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# **Investigation of the Mechanical Properties of Aluminium (Al6061) Metal Matrix Composites reinforced with Silicon Carbide (SiC)**

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**ABSTRACT:** This study focuses on evaluating the mechanical performance of Al6061 alloy reinforced with silicon carbide (SiC) particles using the stir casting technique. SiC was added in varying proportions—2%, 4%, and 6% 8% by weight—to investigate its impact on properties such as tensile strength, yield strength, compressive strength, and ductility. The results showed that increasing the SiC content led to a notable improvement in strength and hardness. Specifically, at 8 wt.% SiC, the ultimate tensile strength and yield strength improved. Remarkably, the Al6061 with 8% by wt. of SiC composite demonstrates notably high yield of 135.99 Mpa as compared to the base yield strength of 135.99MPa. Composites have a lesser percentage of elongation than the metal they are based on reinforcement particles. As the percentage of SiC in the aluminum alloy is raised to 8 wt %, however, the composites' elongation drastically decreases, falling to around 12.35%. This decrease in elongation can be traced back to the incorporation of SiC particles into the aluminum matrix, which reduces the composites' ductility. The percentage elongation of Al6061 alloy is decreased by the incorporation of SiC particles. As the reinforcing fraction in Al6061 alloy rises, this decrease becomes more pronounced. The presence of stiff, brittle particles within the Al6061 alloy matrix is principally responsible for the reduced ductility it was reduced from 15.26 to 11.29 for 8% reinforcement of SiC.

**KEYWORDS:** Al6061 matrix, SiC reinforcement, metal matrix composites, stir casting, mechanical enhancement, tensile properties, microstructure analysis, SEM characterization.

## **I. INTRODUCTION**

Metal Matrix Composites (MMCs) are gaining popularity as suitable materials for advanced aerospace uses, and their characteristics can be customized by incorporating specific reinforcements. Particulate reinforced metal matrix composites have gained significant attention recently due to their remarkable specific strength and specific stiffness at both room and higher temperatures. It is widely recognized that the elastic characteristics of these composites are heavily affected by the micro-structural attributes of the reinforcement, including its shape, size, orientation, distribution, and volume or weight [1]. Among the different types of matrix materials, aluminium and its alloys are commonly utilized in the production of MMCs and have entered the stage of industrial manufacturing. Focus has been placed on creating cost effective aluminum matrix composites that utilize different types of reinforcements, both hard and soft, such as silicon carbide, aluminum oxide, zircon, graphite, and mica. For a long time, graphite has been acknowledged as a material that is lightweight and has high strength, whether it appears in fibres or particles. Aluminium graphite particulate metal matrix composites created through solidification methods are a category of affordable custom materials suited for numerous engineering uses, including parts for automobiles, bushes, and bearings. Composites made of 2024 aluminum matrix reinforced with silicon carbide particles were produced using mechanical alloying and hot extrusion methods. Mechanical alloying and hot-extrusion successfully created a robust bond between SiC and 2024 Al. No chemical substances were created in the area close to the interface. In comparison to non-reinforced alloys, there was a notable enhancement in the Yield strength and Young's modulus. The mechanical properties of composites made from aluminum and silicon carbide were investigated by Vijaya Ramnath. They mentioned that increasing the amount of SiC leads to a reduction in the density of the composite, while simultaneously increasing its hardness[2]. Additionally, it has been noted that as the weight percentage of boron carbide in the composites rises, the final compressive strength of the composites also increases. To improve the mechanical characteristics, such as tensile strength and hardness, efforts have been directed



towards reinforcing the 6061 aluminum matrix composites with SiC. Aluminum matrix was reinforced with silicon carbide particulates sized 105  $\mu\text{m}$  at 2, 4, 6, and 8 wt % by using the stir casting method. Reports indicated that as the weight percentage of SiC reinforcement increased, both the tensile strength and hardness also rose [3] the characteristics of a hybrid metal matrix composite are influenced by the specific properties of the chosen reinforcement material and the type of matrix alloy utilized. Factors such as manufacturing processes, the shape and size of the reinforcement, and its chemical compatibility with the matrix material all affect the microstructure, physical attributes, tribological behaviour, and other favourable traits of the composite. Common ceramic materials that reinforce aluminum alloys in metal matrix composites include silicon carbide, titanium carbide, zinc carbide, boron carbide, silicon oxide, and silicon nitride. A review of the literature indicates that boron carbide exhibits superior hardness compared to other reinforcement options [4].

