Analysis of Mechanical Characteristics of Silicon Carbide Reinforced With Aluminum Metal Matrix Composites

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Abstract: **The intentions of this exertion is to lessons about the microstructures, mechanical properties and wear characteristics of as cast silicon carbide (SiC) non-breakable aluminum matrix composites (AMCs). AMCs of changeable Silicon carbide (SiC) substance (0, 7, 14 and 24 wt. %) were equipped by stir casting process. Microstructures, Vickers hardness, tensile strength and wear performance of the prepared composites were analyzed. The results show those introducing Silicon carbide (SiC) reinforcements in aluminum (Al) matrix increased hardness and tensile strength and 28 wt. % Silicon carbide (SiC) reinforced aluminum matrix composites showed maximum hardness and tensile strength. Microstructure observation exposed clustering and non-homogeneous distribution of Silicon carbide (SiC) particles in the Al matrix. Porosities were observed in microstructures and increased with increasing wt. % of Silicon carbide (SiC) reinforcements in aluminum matrix composites. Pin-on-disc wear test indicated that reinforcing Al matrix with Silicon carbide (SiC) particles increased wear resistance.**

***Keywords*: Metal matrix composites, Stir casting, Tensile test, Microstructure, Wear, Vickers's Hardness.**

I. INTRODUCTION

1.1 Introduction to Composite Material - A Composite material is a material made from two or more constituent materials with significantly different physical or chemical properties that, the new material may be preferred for many reasons: common examples include materials which are stronger, lighter, or less expensive when compared to traditional materials. More recently, researchers have also begun to actively include sensing, actuation, computation and communication into composites, which are known as Robotic Materials.

1.2 General Classification of Composite Materials - Composite materials are generally used for buildings, bridges, and structures such as boat hulls, swimming pool panels, race car bodies, shower stalls, bath tubs, storage tanks, imitation granite and cultured marble sinks and countertops. The most advanced examples perform routinely on spacecraft and aircraft in demanding environments.

1.3 Significance of Composite Material - Fiber-reinforced composite materials have gained popularity (despite their generally high cost) in high-performance products that need to be lightweight, yet strong enough to take harsh loading conditions such as aerospace components (tails, wings, fuselages, propellers), boat and scull hulls, bicycle frames and racing car bodies. Other uses include fishing rods, storage tanks, swimming pool panels, and baseball bats. The new Boeing 787 structure including the wings and fuselage is composed largely of composites. Composite materials are also becoming more common in the realm of orthopedic surgery. And it is the most common hockey stick material. Carbon composite is a key material in today's launch vehicles and heat shields for the re-entry phase of spacecraft. It is widely used in solar panel substrates, antenna reflectors and yokes of spacecraft. It is also used in payload adapters, inter-stage structures and heat shields of launch vehicles. Furthermore, disk brake systems of airplanes and racing cars are using carbon material, and the composite material with carbon fibers and silicon carbide matrix has been introduced in luxury vehicles and sports cars. Pipes and fittings for various purposes like transportation of potable water, fire-fighting, irrigation, seawater, desalinated water, chemical and industrial waste, and sewage are now manufactured in glass reinforced plastics.

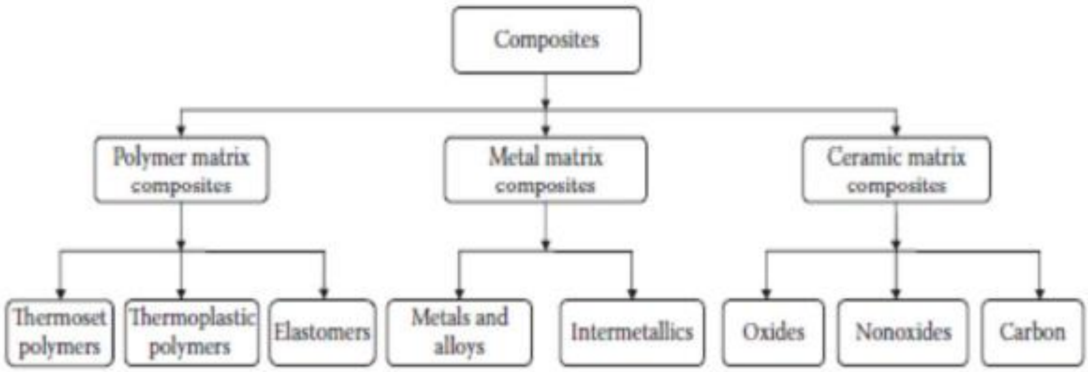

Figure 1 Classification of Composites based on Matrix Material

1.4 Composites Application - The composite materials application is increasing day to day in modern world due to the high tensile strength and with less weight. And Most widely used in Aerospace industry, defense industry, sport goods, marine application etc… and below figure shows the initial to high volume production of goods from a past decades.

