Fabrication characteristics and mechanical behaviour of aluminium alloy reinforced with Al₂O₃ and coconut shell particles synthesized by stir casting

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Abstract. The paper deals with the preparation of Aluminium Matrix Composite (AMC) using coconut shell particles as reinforcement and Aluminium 6061 as matrix material and to study its mechanical properties and flexural properties. Out of the available manufacturing procedures we have adopted the stir casting technique to prepare the AMC. Different volume % of filler of coconut shell particles has been mixed with the matrix material and specimens were prepared for mechanical studies such as compression, impact, torsion, hardness. The overview indicates that the developed method is quite successful and there is an increase in the value of tensile strength and hardness with increase in weight percentage of reinforcement.

1. Introduction

Aluminium matrix composites (AMCs) are known to be a special hybrid composites with enhanced mechanical, chemical and physical qualities that are difficult to achieve when single unified metals are used [1,2]. AMCs appear high next to steel, in a diverse range of technological fields [3]. AMCs are presently finding applications in the design of vehicle, sport and leisure parts, among others [4, 5]. Properties such as high specific strength and rigidity, low thermal coefficient of expansion, corrosion and high temperature tolerance tell their preference in automotive and aerospace applications. Madakson et al. [6] indicated that the optimal desirable quality of a composite is defined considerably by the reinforcement content. In an attempt to address the drawbacks of the high cost of MMCs arising from interfacial reactions and the large density of more frequently used ceramic reinforcements relative to aluminium alloys, researchers have been increasingly interested in using agro waste as a
secondary reinforcement in composite manufacturing [7-9]. In this agro-waste, the greater deposit of silica and hematite renders it suitable as a reinforcement [10]. The main constituent of coconut shell ash, however, is SiO2 [11, 12]. In India, coconut shell is available in large amounts as an agro-waste. Agricultural waste ashes produced by the regulated combustion of agriculture waste material like bamboo leaf, coconut shell and rice husk and several others have the benefits of minimal density values and processing costs relative to traditional artificial reinforcing ceramics such as silicon carbide and alumina[13,14] . Agricultural wastes ashes are being effectively used to manufacture Al matrix composites with quality level that can be strengthened with the addition of artificial reinforcements like silicon carbide and alumina [15]. Nithyanandhan et al. [16] fabricated hybrid MMC’s based on aluminum and then described its mechanical characteristics like hardness and tensile strength. They developed a new method which is a modification of stir casting and was used to fabricate boron carbide (B4C) reinforced aluminum (6061) alloy. They found that the design method is very effective and there is an improvement in tensile strength and hardness with an increase in the reinforcement weight percentage. Oluyemi et al. [17], fabricated Aluminium 6063/Coconut shell ash (CSAp) composites with various weight percent (wt%) by using double stir-casting technique and then described its mechanical characteristics like hardness, density and tensile strength. They found that as the quantity of the CSAp rises in the alloy, substantial increases in hardness and peak tensile strength were evident, but this happens at the cost of ductility as the young’s modules of the composites declines with the rise in CSAp.

From the literature review it is very much clear that AMCs with CSAp are very important because of their enhanced mechanical characteristics and widespread applications in various fields. So this paper focusses on the use of the CSAp into the aluminium alloy (6061) and reinforced Alumina by the process of stir casting to create matrix composites. The research takes into account the different weight fractions of coconut ash shell particles and Alumina with CSAp. Experiments were conducted to find the mechanical behaviour (compression, impact, torsion, hardness) of these AMCs.)

2. Material Selection
The various materials used in this research are as follows:

1. Matrix : Aluminum alloy 6061
2. Reinforcement : Alumina (Al2O3) / Coconut shell particles
3. Magnesium
4. Degassing tablet (Hexa methyl formate)
5. Slag remover

| Sample | Matrix [ A6061 Alloy ] | Reinforcements |
|--------|------------------------|---------------|
|        |                        | Alumina       | Coconut Shell Particles |
| 1.     | 100%                   | 0%            | 0%                        |
| 2.     | 96%                    | 2%            | 2%                        |
| 3.     | 92%                    | 4%            | 4%                        |

1. ALUMINUM 6061
The alloy A6061 was acquired in the shape as shown in fig.1 and Table 2 indicates its chemical properties. It has good mechanical properties and exhibits good weldability.
Table 2 Chemical Composition of A6061

| Element | Mg  | Fe  | Si  | Cu  | Mn  | V   | Ti  | Al   |
|---------|-----|-----|-----|-----|-----|-----|-----|------|
| Weight %| 1.08| 0.17| 0.63| 0.32| 0.52| 0.01| 0.02| Remainder |

Figure 1. Aluminium Alloy 6061

2. Alumina Powder (Al2O3)

The reinforcement of Alumina (Al2O3) with the average size of 25µm into aluminum matrix improves hard, Wear Resistant, Resist alkali attacks at high temperature. Fig.2 shows the alumina powder used for the project.