## **II. LITERATURE SURVEY**

Christy et al. [1] A comparative analysis was conducted on the microstructures and mechanical characteristics of Al6061 alloy and MMC Al6061/TiB<sub>2</sub>. Their research introduced a comparison between the mechanical properties and microstructure of Al 6061 alloy and a metal matrix composite made from Al-TiB<sub>2</sub>, which included 12% TiB<sub>2</sub> by weight and was produced using the in-situ method. The Al-TiB<sub>2</sub> composites that were produced showed greater levels of hardness, tensile strength, and Young's modulus compared to the base alloy. The composite's ductility was slightly less than that of the aluminium 6061 alloy. Ehsani et al. [02] the aging characteristics and tensile strength of squeeze cast Al6061-SiC metal matrix composites were examined in a study by [19]. Al6061 melt was used to squeeze cast into the pores of SiC preforms measuring 16 to 22 microns, aiming to create composites. The findings indicate that incorporating SiC particles into the 6061Al alloy leads to improved hardness, yield strength, and tensile strength. Mahdavi et al. [03] A study conducted by [20] examined how the amount of graphite influences the tribological properties of Al-Gr and Al-30SiC-Gr composites made through the In-Situ powder metallurgy method. The effect of graphite levels on the dry sliding wear properties of Al6061-graphite composites, as well as Al6061-30SiC-graphite hybrid composites, was evaluated through a pin-on-disc wear test. An increase in graphite content was found to decrease the porosity, hardness, and friction coefficient in both types of composites. Yufeng et al [04] created composites of aluminium alloy and SiC. They utilized a semi-solid powder method to produce the Al6061 composite, which was strengthened with a large amount of SiC particles. The mechanism for compaction and synthesis of the Al6061-SiC composite was examined, and the limit for SiC loading was evaluated. The study examined how the size of the reinforcement particles, the size of the matrix particles, the volume of reinforcement loading, and pressure influence the microstructure and mechanical characteristics. The researchers determined that the initial sizes of Al6061 and SiC particles greatly influenced the composite's microstructure, hardness, and fracture surface. Sajjadi et al. [05] on Al-Al<sub>2</sub>O<sub>3</sub> micro and nano composites made through stir casting. A new three-step mixing technique was employed in their research to enhance the wettability and the spread of reinforcement particles in the matrix. The procedure involved heating micro and nano Al<sub>2</sub>O<sub>3</sub> particles, injecting these treated particles into the molten A356 aluminium alloy, and stirring the mixture at various speeds. An investigation was conducted on how different processing parameters, including the heat treatment of particles, injection method, stirring speed, the size of reinforcement particles, and the weight percentage of reinforcement, affect the microstructure and mechanical properties of composites

## **III. METHODOLOGY**

Al6061 belongs to the 7xxx series of alloys, where Zinc and Magnesium serve as the primary alloying elements, often combined with copper. Alloys in this series possess the greatest strength compared to all other series. These alloys have been processed and can undergo additional machining procedures. Alloys in this series demonstrate strong mechanical strength after undergoing heat treatment. Aluminium alloys from the 7xxx series are utilized in different aircraft mounting brackets, including extrusions and forgings, as well as in the production of hydraulic equipment. Additional uses include transportation apps, marine needs, rock climbing gear, bicycle parts, inline skating frames, mobile devices, and other components that endure high stress. Table 4.1 displays the chemical makeup of the Al6061 alloy, while table 4.2 outlines its physical and thermal characteristics.[7]

### **SILICON CARBIDE AS REINFORCEMENT**

The idea of boron carbide first became known in the 19th century as a byproduct of creating metal borides. Detailed studies of silicon carbide began only in 1930. Silicon Carbide has the chemical formula SiC. Silicon carbide is the third

hardest material, following diamond and silicon nitride. Silicon-carbon ceramic substances are utilized in tank armor, sabotage powders for engines, and bullet-resistant vests, along with various industrial uses.[8]



Figure 3.1: Aluminium 6061 alloy



Figure 3.2: SiC particles

Table 3.1: Chemical Composition of Al6061 alloy

COMPONENTS	AMOUNT (Wt. %)
Zinc	6.5
Magnesium	2.1
Silicon	0.12
Iron	0.15
Copper	1.5
Titanium	0.06
Manganese	0.10
Chromium	0.05
Aluminium	Balance