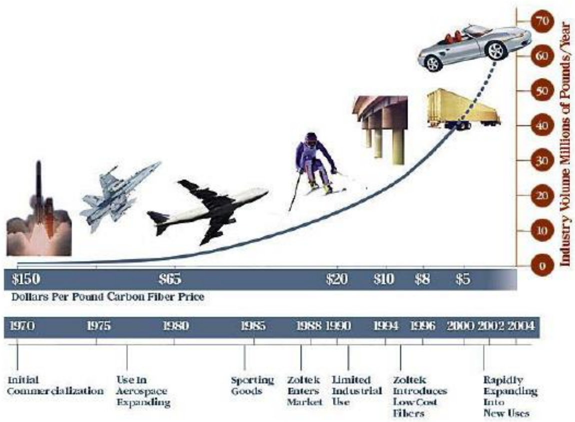

Figure 2 Increase in usage of Composite material in different applications

1.5 Metal matrix composite – It is a type of a composite material with at least two constituent parts, one being a metal necessarily, the other material may be a different metal or another material, such as a ceramic or organic compound. When at least three materials are present, it is called a hybrid composite. An MMC is complementary to a cermets. MMCs are made by dispersing a reinforcing material into a metal matrix. The reinforcement surface can be coated to prevent a chemical reaction with the matrix. They are produced by controlling the morphologies of the constituents to achieve optimum combination of properties. Properties of the composites depend on the properties of the constituent phases, their relative amount, and dispersed phase geometry including constituent part size, shape and compass reading in the matrix.

For example, carbon fibers are commonly used in aluminum matrix to synthesize composites showing low density and high strength. To prevent this reaction, the carbon fibers are coated with nickel or titanium boride. The matrix is the monolithic material into which the reinforcement is embedded, and is completely continuous. This means that there is a path through the matrix to any point in the material, unlike two materials sandwiched together. In structural applications, the matrix is usually a lighter metal such as aluminum, magnesium, or titanium, and provides a compliant support for the reinforcement. In high-temperature applications, cobalt and cobalt–nickel alloy matrices are common.

1.6 Aluminum matrix composites (AMCs) - It is widely found in our on a daily basis life applications. There are some advantages in using particles reinforced aluminum matrix composites AMCs materials than unreinforced materials such as- greater strength and high specific modulus, improved stiffness, light weight, low thermal expansion coefficient, high thermal conductivity, tailored electrical properties, increased wear resistance and improved damping capabilities. Reinforcing constituents can be integrated within the matrix in the form of particles, short fibers, continuous fibers or mono filaments. ***Now it is used in aerospace, thermal management areas, industrial products, automotive applications such as engine piston, brake disc etc.***

Aluminum matrix composites (AMC) can be manufactured by liquid state processing (stir casting, infiltration, squeeze casting etc.), semisolid processing and powder metallurgical route. Usually non metallic and ceramic particles like silicon carbide (SiC), alumina oxide (Al_2O_3), boron carbide (B_4C), graphite etc. are used as reinforcements in aluminum matrix composites AMCs. When loads are applied externally to the composites, metal matrix transmits loads to reinforcements and then loads are carried by detached reinforcements bonded with the matrix. Therefore, good wetting of the reinforcements is necessary during casting. The scope of this study is to examine the effect of Silicon carbide (SiC) reinforcements in Al matrix composites on micro structural aspects, hardness, and tensile strength and wear resistance.

II. EXPERIMENTAL SETUP & MATERIALS USED

This chapter contains the details about materials and the experimental procedure that were considered for the fabrication of composite and the test procedure followed for testing the characterization of composites, respectively. ***The raw materials used for fabrication are***

- ***Aluminum Matrix Material***
- ***Silicon Carbide (SiC)***

2.1 Materials used - ***Al was used as matrix material and Silica Carbide (SiC) particles were added as reinforcements to prepare composites in this lesson***. The chemical composition of Al used as matrix material is given in table 1. To increase the wet ability of Silica Carbide (SiC) particles in the molten Al, 1 wt. % of magnesium (Mg) was added to molten aluminum during casting [5]. Silica Carbide (SiC) particles of mesh size -200/+270 (particle size is below 70μm and above 56μm) and ribbon shaped Mg were used.

