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ORIGINAL RESEARCH PAPER

Experimental investigation of material properties of Al-Sic-fly ash composite

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ABSTRACT

Composite materials are granted first choice in the present manufacturing scenario due to their compatibility with tolerances up to 0.001 mm and lower weight. The research design works on the composites of the metal matrix, which are used primarily for aeronautical and industrial applications. Metal matrix composites are being used extensively in structural engineering. Silicon carbide and fly shell ash were used as compliance in aluminium alloys for the manufacture of metal matrix composites (LM13). The composite metal matrix is created employing Stir Casting method. When compared to open moulding, closed moulding, and cast polymer moulding, it is a less expensive and more effective method. The composites produced were then examined for mechanical properties, from the results it was found that the presence of ash and ceramic grains can adversely impact the properties of the composites and even make them brittle. It is time to change the mechanical properties of aluminium by creating hybrid composites with double and often triple-reinforced sections. Hybrid composites have greater performance, better tolerance to tear, low density, resistance to corrosion and strong rigidity over metal matrix composites. In this research an Al-Sic-fly ash composite is proposed and the mechanical properties of hardness, tensile strength, corrosion strength, micro structure analysis are investigated.

KEYWORDS

aluminium composites, fly ash, SiC particles, stir casting

1. INTRODUCTION

Matrix material composites (MMC) are metals which are mixed with other metals, plastic or chemical blends. They are made by removing reinforcements from the metal matrix. Reinforcements are typically performed to advance base metal properties such as energy, rigidity, conductivity, etc. Aluminium and its alloys have earned the highest attention as base components for commodity matrix composites. In some applications of the automotive and aircraft industries, through offering high-quality surface coating, styling details and manufacturing choices, aluminium composite materials have been called the "material of right choosing." Ceramic aluminium is useful in environments with very high temperatures, and even where pollution is an issue. Given that ceramics have low friction and shear properties, the bulk of uses as protection are in suspended particles form (e.g. zinc and calcium phosphate). Silicon carbide (SiC), alumina (Al2O3), graphite (Gr), silica (SiO2), E-glass fibre, boron carbide (B4C), tungsten carbide (WC), granite dust, and fly ash have all been described as reinforcement materials for Al6061-based hybrid metal matrix composites,

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according to the literature. In comparison to other synthetic reinforcing materials, silicon carbide (SiC) and alumina (Al2O3) are the most often used reinforcement particles for HAMMCs [1, 2]. SiC has a density that is somewhat higher than Al6061. It is, nevertheless, chemically compatible with aluminium and has appropriate bonding with the matrix material without forming an intermetallic phase. In comparison to other reinforcement materials, it is a low-cost material with good heat conductivity and workability [3, 4]. Kumar et al. [5] investigated how SiC affects the hardness of an Al6061–SiC composite. They discovered that increasing the SiC content from 0 to 6 wt percent improves the hardness of the composite by 67 percent. This improvement can be attributed to the fact that SiC has a higher hardness. The presence of SiC in the composite improves its hardness. There have been some attempts to prepare HAMMCs with SiC and other reinforcement materials. For the preparation of an Al6061/SiC/Gr hybrid composite, Mahdavi and Akhlaghi [6] used an in situ Powder Metallurgy process. They tested its hardness, compaction behaviour, tribological behaviour, and other properties, and found that the SiC particles reduce the compressibility of the hybrid powders while increasing the composite's hardness. The hybrid composite with 20 vol percent SiC particles has the best wear resistance. Velmurugan et al. [7] studied the friction and wear behaviour of an Al6061 hybrid composite reinforced with 8% SiC and different amounts of graphite (1 percent, 3 percent, and 5 percent). They claimed that decreasing the weight percentage of graphite particles increased the composite's hardness, and increasing the graphite content increased the composite's wear resistance. The tribological properties of a stir-cast Al6061 alloy reinforced with different percentages of SiC and a constant percentage of B4C particles were investigated by Uvaraja and Natarajan [8]. The hybrid composite sample with 10% SiC and 3% B4C composition has improved tribological properties, according to the researchers. Selvam and colleagues [9] used a modified stir-casting technique to make an Al6061 composite reinforced with varied weight percentages of SiC particles and a consistent weight percentage of fly ash. The mechanical qualities, such as hardness and tensile strength, were improved by increasing the weight percentage of SiC particles in the aluminium matrix while maintaining a constant weight % of fly ash. Khan and Naveed [10] used the vortex process to successfully create Al6061–SiC–Graphite hybrid composites with up to 4% graphite and a constant SiC content of 7 wt%. They discovered that by adding 7 wt percent SiC to Al6061, the ultimate tensile strength rises. The ultimate tensile strength of Al6061, on the other hand, diminishes as the graphite content rises. Reddy and his colleagues [11] conducted an experimental study to explore mechanical properties of an Al6061 alloy reinforced with various compositions of boron carbide and silicon carbide produced by a stir-casting technique. Tensile, flexural, hardness, and impact tests were performed and it was found that the hybrid composites had better properties than pure aluminium. Ceramic materials (CMCs), which are used in very high temperature settings, use a ceramic as the matrix and strengthen it with short fibres, or hairs along with silicon carbide and boron nitride [12]. The usage of waste products originating from agricultural operations (red clay, fly ash) and agro-based materials (rice husk ash, bamboo leaf ash, ground nut shell ash, among others) is increasingly improving aluminium matrix composite (AMC). All the incentives listed have rendered AMCs quite famous and between crown option materials for a wide selection of infrastructure uses, due to the enormous combination of content properties, simplicity of manufacturing, decreased expense and accommodation of raw materials as reinforcing tools [13, 14].