Table 3.2: Properties of Silicon Carbide

PROPERTIES	VALUES
Melting point	2445°C
Hardness (kg/mm <sup>2</sup> )	2900-3580
Density (g/cm <sup>3</sup> )	2.54
Coefficient of thermal expansion(10 <sup>-6</sup> °C)	5

#### ALUMINIUM BASED MMCS PREPARATION BY STIR CASTING PROCESS

Stir casting set up as shown in the Figure 4.3 includes resistance furnace and a stirrer assembly was used to synthesize the composite. The material foundation for the current study is the Al6061 alloy. Table 2.1 displays the chemical makeup of the matrix material. The SiC particles utilized in the experiment range from 80 to 90µm in size, and the reinforcement levels are adjusted to 2, 4, 6, and 8 wt. Micro-sized SiC particles are utilized to strengthen the material when creating composites. The preparation of composites has utilized the stir casting method[9]. A specific quantity of Al6061 alloy was placed in a crucible and heated to a high temperature of 750°C using an electrical resistance heat treatment furnace. A digital temperature controller was used to maintain the furnace temperature with an accuracy of ±500C. Ceramic SiC particulates were heated in an oven to a temperature of 300°C as reinforcements. A new method involves mixing the preheated reinforcing particles in two stages. The vortex of the molten alloy received preheated SiC particles. Solid hexachloroethane (C<sub>2</sub>Cl<sub>6</sub>) is used for the process of degassing. Instead of adding all the reinforcement to the molten alloy at the same time, a measured amount of reinforcement is being introduced gradually in increments of two. This will assist in determining the level of inclusion of SiC particles within the matrix alloy. The total amount of reinforcement needed for casting is calculated and added to the melt twice. Before and after the addition of SiC particles, stirring takes place for 10 minutes, maintaining a speed of 300 rpm with the stirrer.[10]

#### PARAMETERS USED IN STIR CASTING

##### Degassing process

To reduce porosity and blowholes in the casting, degassing of the melt is carried out using Solid hexachloro ethane (C<sub>2</sub>Cl<sub>6</sub>). Molten metal was degassed by putting two to three grams of solid hexachloro ethane powder followed by 5 to 6 minutes of stirring.

##### Preheating Temperature of SiC Particulates

It is essential to preheat the particulate to prevent moisture from accumulating; otherwise, moisture and gases can cause the particulate to agglomerate.

##### Stirring Speed

The stirring speed is a crucial factor to consider in the stir casting process. During this process, the stirring speed was set at 300 rpm, generating a vortex efficiently without causing any splatter. The fluidity of the metal determines how fast it can be stirred; if the metal is more fluid, the stirring speed will decrease. It has been observed that at lower speeds, the distribution of particulates is inadequate due to a weak vortex.



**Figure 3.3: Stir casting equipment**

### **MICROSTRUCTURE STUDY**

Microstructures for samples of both the base alloy and composite with varying weight percentages. Optical microscopy and scanning electron microscopy were utilized to examine percentages of SiC. The specimens were prepared prior to carrying out the microstructural test. The central part of each specimen's castings was trimmed using an automatic cutting device. The surfaces of the specimen were processed by grinding with 300, 600, and 1000 grit sandpapers, followed by polishing with 3  $\mu$ m diamond paste using a specimen polishing machine. Currently, the samples that have been finely polished were washed using distilled water. After this preparation, Keller's reagent was applied for etching to enhance the contrast, and samples were then collected for SEM (figure 4.5). Prepared SEM samples used in the study are displayed in Figure 3.4.



**Figure 3.4: The Scanning Electron Microscope**

### **COMPRESSION TEST**

The compression test consists of subjecting a test specimen to a continually increasing compression strain, generally to fracture, for the purpose of determining one or more of the following compression properties; compression Strength, Declination, Percentage Declination in Length, etc. Testing specimen was prepared according to the American Standard Testing Materials (ASTM-E09) as shown in figure 3.5



**Figure 3.5: Universal testing machine**



### TENSILE TEST

All tests were led as per ASTM norms. Tensile tests were directed at room temperature utilizing the all-inclusive testing machine as a part of understanding with ASTM E8 M-04 in Fig. The tensile test specimens diameter of 9 mm and gage length are 5 times diameter of specimen i.e. 45 mm were prepared from the cast composites with the gage length of the specimen is parallel to the longitudinal hub of the castings.

