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Effect of Cenosphere on structural properties of Al 6061-SiC$_p$ Hybrid Composites

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***Abstract*— In this study, stir casting technique was utilized to fabricate the hybrid Aluminum alloy (Al 6061) metal matrix reinforced with silicon carbide (SiC) and cenosphere particulates. An Al6061-SiC-Cenosphere hybrid composite is selected with 3wt% of silicon carbide and 3wt%, 6wt% and 9wt% proportions of cenosphere particulates. The composites were analyzed by measuring the hardness, tensile. Microstructure of the composites was observed by scanning electron microscope (SEM). The results indicate that the yield stress increases up to 6wt% of cenosphere, hardness increases with increase in percentage of Cenosphere. Microstructure shows better bonding between matrix particle interfaces. Finally, the distribution of particulates and the nature of the tensile specimen fractured surface of various hybrid composites were understood using scanning electron microscope.**

Keywords: Cenosphere, Silicon Carbide, Al6061, Stir casting, Tensile strength.

1.0 INTRODUCTION

In recent past, application of hybrid composites are increasing especially in automobile and aerospace sector. Selection of material selection in the fabrication of these composites will depend on various factors such as service life, number of items to be produced, convolution of product shape, possible savings in assembly costs and on the experience & skills of the designer in integrating the optimum potential of composites. Cenosphere is waste product produced from thermal power plant is used as reinforcements, which helps in clearing environmental issues and contributes in increasing structural properties of the developed hybrid composites. Due to low density, better wear resistance and better tensile strength properties, hybrid composites increases their potential application in aerospace and automotive sectors. Among matrix materials Aluminium and its alloy have sustained to maintain their demand due to their lightweight and high performance characteristics [1]. SiC particulates are used as a reinforcement material due to their distinguished high elastic modulus along with Aluminium alloy based matrix and resulted in enhanced structural properties [2, 3]. Also related to low density, least expensive and ease of availability of huge quantities of fly ash is used as filler material in Aluminium alloy based hybrid metal matrix composites [4-5]. The Al based metal matrix composites with different reinforcements are fabricated using stir casting technique, liquid metal infiltration, squeeze casting and low Pressure Die Casting Process [6, 7, 8, and 9]. Among these fabrication techniques, stir casting process involves the mixing of reinforced particulates into molten metal matrix and good bonding with matrix phase [10, 13]. Experimental investigations conducted on Al6061-SiC composites demonstrated better consolidation of SiC reinforcements using ultrasonic assistance [11]. Studies on the effect of SiC particles on tensile properties of Al6061 metal matrix composites, resulted in increased modulus of elasticity and yield strength with increase in SiC weight content compared to fly ash particulates reinforced with pure Al [12]. Microstructural studies conducted on AA2024-fly ash Metal Matric Composites (MMC) indicates uniform distribution of fly ash using scanning electron microscope (SEM) processed by stir casting route [14]. Recently, two or more reinforcements are used in the fabrication of hybrid metal matrix composites to improve the structural properties [15]. Effect of 3%, 6% and 9% weight content of fly ash along with 3% weight content of graphite are studied on mechanical properties of Al6061 based hybrid composite using stir casting technique [16]. It is observed that tensile strength and hardness depend on weight percentage of fly ash in Al 6061 based hybrid metal matrix composites reinforced with 4%, fly ash and graphite [17]. Based on the above literature review, an attempt is made to fabricate Al6061 based hybrid composites reinforced with 3wt% of silicon carbide and different weight proportions of cenosphere (3%, 6% and 9%) particulates using stir casting method. Also, effect of different weight content of cenosphere particles on structural properties of Al6061-

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SiC-cenosphere hybrid metal matrix composites were studied.