When rice husk ash and alumina particles are added to the mix, it becomes stronger. *The behaviour of aluminium alloys.* They discovered that adding such particles to the melt reduced the density and stiffness of the composites produced by a significant amount, while improving the basic strength and overall tensile strength. *The swirl casting method to operate on the impact of rice husk ash and SiC particles on the aluminium alloy* [15, 16]. They found that the density decreased with the rise of the reinforcement and the porosity amount seems to be under control with the overall variance of just 1 percent with the different variations of the reinforcements used. Compared with the samples strengthened with both ash and SiC particles, the fracture resilience of the composites prepared using just ash provided an improved performance. Even the parallel pattern in the outcome was obtained from their analysis, including in the values of tensile strength of the following tests. Density, stiffness, and total composite tensile power decreased with the augmentation [17]. It was noticed under the corrosion test that the composites developed display more resistance against the acid-based liquids. The purpose of the present research is therefore to study the influence of fly shell ash and SiC particles on the mechanical properties when reinforced using stir casting method with pure aluminium sheet [18].

2. EXPERIMENTAL DETAILS

The composites for the sample were fabricated using a swirl casting system to pour the rim. The aluminium alloy was measured according to the necessary amounts in a weighing scale and was then put within the electrically operated crucible. The aluminium molten temperature used to dissolve was 750 °C. TIMEX Red Alstone Aluminium Composite has commercially available fly ash and SiC with particle sizes of 40 and 60m, respectively, which were used to make the composite (Fig. 1).

Throughout the molten metal mix, a limited amount of Mg was applied to improve the melt's wet ability. The samples were preheated in the oven at a temperature of 200 °C before being inserted into the molten metal mix to prevent some sort of moisture in them. The stirring operation was performed using a mechanical stirrer that moved at a pace of 600rpm. The stirring of the molten mix was continued for 5 min to ensure that reinforcements were distributed randomly uniformly with

