DIFFRACTION (XRD) was recorded with the help of Rigaku, Japan, (SmartLab SE X- Ray).

4.1. Optical microscope

The NIKON MM 400/800 inverted metallurgical microscope was used to find the distribution of reinforcement for the microstructure characterization of the AA6061/SiC composite samples. Test specimens were made from the center part of the composite material the velvet disc polishing machine was used to polish the specimens; the burrs and forging particles were removed with the help of Keller's reagent [14]. The aluminium metal matrix composite with varying wt. % in the reinforcement of SiC in 5%, 10%, and 15% were shown in Fig. 5(a–c) are the images recorded by optical microscopic. Fig. 5 the optical microscopic images evidenced that the SiC particles were uniformly distributed; the increased SiC particles homogeneously increase in SiC wt. % which is confirmed through the black spot on the matrix. The NIKON MM 400/800 inverted metallurgical microscope was used to record the microstructure image of AA 6061/SiC distribution in the matrix form.

4.2. Electron dispersion spectrum (EDS)

The AMMC of Al/SiC is prepared by T6 heat-treated condition by using grinders, the Fig. 6. Shows the EDS analysis. The EDS confirms the Al, Si, and C elements of the presence of the composite material and some oxide particles also presents which shows that the material the oxidation in atmosphere. The Electron Dispersion Spectrum (EDS) was analyzed and recorded with the help of JEOL-MODEL 6390 Scanning electron microscope.

4.3. X- Ray diffraction (XRD)

The AA 6061/SiC composites metallic filings were collected and analyzed with the help of X-Ray Diffraction (XRD) and confirms the formation of the intermetallic phases. Fig. 7. Shows the AA 6061/SiC composite XRD pattern and which is matches with the JCPDS file #04-0787. It parades a robust orientation of (1 1 1) plane at 38.33° and the weak orientation of (3 1 1) peak at 77.91° [15]. It can be understood that the higher full width half maximum (FWHM) appeared along with (2 0 0) plane at 44.56°, resulting in the intended crystalline size of about 44.9 nm.

5. Mechanical properties of Al/SiC composites

5.1. Density

The AA6061/SiC composite material was cast by the friction stir casting in the standard size of 20 X 20 X 15 mm^3 work sample pieces were made. The density of the composite material was calculated by using Archimedes Principle; weight different fractions reinforcement was measured. The calculated composite material value is tabulated in Table 2, The increasing 5 wt% of SiC particles into the aluminium metal matrix composite increases around 0.7%. But to the reinforcement of 10–15 wt% of SiC particles not shown the further significant increase or decrease in density.

Table 1
Properties of SiC.

Mechanical properties	Hardness	Yield strength	Ultimate tensile strength	Modulus of elasticity	Density
Value	107 Hv	276 MPa	310 MPa	68.9 GPa	3.2 g/cm3

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Fig. 4. A photographic view of AA 6061/SiC casted samples.

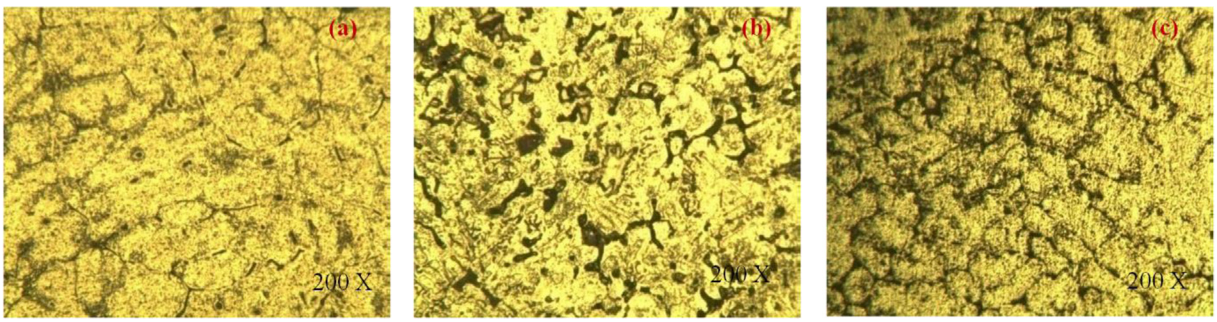

Fig. 5. Microstructure images of Al/SiC composites (a) 5 wt%, (b) 10 wt% and (c) 15 wt%.