2.0 MATERIALS AND METHOD

In the present work, Al6061 alloy is used as matrix material due to its excellent structural properties and cenosphere, silicon carbide (SiC) particles of 15µm and 30µm mean size are selected as reinforcement material for the fabrication of hybrid composites. Various weight percentages of cenosphere particulates (3%, 6%, and 9%) are incorporated into Al6061 alloy, while maintaining a constant SiC content of 3%. Stir casting technique was used for the fabrication of Al6061-SiC-cenosphere hybrid metal matrix composites. The slabs of Al6061 alloy are heated up to 720°C in a crucible furnace. Reinforcement particulates are preheated to remove the volatile substances and ensure good bonding and uniform dispersion in matrix phase. Hexachloro-ethane tablet, degassing agent is added to the slurry mixture to prevent from oxidation and to avoid defects in the casting. Ladle was used to remove the liquid flux and the mixture in the crucible was stirred for 6-10 minutes. The homogenization of the mixture was achieved using mechanical stirring at 500 rpm speed and immersed at 1/3rd the height of molten melt from the bottom of the crucible. To improve the wetting properties and homogeneous mixing of particulates in the molten metal the stirring was done up to 15 minutes. Finally, hybrid composites reinforced with different reinforcement weight content of SiC and cenosphere were casted and the liquid melt is poured to the graphite mold and allowed to solidify [16, 17].

3.0 EXPERIMENTATION

Tensile test was conducted on Al6061 alloy reinforced with 3wt% SiC particles, with varying weight proportions of cenosphere (3%, 6%, and 9%). Consequently, the dog-bone tensile specimen as per ASTM B557 M-94 standard were machined from the rectangular slabs of cast hybrid composites with 6±0.1 mm of gauge thickness and 25mm of gauge length as shown in Fig.1. Identical 5 specimens were prepared for each composite to measure the tensile properties such as: yield strength, Modulus of Elasticity and % elongation. Tensile experiments were conducted using computer interfaced servo hydraulic universal testing machine of with 100kN capacity as shown in Fig. 2 along with extensometers to estimate the deformation. Micro hardness of developed hybrid composites were tested using Vickers micro hardness tester. Microstructural examinations are also carried out to assess the bonding characteristics between the matrix and the distribution of particulates within the composite. Additionally, the fracture surfaces of the tensile test samples for different compositions of hybrid composites were scrutinized using Scanning Electron Microscopy (SEM) to determine the type of failure.

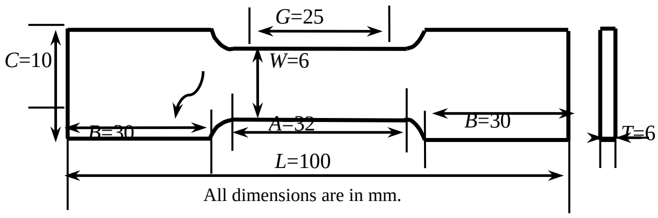

Figure 1. : ASTM B557 M-94 standard tensile specimen

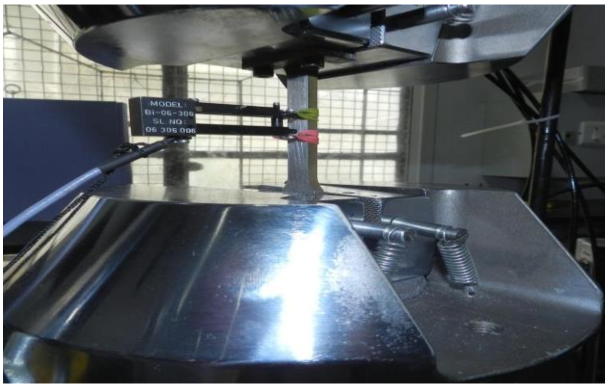

Figure 2: Tensile test Rig [23]

4.0 Results and Discussion

Fig. 3(a-c) depict SEM micrographs illustrating various compositions of fabricated Al6061 hybrid composites, reinforced with 3%, 6%, and 9% weight content of cenosphere, while maintaining a constant 3wt% SiC particle content. SEM images indicates the distribution of reinforced particles in the hybrid composite. It is clearly evident from the Fig.3 (a-c) that cenosphere particles are densely packed for 9% compared to 3% and 6%.