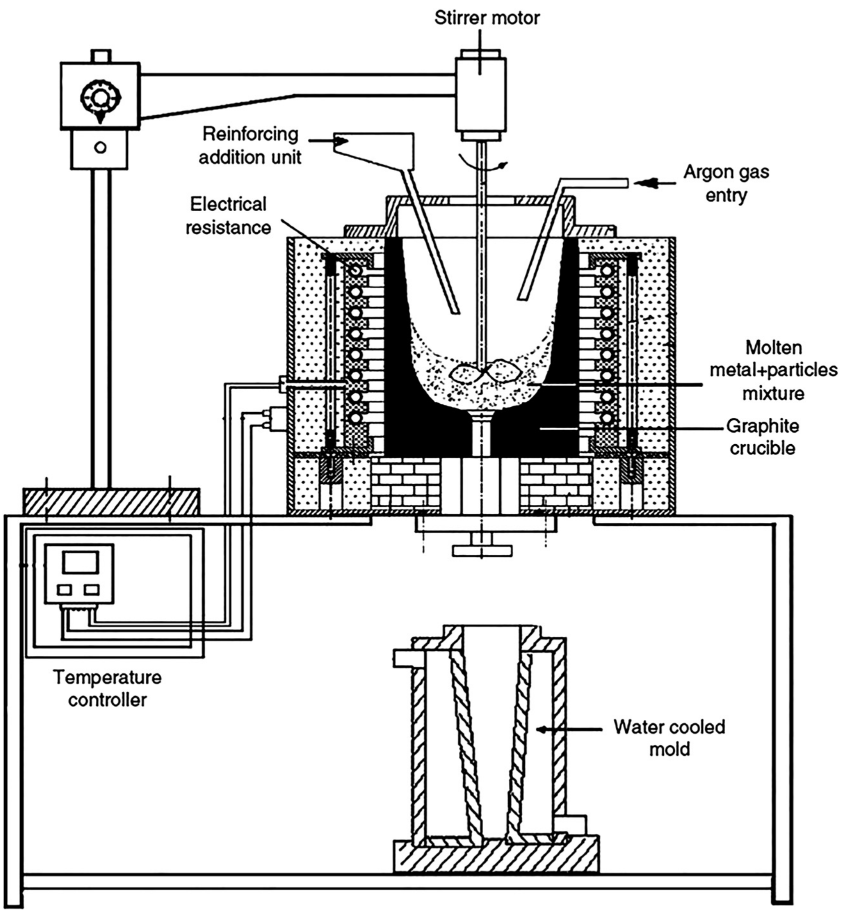

Fig. 1. Schematic diagram of experimental set-up for manufacturing AA2024/B_4Cp composites [11]. Re-published under CC BY 4.0, without any changes

the matrix. The blend then went into the cyst of the mold and was allowed to solidify. Upon solidification the composite was exposed to rapid quenching in water in order to avoid any chilling effects. The same method was used to render all the composites that were used in this study.

3. EXPERIMENTAL RESULTS

3.1. Corrosion

Immersion corrosion tests were performed on both cast and solution heat treated specimens in two different corrosion conditions at chamber temperature of 43.5 °C–35.75 °C and salt P^H value 6.65–6.85. The test specimens were prepared to a width of 6.92 mm and a thickness of 5.80 mm, after which the samples' surfaces were polished with abrasive materials of various grit sizes. The samples were then subjected to an immersion blasting process at 4.80%–5.30% of NaCl solution, and weight loss was recorded according to ASTM G31 standards for each sample. As per established protocols, the corrosion rate for each specimen was derived using data received from losing weight observations.

4. THE EFFECTS OF CORROSION IN A NACL SOLUTION

Immersion corrosion tests on 3 wt%, 5 wt%, and 10 wt% NaCl solutions were conducted over a period of one day, with 5 h intervals. The samples were cleaned using thorough scrubbing reagent and then rinsed in saline solution before being immersed in 5 %wt NaCl salt solutions. Both as cast and solution heat treated specimens comprising varying percent reinforcement were examined for mass loss during immersion corrosion tests in a 5 %wt NaCl solution (Table 1).

In vital media, the corrosion resistance of the composite aluminium alloy matrix reinforced with SiC particulates was evaluated. Throughout the assessment, water and environment were omitted as aluminium was considered to show a very strong resistance to such conditions: any test of such conditions would take a very long period for acceptable performance (Table 2).

The weight loss was calculated from the difference between each coupon's original and final weight during each immersive experience cycle as shown in equation (1) and determining the levels of corrosion as shown in equation (2) in millimeters per year.

Table 1. Experimental parameter

	Trial one	Trial two
Parameter of sample	AluminiumLM-13	AluminiumLM-13+Sic
Duration of test (Hrs)	24	24
Specific gravity	1.028 to 1.0413	1.028 to 1.0413
Temperature (T°C)	35	35
Investigation	Salt spray test	Salt spray test

$$W = W_i - W_f \quad (1)$$

where, W_i = initial weight (kg), W_f = final weight (kg).

$$\text{CPR(mmpy)} = 8600W/(D \times A \times t) \quad (2)$$

where, W is weight loss (mg) during visibility time t (Hrs), D is metal density (g mm^{-3}), and A is the province of the samples area (mm^2).