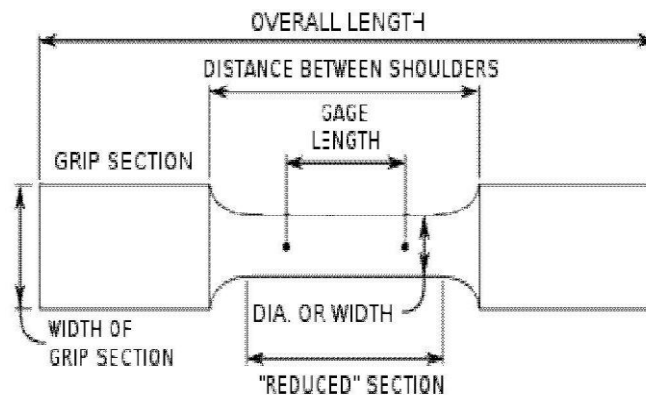


Figure 3.6: Tensile test specimen nomenclature

## IV. EXPERIMENTAL RESULTS

### EVALUATION OF MICROSTRUCTURE

Microstructure is visualized with the help of scanning electron microscope. For the specimen preparation first of all specimens were cut into small cylindrical shape and then the different samples were grinded on different grit size papers sequentially i.e. 220, 400, 600, 800 and 1000. After grinding the specimens were mechanically by alumina paste and then etched by Keller's reagent to obtain better contrast. The specimens were visualized on different magnifications to show the presence of reinforcement and its distribution on the metal matrix. The microstructures of all the samples i.e. as cast, 2,4,6 and 8wt. % of SiC are shown in Figures. In the current work, an attempt has been made to prepare Al6061 aluminium alloy matrix composites with micro size SiC particles by stir casting method combined with preheating of the reinforcing particles.

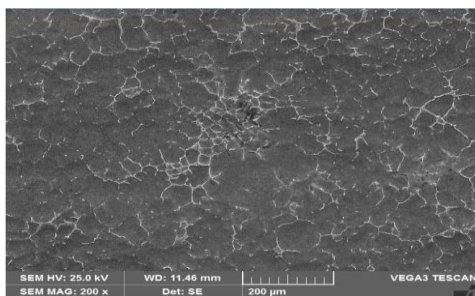


Fig 4.1(2%SiC)

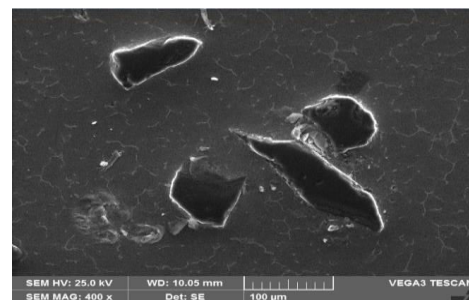


Fig.4.2(4%SiC)

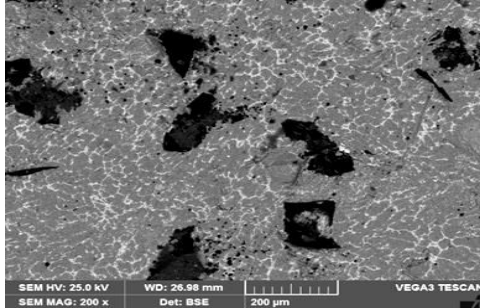


Fig 4.3 (6%SiC)

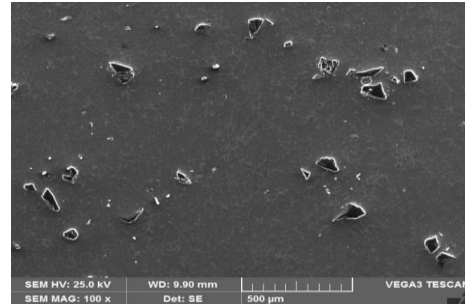


Fig 4.4(8%SiC)

### Compressive Strength

Following the ASTM E9 standard, the manufactured aluminum composites were compressed at room temperature. Compressive strength in Al6061-SiC composites was expressively improved by the addition of SiC to the matrix. It is crucial to understand that a metal composites compressive strength almost always exceeds its ultimate tensile strength. This causes these MMCs to be significantly more brittle than monolithic materials, with percentage elongation values typically falling below 5%. The compressive strength data supports earlier findings and demonstrates a notable improvement over the cast composites with constant reinforcement. The outstanding compression strength of ceramic particles, such as SiC, is more characteristic than their tensile strength. In example, the compression strength of SiC particles is much higher than that of the Al matrix