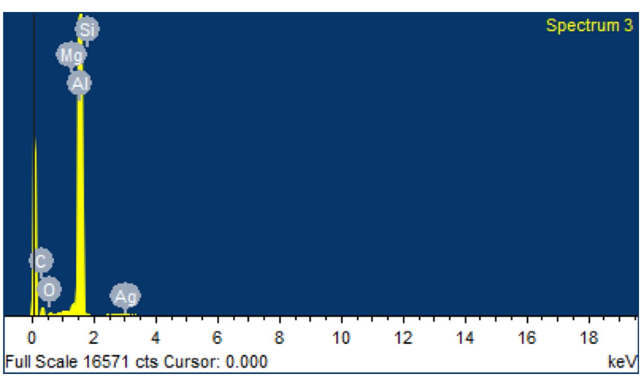

Fig. 6. EDS image of Al/SiC composite.

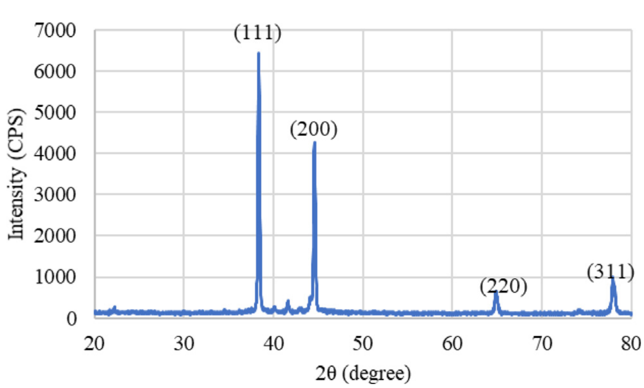

Fig. 7. XRD pattern of Al/SiC composit.e.

5.2. Hardness

The hardness value was measured in the Rockwell hardness test method and followed as per ASTM E-18 standard procedure. The Rockwell hardness is one of the easiest and most commonly used methods to measure the hardness value in the material testing world; which is more accurate also. The hardness value was measuring an average of 5 different locations of the test specimens and each sample to assess its reproducibility the hardness value is plotted in the graphically represented which is shown in the Fig. 8. In the aluminium metal matrix composite (AA 6061) increasing (Reinforcement) of ceramic (Silicon carbide) particle increases the hardness value of the AMMC. The hardness of the 15 wt% SiC in AA 6061 achieved the maximum hardness of 110R_b.

5.3. Tensile strength

Any composite prepared newly their standard to be evaluated by the mechanical properties in which finding of tensile strength value is one of the important tasks of the researchers. In this work, ASTM B-557 standard is used for the preparation and testing of the material. One of the basic essential mechanical properties of the composite is tensile strength; the test was conducted as per ASTM B-557 on the samples. The dimension of the test sample is shown in Fig. 9. A computerized UTM (Ultimate Tensile Testing Machine) was used for testing, in the room temperature the ASTM B-557 samples were tested and the results were observed and recorded.

The Universal Testing Machine (UTM 40) is used to find both tensile strength and young's modulus values of the aluminium metal matrix (AA 6061/SiC) composite material and the observes value is graphically represented in the Figs. 10 and 11 respectively. The increase of SiC 15 wt% in the base metal of AA 6061 which increases the tensile strength directly proportional to the SiC ceramic content and value increased in appreciable level. The test results show that the reinforcement of SiC the young's modulus increased about 59% with 15 wt% from the base metal (AA 6061) young's modulus value; the same kind of result are observed by the in the young's modulus in the AA 6061/SiC composites because of inheritance of the reinforcement behavior to the base matrix.