5. HARDNESS

Durability will be improved due to the inclusion of hardening factors such as SiO, MgO, MnO in hardened powder, because the aluminium matrix has a similar particle distribution. The load is drawn from the SiO particles, which are distributed uniformly in the matrix.

The hardness of base metal aluminium was determined to be 37.23 BHN from brinell hardness tester, so as contrasted with the toughness of the samples prepared using just CSA, there is a 5.2% improvement in hardness value between Al so 3% CSA as hardened.

This simply implies that the structure improves admirably as the unreinforced matrix is combined with strong reinforcement. Similarly, within the study 3% and 5% and 5% and 10%, respectively, a 4.4% and 3% rise in the hardness value is found. This may also be inferred that the application of CSA as reinforced to pure aluminium base material improves the toughness of the base matrix content.

As the wt proportion of fly shell ash combined with silicon carbide rises, a growing pattern of hardness is observed. It is observed that silicon carbide combination with fly shell ash particles has higher hardness than aluminium.

This is because of the higher density and hardness of silicon carbide particles. As mentioned, the ash particles from the fly shell have various stiffening elements. Because of which the mixture has higher strength than pure aluminium. The SiC particles in the alloy tend to shoulder the load going to act on it. The load working on the specimen, owing to the low density and greater strength of the particles, will be nullified.

6. TENSILE STRENGTH

It is very clear that the addition of ash particles into the aluminium matrix improves the composite's load-taking capability or, in other terms, as shown in Fig. 4, enhances the composite 's tensile power. According to the various types of materials found in CSA, as seen in Fig. 2, the intensity increases with the rise of the reinforcing particles. The appearance of particles such as SiO, MgO, MnO, Al_2O_3, etc. in the powder, which are simply oxide-based or ceramic-based, differs with the matrix of aluminium, which connects the particles with the matrix (Fig. 3).

Fig. 2. The Brinell Hardness Test setup

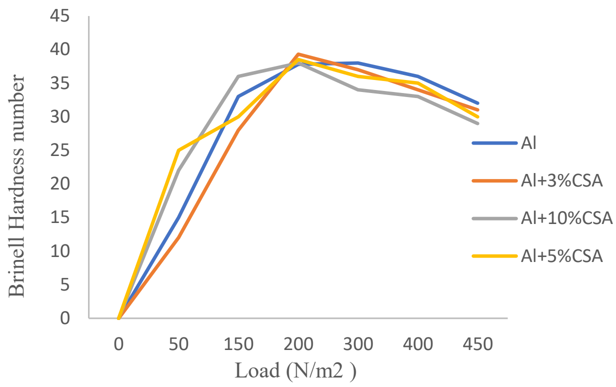

Fig. 3. Brinell hardness number vs load N/m^2

Table 2. Weight loss and corrosion rate

Material	Immersion time (Hrs)	Area (mm^2)	Density (kg mm^{-3})	Weight loss (mg)	Time (Hours)	Corrosion rate (g/mmHr)
Al	1	66	2.7	5	24	0.0115
Al+Sic	1	66	2.95	3	24	0.0063

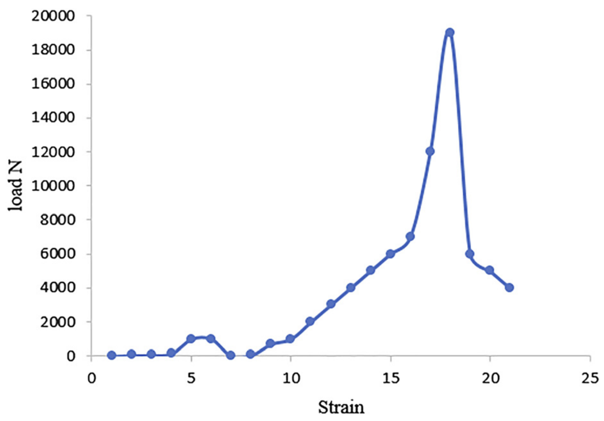

Fig. 4. Load (**N**) Vs Strain (**σ**) variation

Therefore, as the tensile examination is carried out by universal testing machine (UTM), the pulling force or load is shifted from the matrix as added to the specimen and therefore the reinforcing particles are presumed These reinforcing particles help matrix material withstand any kind of deformation to the point of yield. Although these hardened particles take up much of the load while processing, it is still a ceramic material, implying that post yielding the composites may not exhibit much necking and result in abrupt failure [11].