Figure 3 Aluminum Matrix Material & Silicon Carbide (Sic) Powder

Table 1 Composition of Al used as matrix material (wt. %)

Element	Fe	Si	Mn	Cu	Mg	Al
%	0.16	0.19	0.01	0.01	0.01	Balance

2.2 Preparation Of Composite Material - Silicon Carbide (SiC) reinforced Aluminum matrix composites (AMC) were prepared by stir casting process.

2.2.1 Casting - ***Casting is a manufacturing process in which a liquid material is usually poured into a mould, which contains a hollow cavity of the desired shape, and then allowed to solidify. The solidified part is also known as a casting***, which is ejected or broken out of the mould to complete the process. A mould is formed in to the geometric shape of a desired part. Molten metal is then poured in to the mould. The mould holds this material in shape as it solidifies. A metal casing is created. Although this seems rather simple the manufacturing process of metal casing is both a science and an art. The following steps involve the procedure of casting manufacturing process to prepare the mould:

- Prepare the sand and mould.
- Place a pattern in sand to create a mould.
- Incorporate the pattern and sand in a gating system.
- Remove the pattern.
- Preparation of furnace.
- Prepare molten metal.
- Stirring Process
- Pouring the metal.
- Allow the metal to cool.
- Break away the sand and remove the casting.

Al was melted in furnace and when the temperature of the liquid Al reached at 780°C, Mg was added in the melt. Heat treated Silica Carbide (SiC) particles were added in molten metal through funnel at 790°C. Silicon carbide (SiC) particles were preheated at 840°C for about two hours. An electrical resistance furnace assembled with titanium impeller used as stirrer was used for stirring purpose. After Silicon carbide (SiC) addition, the liquid metal-reinforcements mixture was stirred for 10 minutes at an rpm of 750. Finally composites were poured in preheated metal moulds at 940°C. The melt was allowed to solidify in the mould.

2.3 Characterization of Mechanical Properties of Specimens - After fabrication, the characterization mechanical properties of each specimen subjected to the following mechanical tests as per the workshop equipments are listed in the below tabular column as follows:

Table 2 Below Table Shows Type of Test Performed and Type of Machine Setup used

Tensile Test	Universal Testing Machine
Wear Test	Pin on disc Method
Hardness Test	Vickers's Hardness Testing Machine
Microstructure	Optical Microscope

2.3.1 Tensile Test - ***The Tensile test is performed on specimens Universal Testing Machine***. In each case three samples of different compositions are taken and their values are recorded.

Specifications of Tensile Test Specimen - The tensile properties of the samples of sizes of length of the specimen is 260 mm long, and minimum diameter of the specimen 20 mm were considered for conducting the tensile test on sample specimen. The tensile test determines the overall strength of the given object. In a tensile test, the object fitted between two grippers at either end then slowly pulled apart until it breaks. The tensile strength is determined as, the elongation measurement is used to calculate Engineering strain.

$$\epsilon = L - L0 / L0$$

Where, LO is the change in gauge length & L is the final length.
The force measurement is used to calculate the Engineering Stress=FA
Where, F is the tensile force, and A is the nominal cross-section of the specimen .

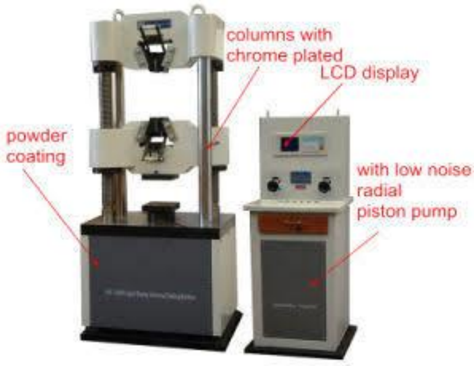

Figure 4 Universal Testing Machine

2.3.2 Wear Test - ***Wear test was conducted using pin-on-disc method at room temperature and dry sliding condition***. Cast iron discs of diameter 9 cm and Rockwell hardness HRC-47 were used as counter discs. The diameter of head and tail were 8mm and 5 mm respectively and the length of head and tail were 4 mm and 8 mm respectively of wear test sample. All wear tests were conducted at 300 rpm of rotating counter disc and applying a fixed load of 10N on test samples. During wear test, weight losses from the worn surfaces were measured at one hour interval with total time duration of 5 hours for each sample.

