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Evaluation of Mechanical Properties of Aluminium Metal Matrix Reinforced with Silicon

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Abstract -*The present work focuses on silicon embedment on the mechanical properties of Aluminium 356-grade matrix composite. The composite is formulated by embedding 3%, 6%, and 9% of Silicon on a weight percentage basis in the Al matrix. Borax is used as an additive, and the composite is prepared by using the stir casting technique. The aluminum matrix composite with Silicon is prepared using the stir casting technique, and borax is used as an additive.After preparing the composites, their mechanical properties are tested. Tensile strength, impact energy, microstructure, and hardness are assessed and evaluated. During the testing and evaluation of mechanical properties, tensile strength, and hardness increased withSilicon. It is observed that impact energy at first decreased marginally and increased later with an increase in % of Si. The samples' microstructures revealed that the reinforcing particles (Si 5% and Si 10%) are visible and fairly well distributed in the Aluminum metal matrix.*

Keywords - *Stir casting, Metal matrix composite, Mechanical properties.*

I. INTRODUCTION

Metal matrix composites (MMC) are engineered materials with a combination of two or more dissimilar materials (at least one of which is a metal) to obtain enhanced properties. The common metallic alloys utilized are alloys of light metals (Al, Mg, and Ti). However, other metallic alloys like zinc (Zn), copper (Cu), and stainless steel have been used, and aluminum remains the most utilized metallic alloy as matrix material in MMC development. MMC consists of at least two chemically and physically distinct phases, suitably distributed to provide properties that are not obtainable with either individual phases alone. Recently, agro/industrial wastes as a secondary reinforcement in composites' fabricationare gaining more importance. The advantages of using these wastes are the production of low-cost by-products, reduction in aluminum products, ease of availability with low cost, and lower densities than most technical ceramics (boron carbide and Alumina).

II. LITERATURE REVIEW

Many researchers have worked with the fabrication and evaluation of the strength of different composites. For instance, Mahendra and Radha Krishna [1] used conventional foundry techniques and produceda hybrid metal matrix composite. Fly ash and SiC were added in 5%, 10%, and 15% by weight (equal proportion) to the molten metal. They reported that the tensile strength, compression strength, and impact strength increased with increasedfly ash and SiC. They noticed that the resistance to dry wear and slurry erosive wear increased with increased fly ash and SiC content. Siva Prasad and Rama Krishna [3] implementedthe vortex technique to fabricate Al/Rice husk ash (RHA) metal matrix composites. They observed that rice husk ash particles' addition reduces composite density while increasing their mechanicalproperties. Ramachandraand Radhakrishna[4] also used the vortex method and synthesized Aluminium based metal matrix composite containing fly ash particulates up to 15% by weight. They, too, concluded that fly ash particles' addition reducedcomposite densityand increasedsome of their mechanical properties. Sharanabasappa R Patil etal. [6] investigatedthe mechanical properties of fly ash and Alumina reinforced aluminum alloy (LM25) composites, processed by stir casting technique. Tensile strength, impact strength & hardness were studied. It was found that the tensile strength & hardness of the aluminum alloy (LM25) composites increased with the increase in weight percentage of Al_2O_3 upto a certain limit. The Charpy test resultsrevealed a decrease in impact load absorption with an increase in %weight of reinforcement. This study's main objectivewas to fabricate the hybrid metal matrix composite using fly ash and Alumina as particulate. They compared the results of hybrid composite with simple composite and with parent metal and found strength enhancement in hybrid composite.K.K.Alane et al.[8] studied mechanical microstructure properties and corrosion behavior of Al-Mg-Si matrix composites containing 0:10, 2:8, 3:7,and 4:6percentagesby weight of bamboo leaf ash

(BLA) with SiC (silicon carbide)reinforcements. The experimental results found that hardness, ultimate tensile strength, and percentage elongation decreased with increased BLA content. Fracture toughness of hybrid composites was higher than single reinforced Al - 10 wt% SiC composite.Suresh [10] studied wear characteristics of hybrid aluminum matrix composites reinforcedwith graphite and silicon carbide particulates and found that hybrid composites exhibit better mechanical properties and wear characteristics. Hence, in this context, the present work investigates the mechanical properties of Aluminium metal matrix embedded with silicon particles at different percentages by weight.

III. METHODOLOGY

In thepresent work, fabrication of composite is done by taking Aluminum 356 as the matrix material and Silicon (Si) as the reinforcement in three different compositions, i.e., 3%, 6%, and 9% through stir casting.Liquid state fabrication of MMC involves incorporating dispersed phase into a molten matrix of metal, followed by its solidification. Good interfacial bonding (wetting) between the dispersed and liquid metal matrix is obtained to provide good mechanical properties uniformly throughout the composite. One way to improve wetting is by coating the dispersed phase. The proper coating reduces the interfacial energy and prevents chemical interaction between the dispersed phase and matrix. The simplest and most effective method forliquid state casting is stir casting.