Failure is a known truth about SiC particles, which simply indicates that they would be an intriguing aspect of load bearing and load in composites. Result shows that the maximum force is 9.13 KN. Despite of its strength of the SiC molecule appears to be a strong and brittle substance. If this material is reinforced on a comparatively softer matrix material, it leads to tremendous results.

The tests given in Fig. 4 explicitly confirm the following. The existence of SiC particles in the plastic deformation cycle obstructs the motion of dislocations and therefore enables the matrix to act as an isotopical substance. That is the reason why the composites have increased ultimate tensile strength (Tables 3 and 4).

Table 3. Observation data from universal testing machine (UTM)

Mode of Test	Tension
Sample	Flat strip (6.992 × 5.80 × 25 mm)
Thickness	5.80 mm
Width	6.92 mm
Area	40.14 mm^2
Gauge Length	25.00 mm
Final Gauge Length	26.120 mm

Table 4. Observation from tensile test

Parameter	Output value
F_{max}	9.13 KN
Ultimate tensile strength	227.42 MPa
% Elongation	4.48%
Yeild stress	199.36 MPa

7. CHARPHY TEST

Impact analysis by Charpy. The toughness of the materials was determined via Charpy impact testing. It is performed in accordance with ASTM D256. It has been applied to composites due to its low cost and quickness. A rectangular bar with a machined notch is used for Charpy impact testing. In the case of a standard fibre reinforced polymer, the Charpy specimen is 75 mm long, 10 mm broad, and 10 mm thick (Table 5). The Charpy test is carried out by inserting the pendulum in the equipment which has a known mass and length. The pendulum is lifted to a certain height and then let to drop. The specimen rises to a measured height as the pendulum swings, impacting and breaking it. The quantity of energy lost during the fracture is related to the difference between the beginning and ultimate heights. The total energy absorbed during the fracture is determined by

$$T_{\text{total}} = mg\times(h_i - h_f)$$

where T_{total} is the total energy, m is the mass, g is the acceleration due to gravity, h_i is the initial height, h_f is the final height.

The direction of the Charpy test composite specimen affects its failure. Fibre fracture and fibre pull out are common failure modes, although de-lamination failure is also a possibility. The Charpy impact specimen failure scenarios are depicted in Fig. 5.

8. MICROSTRUCTURE TEST

The microscopic examination of the distribution of sic and Fly ash (csfa) particles in matrix using an ignites analyser. The structure is completed with this specimen dimensions of 40 × 40 × 10 mm. The non-homogeneous distribution of reinforcement occurs as a result of contact type differences between molten aluminium matrix and silicon during composite casting, resulting in poor wetting behaviour and a high surface tension of particals in liquid. The reinforcement has been uniformly dispersed in the aluminium matrix material as a result of the obtained outcome. Reinforcement and matrix have a role in micro structural interface casting. The distribution of silicon particles in the aluminium matrix is clustering and non-homogeneous, according to the microstructure analysis. Figure 6 demonstrates a correct interfacial reaction layer between the aluminium matrix material and the fly-ash. This correct interfacial reaction layer may be responsible for increasing the hybrid composite's mechanical characteristics. The microstructure

Table 5. Charphy test parameter

Test parameter	Sample ID:1	Sample ID:2	Sample ID:3	Average
Absorbed energy in joules	6	6	6	6