Figure 5 Pin-on-disc Method

2.3.3 Study of Micro Structure - Metallographic study is the study of metals by optical and electron microscopes. Structures which are coarse enough to be discernible by the naked eye or under low magnifications are termed macrostructures. Useful information can often be gained by examination with the naked eye of the surface of metal objects or polished and etched sections

Microstructures of the composites were observed to reveal the distribution of Silicon carbide (SiC) particles in Al matrix. Samples were polished on emery papers of different grades and then cloth polished with fine alumina powder on revolving wheel. Microstructures were seen in unreached condition using optical microscope at 500X magnification.

2.3.4 Vickers Hardness Test - Vickers hardness of the samples was determined using Future Tech - FV 800 Vickers hardness testing machine. Samples were mounted with Bakelite so that samples could not move when the load was applied. A diamond indenter was impressed on material at a load of 5 kg for 10 seconds. To avoid the segregation effect of the reinforcements in the matrix, four readings were taken for each sample

Figure 6 Vickers Hardness Test

III. EXPERIMENTAL RESULTS

3.1 Micro structure Results - The properties of composites depend on the microstructure and interface characteristics between reinforcements and matrix. Figure 7,8 & 9 show the optical microstructures of 7, 14 and 28 wt. % Silicon carbide (SiC) reinforced aluminum matrix composites (AMCs) respectively. From microstructural analysis, clustering and non-homogeneous distribution of silicon carbide (SiC) particles in Al matrix were observed. This was due to the variation of contact time between silicon carbide (SiC) particles and molten Al during composites processing, high surface tension and poor wetting behaviour of silicon carbide (SiC) particles in the liquid Al. Non-homogenization of silicon carbide (SiC) particles in Al matrix can be observed in the microstructure of 14 wt. % silicon carbide (SiC).reinforced AMC as shown in Figure 8. Some places in Al matrix can be identified without silicon carbide (SiC) reinforcing particles. Porosities were observed in all microstructures. This was because when silicon carbide (SiC) particles were added in the melt during casting, it introduced air in the melt entrapped between the particles. Therefore increasing wt. % of silicon carbide (SiC) Particles increased entrapped air resulted in higher amount of porosity

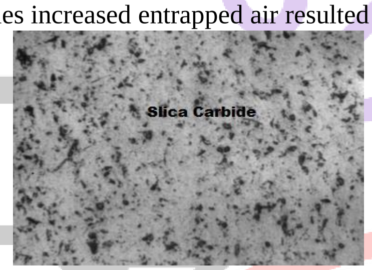

Figure 7 Microstructure of 7 wt. % silicon carbide (SiC) reinforced Aluminum matrix composites (AMC)

Figure 8 &9 Microstructure of 14 & 28 wt. % silicon carbide (SiC) reinforced Aluminum matrix composites (AMC)

3.2. Hardness - The resistance of materials against surface indentation is termed as hardness. The micro hardness of composites evaluates the interface bonding strength between reinforcing particles and matrix.

Table 3 Vickers hardness of silicon carbide (SiC), reinforced Aluminum matrix composites (AMC)

Materials	Vickers Hardness
Al + 0% silicon carbide (SiC)	24.50 ± 0.35
Al + 7% silicon carbide (SiC)	40.67 ± 1.81
Al + 14% silicon carbide (SiC)	44.30 ± 2.43
Al + 28% silicon carbide (SiC)	49.40 ± 1.06

Table 3 shows the Vickers hardness values reinforced Aluminum matrix composites (AMCs) containing varying wt. % of silicon carbide (SiC) reinforcements. The table shows that addition of silicon carbide (SiC) particles in Al matrix composites enhances the hardness of Aluminum matrix composites (AMCs) when compare with unreinforced Al. When unreinforced Al has Vickers hardness value of (24.50 ± 0.35), hardness value increases with increasing silicon carbide (SiC) content and maximum obtained hardness value is (49.40 ± 1.06) for 28 wt. % silicon carbide (SiC) reinforced Aluminum matrix composites (AMCs). The presence of harder and well bonded silicon carbide (SiC) particles in Al matrix that impede the movement of dislocations increases the hardness of Aluminum matrix composites (AMCs)..