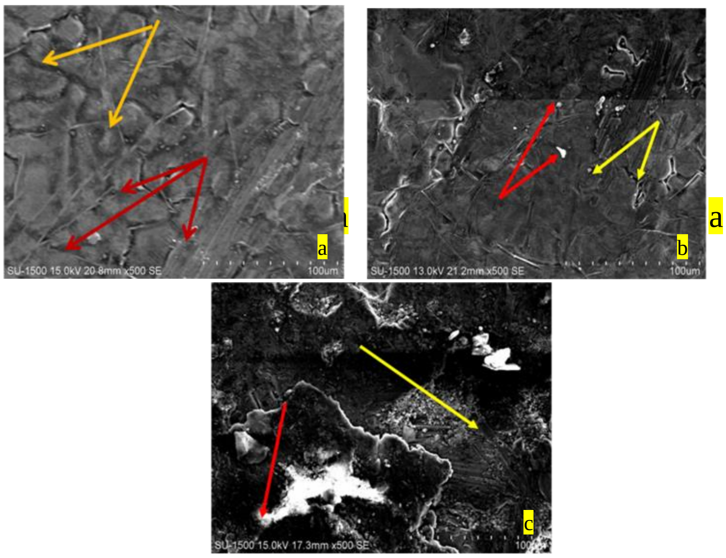

Figure 3. Distribution of Cenosphere and SiC particles in a) Al6061+3% SiC+3% Cenosphere b) Al6061+3% SiC+6% Cenosphere c) Al6061+3% SiC+9% Cenosphere

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The tensile character for different proportions of hybrid Al6061-SiC-Cenosphere composites is shown in Fig. 4 in the form of true stress vs true strain. Average values of 5 specimens are taken to estimate the tensile properties. Fig. 4 reveals that the incorporation of cenosphere into hybrid composites leads to an increase in both yield strength and modulus of elasticity. However, this comes at the expense of a reduction in percentage of elongation compared to the monolith. Tensile characteristics for different compositions of Al6061-SiC-Cenosphere hybrid composites are shown in fig.4 in the form of true stress vs true strain. Average values of 5 specimens are taken to estimate the tensile properties. Fig. 4 illustrates that the addition of cenosphere to hybrid composites increases the yield strength up to 6wt%, after which it begins to decrease for 9wt%. Decrease in percentage of elongation is observed as wt% cenocphere increases [18]. The increase in yield strength, is possibly due to the ideal interfacial bonding between the particulates and matrix of the hybrid composites. Hence, there will be better wetting between the particulates and matrix at the liquid phase, there by nucleation of solid on the particle surfaces will increases by eliminating the presence of adsorbed gases at particle-liquid interface [19].

Table 1 provides a comprehensive overview of the tensile test results conducted in accordance with the ASTM B557 M-94 standard on Al6061 hybrid composites.

Table 1: Tensile strength of Al6061 hybrid composites

Sl. No	Composition	Yield stress MPa	Modulus of Elasticity GPa	% elongation
1	Al6061	92.53	61	21.7
2	Al6061+3wt%SiC +3wt%Cenosphere	97.53	63	19.4
3	Al6061+3wt%SiC+ 6wt%Cenosphere	114	68	11.9
4	Al6061+3wt%SiC+ 9wt%Cenosphere	110	65	8.5

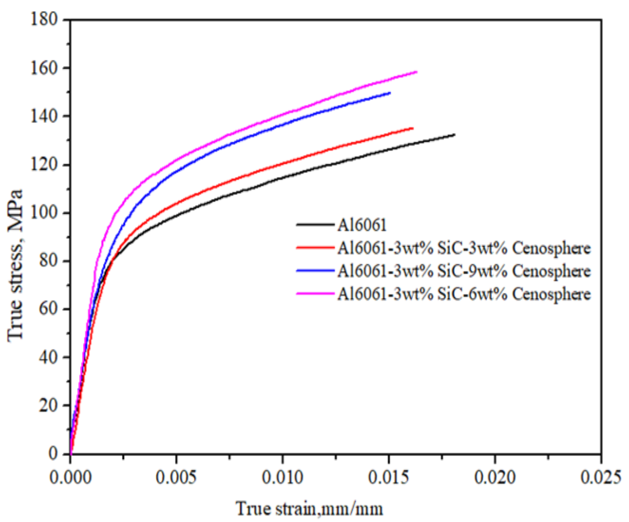

Figure 4. True Stress-Strain Curves [23]

Micro hardness was measured using Vicker Hardness Testing Machine [21] for various hybrid composites and presented in Table 2. Hardness increases with increase in weight content of cenosphere and SiC particles and decreases in percentage elongation. Fig. 5 illustrates a notable enhancement in hardness, indicating a substantial improvement in the material's resistance to localized deformation. This highlights the reinforcing impact of SiC and cenosphere additives. The observed increase in hardness up to 11% suggests that the composite structure, with its integrated reinforcements, has led to improved mechanical characteristics, rendered to more resistance to indentation [22].