Figure 2. Alumina Powder (commercial pack)

3. Magnesium

Magnesium is 1/3rd less dense than aluminium. When employed as an alloying agent, it enhances the mechanical, fabrication and welding features of aluminium. Fig. 3 shows the Magnesium Bar used in the project.
Figure 3. Magnesium Bar

4. Coconut shell ash

Due to its outstanding natural structure and small ash content, the coconut shell is ideal for carbon black preparation. Fig.4 shows the coconut shell ash.

Figure 4. Coconut shell ash

The methodology adopted in this research is schematically shown in Fig. 5 below.
5. **Fabrication using stir casting technique**

For the production of composite, the stir casting method consists of an induction furnace and 3 mild steel stirrer blades. Here by mechanical stirring, the reinforcements are spread into a molten aluminium matrix. The reinforcements are individually elevated closer to the optimal process temperature of 400 °C during the preheating stage, whereas aluminium is heated at a temperature of 830 °C in a different crucible. Now it mechanically stirs the preheated reinforcements. In general, the stirrer is composed of a substance that can tolerate a greater melting temperature than the matrix temperature. In stir casting, graphite stirrer is usually used. The agitator is usually located in a vertical direction and is turned at different speeds by a motor. And the resulting molten metal is poured into the die for casting. Stir casting is ideal for the fabrication of composites with reinforcement fractions of up to 30 percent volume. Fig. 6. Shows the stir casting equipment.
3. Testing and results

The Aluminum Matrix composites with 2 and 4 wt% of Alumina& CSP is subjected to following measurements to evaluate its mechanical properties.

1. Compressive Test (ASTM E9)
2. Hardness Test (Rockwell Hardness) (E18)
3. Torsional Test
4. Impact Test (ASTM E23)

1. Compressive test (ASTM E9)

The composite specimens for determining the compressive strength were prepared according to the ASTM standard E9 [18]. The standard dimensions of tensile test specimen (Dia: 12.5 mm, Length: 25 mm) are shown in fig. 7a with compressive testing machine in Fig. 7b. The tensile strength was measured using a computerized universal testing machine. The hybrid composites' compressive strength is plotted and displayed in Fig. 8. It is visible from Fig. 8 that the introduction of reinforcement weight percentage enhances the compressive strength. In composite materials, the inclusion of reinforcements enhances the strength properties and the absorbed load.
The test specimen along with the testing machine is shown in figure 9a and figure 9b. Rockwell hardness A6061 reinforced with hybrid composite alumina-CSFA is depicted in Fig. 10. In each specimen, the hardness values were assessed at 3 places and a mean of all hardness values were calculated for each specimen. It shows that with the inclusion of alumina and CSFA reinforcement in aluminium alloy, the hardness of the composite material enhances. The rising percentage of reinforcement provides an improvement in the hardness value from 14.6 BHN to 19.0 BHN. The various reinforcements help to reduce particle porosity and fine grain structure, along with providing plastic deformation resistance that enhances the hardness of hybrid composites [19-47]. By combined reinforcement of 4wt% alumina and CSFA particles in aluminum alloy, the overall hardness was 19.0 BHN.
3. **Torsion test**

The shape of the specimen (Length=70mm, total length=200mm, diameter=8mm) along with the machine is shown in figure 11a and figure 11b. Figure 12 shows the test results. It can be seen that the torsion strength increases with increase in the reinforcement and maximum value was obtained for 4% weight percentage of alumina and CSFA.
Figure 11. a) Torsion test specimen  

Figure 11. b) Torsion test

Figure 12. Test result graph (torsion test)

4. Impact test (ASTM E23)

The shape of the specimen (length=100mm, diameter=8mm) along with the machine is shown in figure 13a and figure 13b. Figure 14 shows the test results. From the above graph in figure 15, it was observed that as the percent of reinforcement increases the impact energy absorbed in the given composite material increases during the Izod test. Hence the impact strength improves for the material.
From the above graph in figure 16, it was observed that as the percent of reinforcement increases the impact energy absorbed in the given composite material increases during the charpy test. Hence the impact strength improves for the material.
4. Conclusion
By stir casting method a reasonably homogeneous distribution of Al$_2$O$_3$ and coconut shell ash particles, aluminum matrix composites have been efficiently fabricated. The results indicate that the stir-formed Al alloy Al$_2$O$_3$ and coconut shell ash reinforced composites are obviously better compared to the base Al alloy in terms of compressive strength, hardness, impact strength and torsional strength. The following conclusion can be drawn:

- Addition of reinforcement, improves the compressive strength, as by adding reinforcement it inhibits the crack propagation and dislocation movements within crystal.
- The hardness of the specimen is improved by increasing reinforcement in the Rockwell hardness test.
In the torsion test, the value of torsional yield strength increased by adding more reinforcement, as the twisting moments acting on material could be avoided by grain boundary strengthening.

In the impact test, we found that with an increase in reinforcement, the energy absorbed by the specific specimens steadily increases.

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