3.3. Tensile strength - The relation between tensile strength and wt. % of silicon carbide (SiC) reinforcements of fabricated composites are shown in the below graph. From the tensile test results, it is observed that the tensile strength of aluminum matrix composites (AMCs) is greater than unreinforced Al. Increase of tensile strength in aluminum matrix composites (AMCs) can be attributed due to the applied tensile load transfer to the strongly bonded silicon carbide (SiC) reinforcements in Al matrix, increased dislocation density near matrix-reinforcement interface, and grain refining strengthening effect.

In a composite containing strong matrix with strong interface, the crack has to propagate across both matrix and reinforcements. With the increase of wt. % silicon carbide (SiC), although porosity increases but increase of strength due to strong interfacial bond contributes to enhance the tensile strength of aluminum matrix composites (AMCs). The decrease of tensile strength for 14 wt. % SiC reinforced aluminum matrix composites (AMCs) is due to the effect of segregation of silicon carbide (SiC) particles in tensile test specimens.

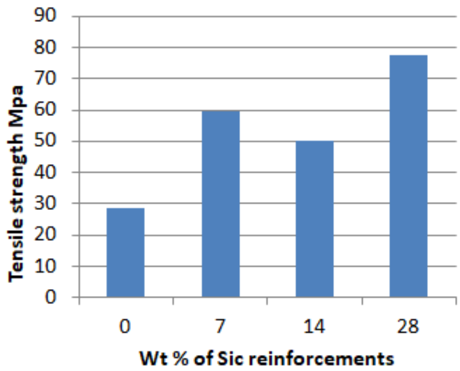

Figure 10 Tensile strength of silicon carbide (SiC) reinforced aluminum matrix composites

3.4 Wear test - Wear is a process of material removal. The cumulative mass loss from sample's surface as a function of time during wear test. It is seen from the graph that mass loss for unreinforced Al is greater than silicon carbide (SiC) reinforced aluminum matrix composites (AMCs). This is because the softer Al matrix is worn away first from sample's surface during wear test leaving the hard silicon carbide (SiC) particles on worn surface. These exposed silicon carbide (SiC) particles protect the Al matrix from further wear. As the wt. % of silicon carbide (SiC) in the aluminum matrix composites (AMCs) increases, the resistance to wear at contacting surface is increased. As seen in Figure 11. 28 wt. % silicon carbide (SiC) reinforced aluminum matrix composites (AMCs) showed lowest amount of mass loss and hence maximum wear resistance.

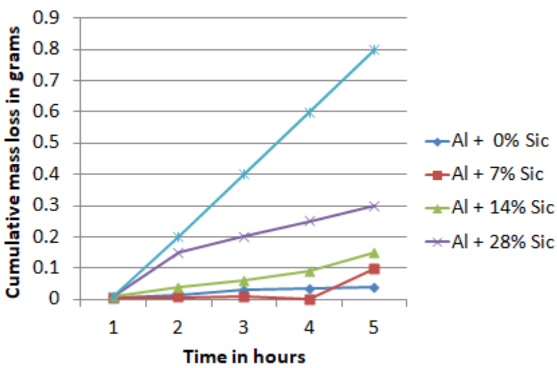

Figure 11 Cumulative mass loss of aluminum matrix composites (AMCs) as a function of time

IV. CONCLUSION

In this experimental study, aluminum matrix composites (AMCs) of varying silicon carbide (SiC) content (0, 7, 14 and 28 wt. %) were prepared using stir casting fabrication technique. Microstructural aspects, hardness, tensile strength and wear characteristics of the prepared composites were studied. Based on experimental evaluation, following conclusions can be expressed as below

- Clustering and non-homogenous dispersion of silicon carbide (SiC) particles in Al matrix were observed in the microstructures. Porosities were found in the microstructures.

- Addition of silicon carbide (SiC) in Al matrix increased Vickers hardness and tensile strength of composites when compared with unreinforced Al. 28 wt. % silicon carbide (SiC) content aluminum matrix composites (AMCs) showed maximum hardness and tensile strength.
- Wear resistance of silicon carbide (SiC) reinforced aluminum matrix composites (AMCs) showed an increase with increasing silicon carbide (SiC) content in Al matrix. 28 wt. % silicon carbide (SiC) reinforced aluminum matrix composites (AMCs) showed maximum wear resistance.

From the results above, silicon carbide (SiC) reinforced aluminum matrix composites (AMCs) showed better hardness, tensile strength and wear resistance than unreinforced Al.

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