A. Preparations of composites

In the present study,Aluminum 356 is used as a metal matrix material, and high purity fine powder form of Silicon is used as reinforcement material. The chemical composition of Al 356 is shown in table 1.

Table 1: Chemical composition of Al 356

Element/ wt %	Si	Fe	Mn	Mg	Zn	Ti	Cu
Weight % of element	6.5-7.5	0.6	0.35	0.2-0.45	0.35	0.25	0.03

Al 356 alloy was obtained in the form of ingots. The synthesis of the composite was carried out by stir casting. A specific pre-weighed quantity of Al 356 alloy was taken into a graphite crucible and melted in an electric furnace. The temperature was slowly raised to 850°C. This molten metal was stirred using a graphite impeller at 630 rpm to create a vortex. The impeller blade is designed to create a vortex to achieve particle mixing easily. The vortex method is a well-known method to create and maintain a good distribution of reinforcement in the molten metal matrix. The Si sand is mixed properly and preheated to 450°C to drive off moisture. After forminga vortex in the melt, the reinforcement particles are added with a spatula at the rate of 20-30 gm/minute into the melt during stirring. Stirring is continued for 5 minutes after the addition of reinforcement is discontinued for homogeneous distribution of reinforcement. The mixture is then poured into the metal mould and solidified to room temperature. During sample production, the amount of charge material, duration of stirring, and stirrer positions in the crucible were kept constant.The stir casting process is shown in figure 1. Casted specimens are presented in figure 2. Specimens and their compositions are shown in table 2.

(a) Stir casting machine (b) Stirring using graphite impeller

Fig 1:Fabrication of Si-based Al-MMC

Fig 2: Casted specimens

Table 2: Specimens and their compositions

% of Al356	100	97	94	91
% of Si	0	3	6	9

B. Assessment of mechanical properties

To assess composites' mechanical strength and structure, prepared various tests are conducted and discussed in this section.

a) Tensile strength

Tensile tests were performed on pure Aluminum 356, Aluminum with 3%, 6%, and 9% Si. The tests were conducted on the INSTRON tensile strength testing machine (figure 3). All the properties such as maximum load-carrying capacity, load at the break, ultimate tensile strength, tensile test at yield (offset 0.2%), and modulus of elasticity increased in both the composite materials compared to the pure aluminum 356. The sample is made in a dumble with an outer diameter of 12mm inner diameter of 9mm. The specimen's gauge length is 54mm, and the holding length is 70mm, i.e., 35mm on both sides.

Fig 3: INSTRON Machine used for tensile test

b) Izod test for impact strength

The Izod test is a standard testing procedure for comparing the impact resistances of metal composites.This test is most commonly used to evaluate the relative toughness or impact toughness of materials and is often used in quality control applications where it is fast and economical. Metallic samples generally tend to be square in cross-section (75*8*8)mm, while polymeric test specimens are often rectangular, being struck parallel to the rectangle's long axis. Izod test samples usually have a V-notch cut into them (figure 4).

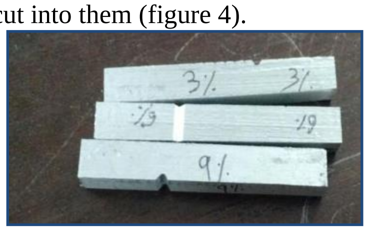

Fig 4: V-notch made to specimens for Izod test

c) Microstructure through the optical microscope

The analysis of the microstructure of composites is important because it affects their mechanical and tribological properties. In the present work, microstructure analysis is done using an Olympus metallurgical microscope. Various specimens that are used for this analysis are shown in figure 5.

Fig 5: Specimens used for Microstructure

d) Hardness test

For measuring Al 356, Rockwell hardness "A" scale,i.e.HRA scale, is employed. This HRA scale uses a Diamond indenter with an application of 60kgf load for 15-45 seconds. The diameter of the steel ball indenter is 10mm. The indent (d) size is determined optically by measuring two diagonals of the round indent. The Brinell's hardness number (BHN) is calculated for the unreinforced and Al356 composites using the equation (1). An average of five readings was taken of each sample for hardness measurements.

$$\mathrm{BHN} = \frac{2F}{\pi D\left(D - \sqrt{D^2 - d^2}\right)} \tag{1}$$

Where: F is the applied load (N), D is the diameter of the steel ball (mm), and d is the size of the indent (mm).

IV. RESULTS AND DISCUSSION

The results of various tests conducted for the aluminum matrix composites are consolidated and discussed here.

A. Tensile strength

The ultimate tensile strength of various materials considered is shown in figure 6. It is observed that the increase in the tensile strength is due to the presence of the hard and higher modulus Si particles embedded in the Al matrix, which acts as a barrier to resist plastic flow when the composite is subjected to strain from an applied load.