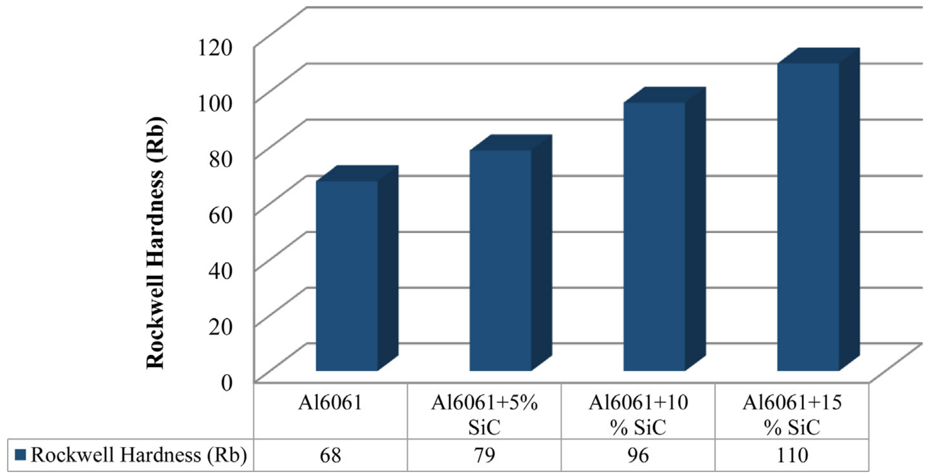

Fig. 8. Hardness of AA 6061/SiC composites.

Fig. 9. AA 6061/SiC specimens for tensile test.

5.4. Buckling analysis

The test specimens were prepared 115 X 20 X 15 mm^3 in the size; the UTM (computerized) machine is used for testing the buckling analysis. In this work both the fixed - fixed and hinged- hinged end conditions buckling analysis were analyzed and the results are recorded and graphically represented in Fig. 12. The analysis shows that the buckling strength varies because of the composition of reinforcement and improved porosity of the specimens.

Table 2
Density of AA 6061/SiC composites.

Reinforcement (wt. %)	0	5	10	15
Density (g/cm3)	2.68	2.7	2.71	2.73

In buckling load analysis, it was observed that up to 5 wt% of SiC no big difference of change has not appeared for both the Fixed – Fixed Ends and Fixed – Hinged Ends methods; because of the Sic particle lack of dispersion throughout the structure of the composite. In the aluminium metal matrix, the formation may lack insufficient SiC particles filling in reinforcement leads to crack formation at the interface of the hard and soft zone. But in the SiC with 10 wt% and 15 wt% had a gradually increased value in both the Fixed –Fixed Ends and Fixed – Hinged Ends methods. The results of the buckling load analysis evidenced that the increasing of wt.% of SiC particle in the composite material increases the buckling strength of the composite material.

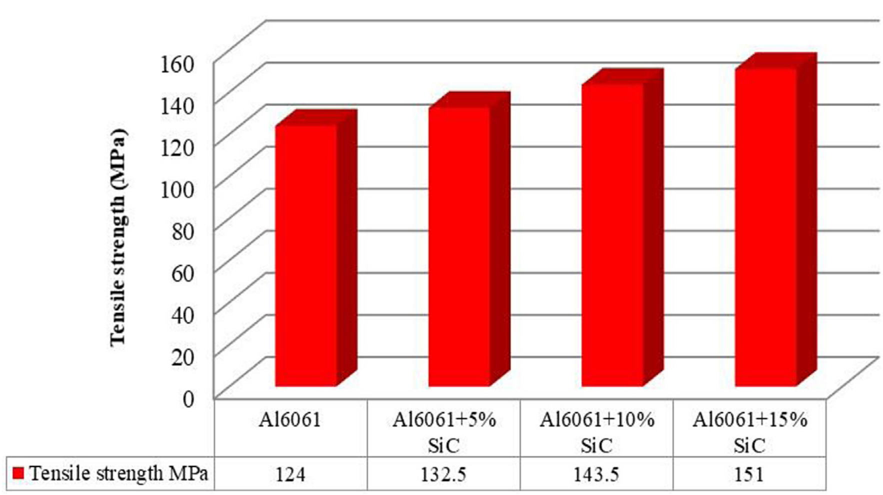

Fig. 10. Tensile strength of AA 6061/SiC composites.

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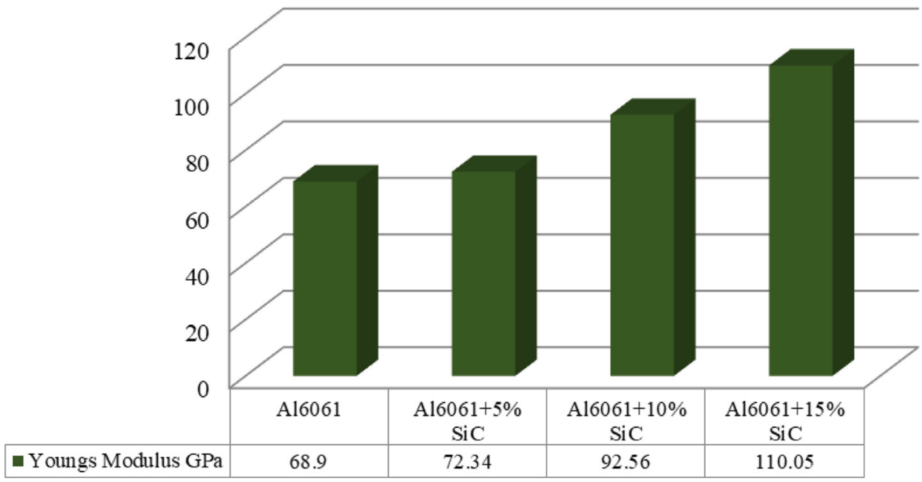