Fig. 5. Observation of Charphy test

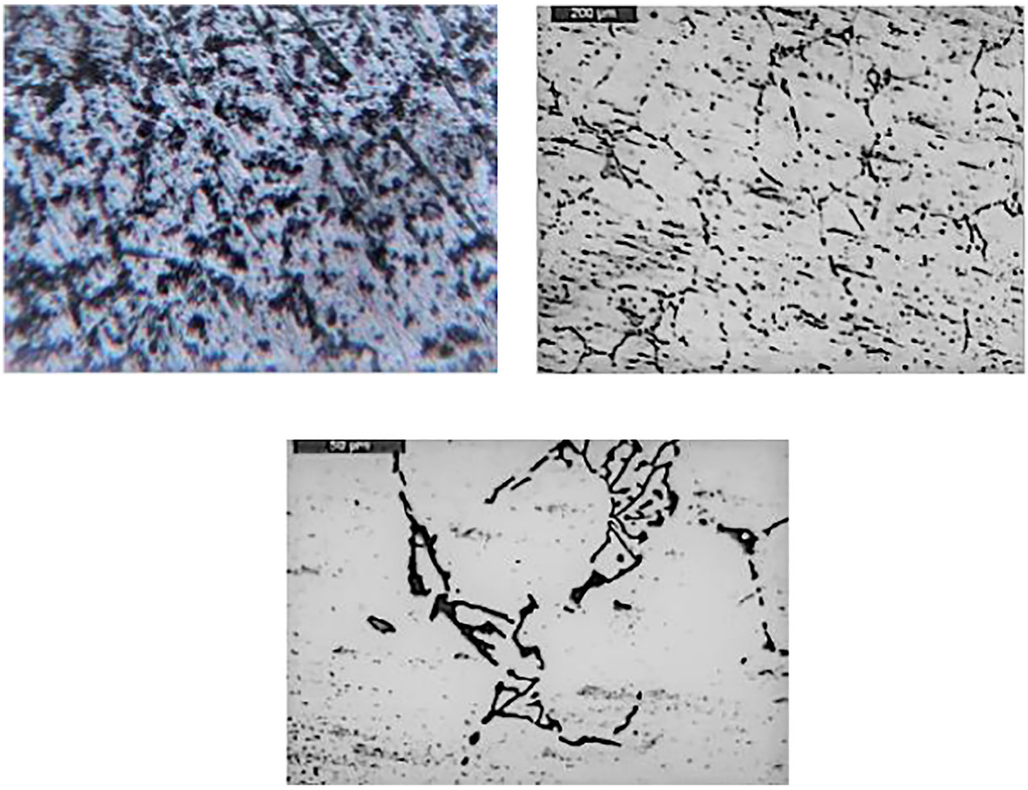

Fig. 6. SEM image of 3% CSA

image of the Al 6061/Al2O3/fly-ash hybrid composite material is shown in Fig. 6. The presence of Al2O3 and fly-ash in the AA6061 matrix material can be seen in the microstructure photograph. The reinforcement particles are evenly dispersed in the matrix material, as seen in the microstructure image.

Figure 6 shows the microstructure images of the produced specimens analysed with various magnifications using SEM, as well as the worn surfaces of composites. SEM image discovered indicate that these composites have high degrees of abrasion and delamination wear processes. Figure 4 shows surface damage with fractures and small cavities with distinct grooves, as well as material decohesion on the worn surface of Al-SiC 3 wt percent. Through the dispersed SiC particles, a thin rich tribo film was created, which helps to avoid direct metal contract, demonstrating that the wear rate is dependent on the available SiC film layer. It may operate as a protective barrier, preventing hard SiC particles from breaking, resulting in less surface damage and delamination wear in specific areas. It can be observed that the presence of SiC acts as a barrier to the moment of dislocation, preventing plastic deformation of the matrix and providing better wear resistance than a base alloy with mild patches and grooves.

9. CONCLUSIONS

Aluminium composites as matrix material and reinforcement materials fly shell ash and SiC spores may be treated well using stir casting processes. Using an increase in the reinforcement material, the density of the composites formed as reinforcements with CSA alone decreased. The addition of SiC particles to the mix increased the sample density by a noticeable amount, but due to the higher ash content, such composites still showed the same pattern. However, the findings of a composite's hardness test revealed that as the ash level in the mix increases, the resilience diminishes. Similarly, adding ceramic particles to composites improves their strength by acting as load-bearing elements in the samples created. The Ultimate Tensile Strength of the composites increased as the proportion of fly shell ash increased. Due to the hard ceramic, there is a noticeable improvement in the values, which tends to limit any elongation in the composite generated when loaded.

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