Table 2: Vickers Hardness of Al6061 hybrid composites

Material	Micro Hardness VH
Al 6061	63
Al6061+3wt% SiC+ 3wt% Cenosphere	64
Al6061+3wt% SiC+ 6wt% Cenosphere	68
Al6061+3wt% SiC+ 9wt% Cenosphere	70

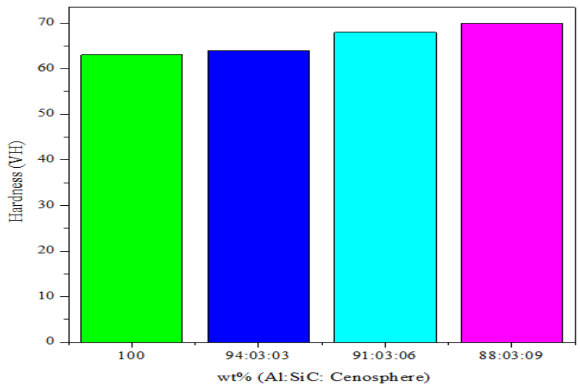

Figure 5. Hardness vs Variation in cenosphere composition [24]

Micro-mechanism failure examination are done on the fractured tensile specimen surfaces of Al6061 alloy and various compositions of Al6061-SiC-Cenosphere hybrid composites. Acetone was used to clean the specified cut dimensions of fractured tensile surfaces and then examined under SEM. From Fig. 5(a) indicates several dimples over the fractured surface of Al6061 alloy there by signifying a ductile fracture behavior. From Fig. 5 (b-d) it is observed that, void nucleation and coalescence increases with increase in the composition of cenosphere which results in the brittle fracture [20]. The transition state of ductile and brittle fracture was also observed for the 3% and 6% of cenosphere in hybrid composites.

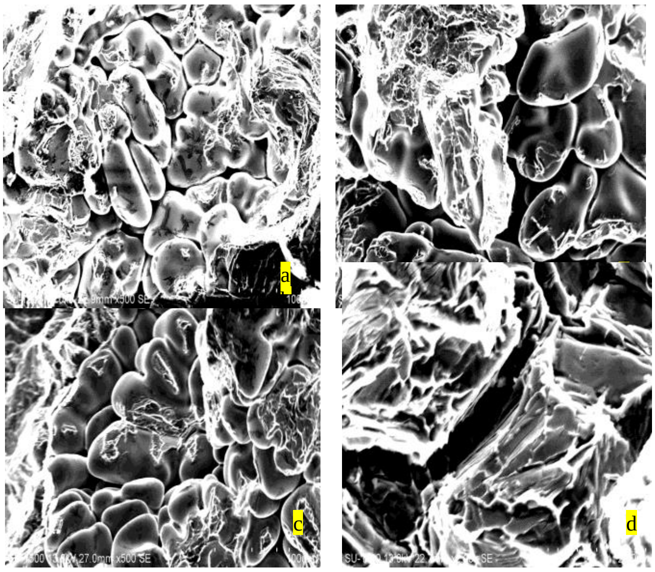

Fig. 5. SEM Fractographs a) Al6061alloy, b)Al6061+3% SiC+3% Cenosphere, c) Al6061+3% SiC+6% Cenosphere d) Al6061+3% SiC+9% Cenosphere

5.0 CONCLUSION

Following conclusions are drawn from this investigations:

- Uniform distribution of SiC and cenosphere particles in the Al6061 matrix processed through stir casting technique incorporating the interfacial bonding of reinforced particles and Al6061matrix,
- Grain structure of the hybrid composite material undergoes refinement due to additions of cenosphere particles will increase the strength of hybrid composites compared to Al6061 alloy.
- Mechanical properties, such as yield stress, exhibit an increase up to 6wt%, while hardness shows a corresponding rise with an increase in the percentage of cenosphere, resulting in a decrease in percentage of elongation.
- Analysis of SEM fractured surfaces of hybrid composites clearly illustrates that addition of cenosphere increases the strength of composite and material undergoes ductile-brittle fracture.

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