Fig. 11. Young's modulus of AA 6061/SiC composites.

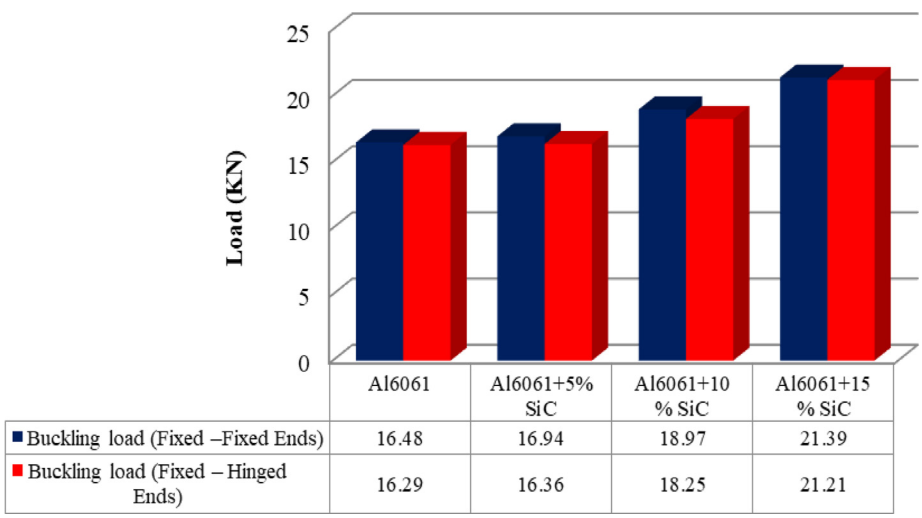

Fig. 12. Buckling load analysis of AA 6061/SiC composites.

6. Conclusions

In this research, the article made an attempt to investigates the mechanical properties with microstructural analysis of the manufactured aluminium metal matrix composites (AMMC) AA 6061/SiC composites. The Aluminium Metal Matrix (Al/SiC) was successfully synthesized by reinforcing AA6061 with different weight % of 5, 10, & 15% by the stircasting method. The following conclusions are derived from the present work.

- The density and mechanical properties like hardness, tensile strength, young's modulus, and buckling strength of the AA 6061/SiC composites are determined, which are increased by the influence of hard ceramic phase compared to base matrix.
- The Optical Microscope images confirm that the presence of SiC with the base metal (AA6061); through the black spot on the composites the presence of SiC was confirmed, which increases homogeneously with an increase in SiC wt. %.
- The XRD of the aluminium metal matrix (AA 6061) with the SiC composite pattern matches with the JCPDS file #04–0787, which confirms the strong orientation of (1 1 1) plane at 38.33° and weak orientation of (3 1 1) peak at 77.91° with an osbornite phase.
- In the density analysis; increasing of 5 wt% of SiC particles into the aluminium metal matrix composite increases around 0.7%. But to the reinforcement of 10–15 wt% of SiC particles not shown the further significant increase or decrease in density.
- The hardness value of the composite AA 6061/SiC increases directly proportional to the ceramic reinforcement of SiC particles and a maximum hardness value of 110Rb achieved for 15 wt% SiC.
- The value of tensile strength and young's modulus of the AMMC of AA 6061/SiC values were raised an appreciable level because of the inheritance of the reinforcement behavior to the base matrix.
- In buckling load analysis, it was observed that up to 5 wt% of SiC no big difference of change has not appeared for both the Fixed – Fixed Ends and Fixed – Hinged Ends methods, but in the SiC with 10 wt% and 15 wt% had a gradually increased value in both the Fixed –Fixed Ends and Fixed – Hinged Ends methods. which is due to the better dispersion and homogeneity of the SiC particles.

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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Further Reading

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