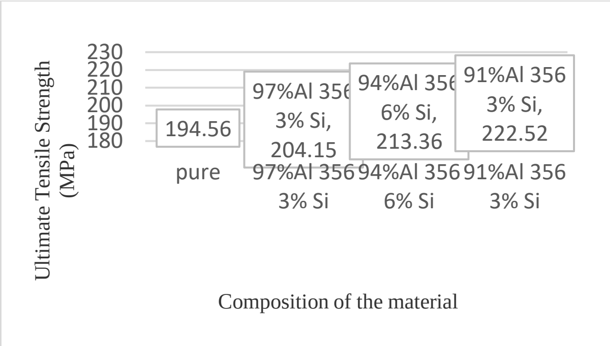

Fig 6: Comparison of the ultimate tensile strength of the material

B. Impact energy

The results of the Izod test are presented in table 3. It is observed that energy slightly decreased and increased later with an increase in the % of Si. A comparative analysis is shown in figure 7.

Table 3: Impact energy of specimens with varying % of Si

Specimen (% Si)	3%	6%	9%
Energy (Joule)	144	142	146

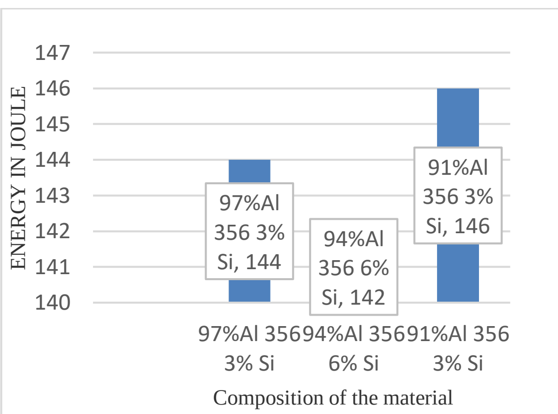

Fig 7: Comparison of impact energy

C. Microstructure

Representative surface images using Olympus metallurgical microscope of composites are produced, as shown in figure 8. It is observed that the reinforcing particles (Si 5% and Si 10%) are visible and fairly well distributed in the Aluminum metal matrix. This is an indication that the stir casting process adopted for composite production is reliable. The microstructural results reveal that the silicon particles are uniformly distributed throughout the MMC castings.

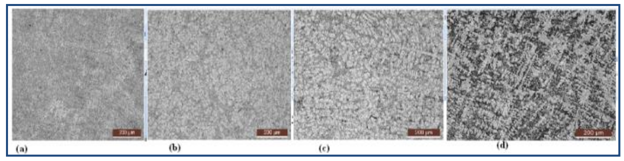

Fig 8: Surface images
(a) 0% Si (b) 3%Si (c) 6% Si (d) 9%Si

D. Hardness

The variation of hardness with weight %of Si reinforcement is shown in table 4. It was observed that the hardness increases with increasing weight fraction of the reinforcement. The increase in the hardness value results from the hard particles in the matrix. Hardness increases as the percentage of Silicon in the Al356 matrix increases. For the pure sample, the hardness was around 26 HRA or 66BHN, and it rose to 83BHN or 35 HRA. Thus, Silicon's addition to the aluminum metal matrix increasesthe composites' hardness, as shown in figure 9.

Table 4: BHN readings for each specimen

% Si	**Reading#1 (HRA)**	**Reading#2 (HRA)**	**Reading#3 (HRA)**	**Average (HRA)**	**BHN**
0	27	24	27	26	66
3	29	32	30	30.3	74
6	31	35	33	33	79
9	36	33	36	35	83

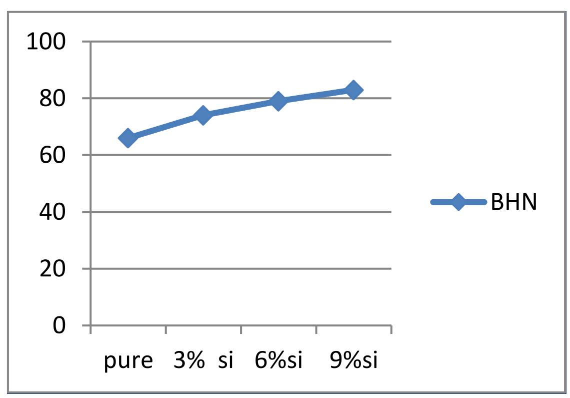

Fig 9: Variation of Brinell's hardness of the composites with variation in the percentage of Silicon

V. CONCLUSIONS

The current study is carried out to determine the influence of Silicon on Al 356 alloy. In this study, tensile, hardness, and microstructure characteristics of two composites of Al 356 reinforced with 3%, 6%, 9% Si were examined and compared to the pure alloy.The following inferences are drawn from the results obtained:

- The addition of Silicon reinforcement to Al 356 leads to an increase in Young's modulus. The strength of the composite is found to be greater than that of the pure alloy.
- Impact energy slightly decreased and increased later with an increase in % Si, and the highest impact energy is tracked at 9% Si.
- The reinforcing particles (Si 5% and Si 10%) are evident and very well distributed in the Aluminum metal matrix.
- It was observed that the hardness increases with increasing weight fraction of the reinforcement.
- Thus due to these effects, the composite may be more suitable than the pure alloy in high wear prone applications like rotors, propellers, etc

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