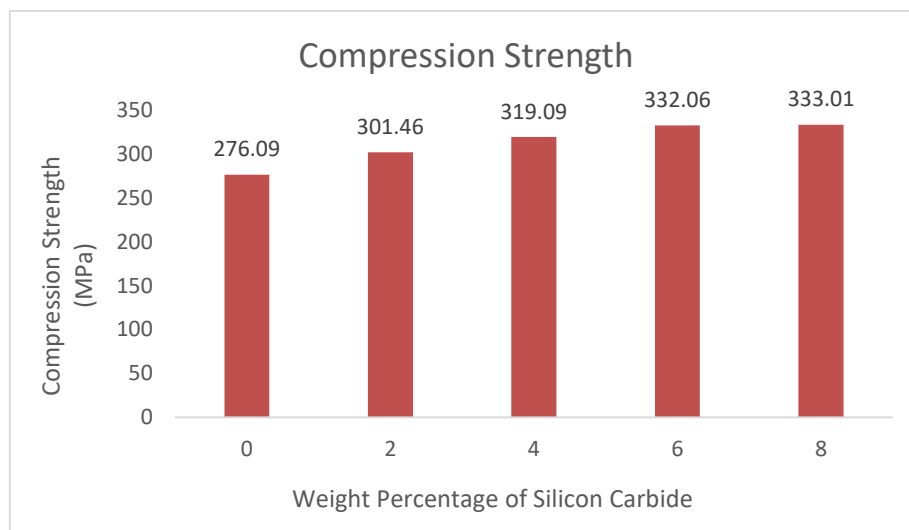


Figure 4.5 Compression strength of Al6061 alloy with Silicon carbide particle reinforced composites

### Tensile Properties

The composites were subjected to room temperature tensile testing in line with the ASTM E-8 standard. Errors were kept to a minimum by carefully preparing three sets of standard specimens and averaging the results. Figure 6 displays the results, which show that the synthesized hybrid composites have expressively higher tensile and yield strength than the monolithic Al6061 alloy. The ultimate strength of as cast alloy (A) is 98.32MPa, the increased proportion of SiC reinforcement, the existence of Silicon carbide particulates, the uniform dispersion of reinforcements within the microstructure, the strong interfacial bonding between the matrix and the reinforcements, the grain size, and the strain gradient strengthening effect are all likely contributors to the observed improvement with 138.64 MPa in case of composite (8 wt.% of SiC). Fig.4.6



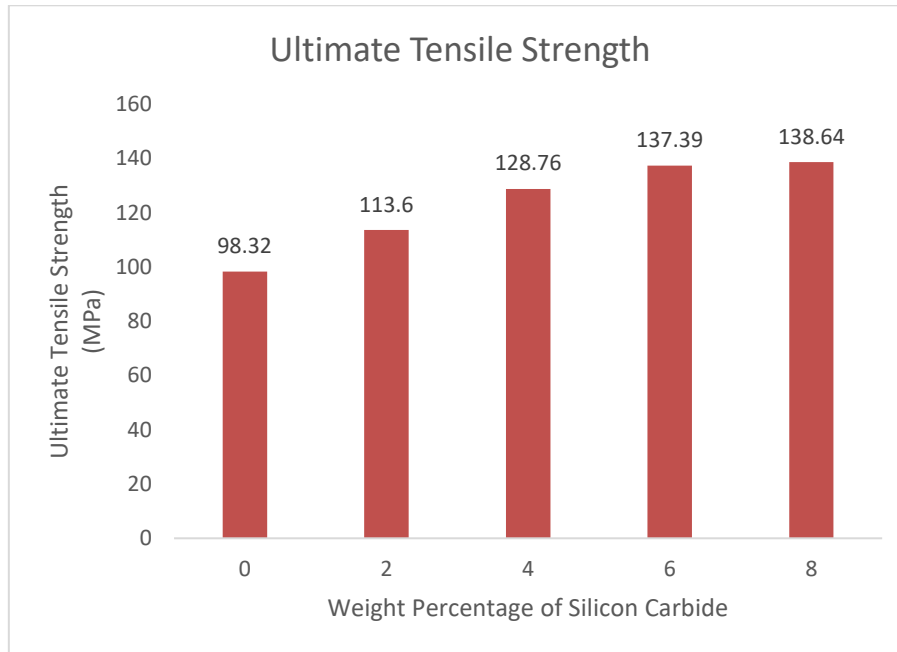


Figure 4.6 Ultimate tensile strength of Al6061 alloy with Silicon carbide particle reinforced composites

#### Yield Strength

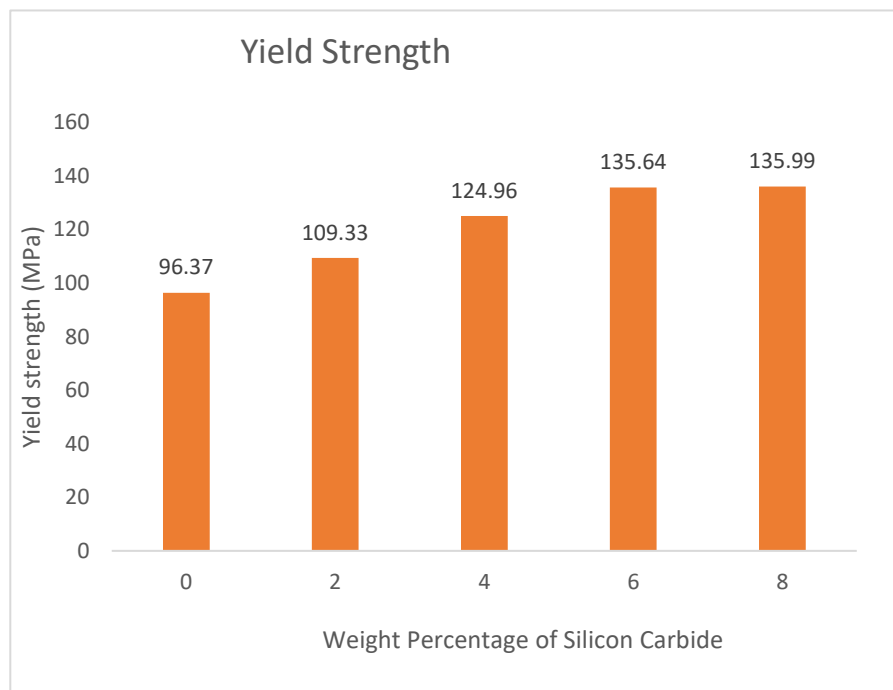


Fig. 4.7. Yield strength of Al6061 alloy with Silicon carbide particle reinforced composites

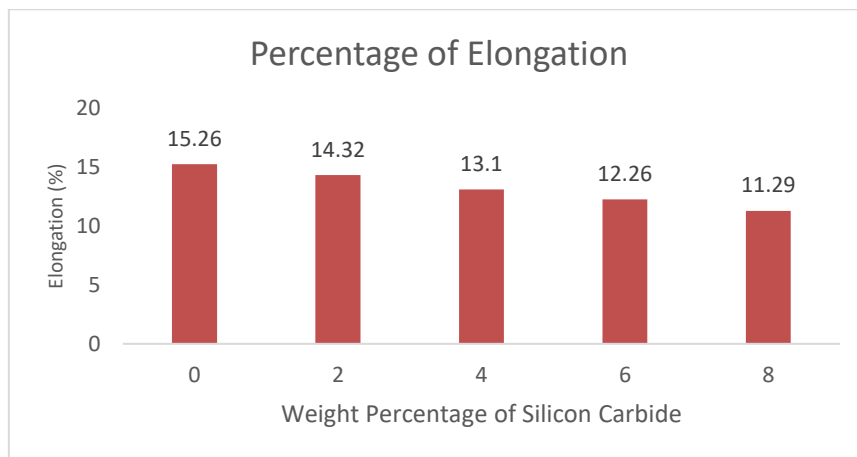


Fig.4.8. Elongation of AL6061 alloy with Silicon carbide particle reinforced composites

## V. CONCLUSION

The present work entitled, “investigation of mechanical properties of Aluminium Metal Matrix Composites Al6061 reinforced with Silicon Carbide (SiC)” has led to following conclusions. Al6061-SiC particulate composites were successfully produced by liquid stir casting route with different weight percentage (viz 2,4,6) of reinforcement. The scanning electron microscopy photographs of composites produced by Melt stirring method shows uniform distribution of SiC particulates in the Al6061 metal matrix. Energy dispersive spectrographs revealed the presence of SiC particulates. The densities of Al6061-2,4,6,8 % SiC composites decreased with the addition of SiC particulates in Al6061 base alloy. There is increase in compression strength with addition of 2,4,6 8. % SiC particulates to base Al6061 alloy.

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