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MECHANICAL PROPERTIES OF MARBLE DUST REINFORCED ALUMINUM MATRIX STRUCTURAL COMPOSITES FABRICATED BY STIR CASTING PROCESS

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Abstract. The use of aluminium and its alloys in aerospace, transportation, automobile, and power transmission is growing these days because it has good corrosion resistance, is lightweight, and has high specific strength. But aluminium and its alloys have some drawbacks, such as low absolute strength at higher temperatures, low impact resistance, low hardness, etc. In this research, the aluminium metal matrix composite has been manufactured with the help of the stir casting technique to improve the aluminium alloy's mechanical properties. Where, Al6063 has been taken as the matrix material and the graphite (Gr) (2 wt.%), glass fibre (2 wt.%), boron carbide (B_4C) (4 wt.%), and marble dust (2 wt.%, 4 wt.%, and 6 wt.%) in powder form have been taken as the reinforcement materials. The present research work has been undertaken to explore marble dust as a reinforcing material as a low-cost option for improving mechanical properties.
Keywords: aluminum metal matrix structural composite, stir casting technique, graphite, glass fibre, boron carbide, marble dust

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1. Introduction

Composite materials are the unique system of two or more materials popularly known as matrix and reinforcement [1-3]. Matrixes are the basic part of the composite system whose properties can be altered by adding the secondary phases (reinforcement materials). The main functions of matrix materials are to transfer the stresses generated due to the application of the load to the reinforcement particles or fibres to protect matrix materials [4-7]. Reinforcement phases are generally particles or fibre dispersed in a controlled amount within the matrix for getting the desired properties. The reinforcement particles generally improve the mechanical properties like hardness, wear resistance, ultimate strength and stiffness, etc. [8-12].

Based on the chemical nature of the matrix materials, composites are divided into three groups polymer matrix (PMC), metal matrix (MMC), and ceramic matrix composites (CMC).

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Nowadays, MMCs are quite popular among researchers due to their capability to change the physical properties (thermal expansion, density and thermal diffusivity, etc.) and mechanical behaviour (ultimate strength, fatigue strength, creep strength, corrosion and wear resistance, etc.) of matrix materials by changing the different reinforcement phase [13,14]. Also, the increase in the demand for aerospace, structural components, and lightweight automotive applications like brake disks and engine pistons led to rapid growth in the field of MMCs [15]. Aluminium MCs are more prevalent in MMCs due to their lightweight, corrosion resistance, good electrical conductivity, and high specific strength.

In general, composites of aluminium can be fabricated by semisolid processing (Friction stir processing), liquid state processing (squeeze casting, stir casting, etc.), and powder metallurgy method [16-18]. Generally, hard particles like ceramics (boron carbide, alumina, graphite, silicon carbides, etc.) are used as reinforcements in the case of AMCs.

On the externally applied load to the AMCs, aluminium matrix transfers load to disperse reinforcement particles, and the applied external load is shared by both reinforcement and matrix; this is the leading cause for the strengthening of the matrix material. A strong interface between the matrix and the dispersed reinforcement particles is required to obtain higher mechanical properties of composites. The mutual dissolution creates the interface bonds throughout the casting, so superior wetting is required for the reinforcement particles [19,20].

The objective of this work is to fabricate of an advanced series of Al6063 based MMCs reinforced with and without marble dust particles and observe the effect of reinforcement particles on the mechanical properties

2. Experimental Procedure

Selection of Matrix and Reinforced Materials. In this present research work, Al6063 alloy having a density 2.7gm/cc and melting point 655°C was used as the matrix material, and glass fibre (2%) (0.005 - 0.01mm dia.), graphite (2%), B_4C (4%) and varying % of marble dust powder (0, 2, 4, 6%) were added as the reinforcement particles for the preparation of hybrid composite. Marble dust having a density of 2.8gm/cc is an industrial waste utilized in this research work; it contains approximate 28.35% SiO_2, MgO 16.25%, CaO 40.45%, and Fe_2O_3 9.7%. Graphite powders of size 25-35μm, boron carbide particles of size 20-30μm, and marble dust of size 30-50μm were used for this research work. During casting, 1-1.1wt% of magnesium was also added to the molten metal to enhance the wettability of reinforcement particles with the molten matrix metal (aluminium 6063). The chemical compositions of al 6063 used as the composite matrix are shown in Table 1.

Table1. Chemical composition of Al6063

Elements	Al	Mg	Si	Fe	Others
Wt.%	Max 97.5	0.45-0.90	0.2-0.6	Max 0.35	0.65

Preparation of AMCs. Marble dust reinforced hybrid AMCs were produced by stir casting technique in the electrical resistance furnace, as shown in Fig. 1. Matrix material (Al6063) was placed inside the graphite crucible. It was melted inside the electric furnace in the inert atmosphere. When the temperature of liquid metal reached 770-790°C, magnesium powder was added to enhance the bonding between the aluminium and reinforcement particles.

By adding magnesium particles to the melted aluminium, the viscosity and surface tension of the molten matrix metal decreases. After that, preheated reinforced particles (glass fibre (2%), graphite (2%), B_4C (4%), and varying % of marble dust powder (0, 2, 4 and 6%

weight)) were added through a funnel, and the mixture of melted metal and reinforcement particles were stirred at 450-550 rpm for 15-20 minutes. After that, the liquid mixture was poured into the sand mould (as shown in Fig. 2), and the melted composites were allowed to cool, and by this way, four different grades (0, 2, 4, and 6 weight % of marble dust) of AMC's were prepared. The details of prepared different aluminium matrix composites composition are presented in Table 2.

Fig. 1. Stir casting setup

Fig. 2. Sand mould with casted product

Table 2. Designation of samples

Designation	**Composition (wt %)**
A0	Al 6063+ Glass Fiber (2%) + Gr (2%) + B_4C (4%)
A1	Al 6063+Glass Fiber (2%) + Gr (2%) +B_4C (4%) + Marble Dust (2%)
A2	Al 6063+ Glass Fiber (2%) + Graphite (2%) + B_4C (4%) + Marble Dust (4%)
A3	Al 6063+Glass Fiber (2%) + Gr (2%) + B_4C (4%) + Marble Dust (6%)

Mechanical Testing. Test specimens were cut using wire-cut EDM to find out the change in the microhardness, tensile strength, and flexural strength of different AMCs. Samples for hardness were finished using emery papers and cloth polishing. Micro-hardness of different composites was determined with the help of a Vickers microhardness tester as per the guidelines of ASTM E384. Mirror polished samples of the composite were placed on Bakelite so that the hardness sample could not slide on the load application. In the hardness test, a load of 5 kg was applied with the help of a diamond indenter for 15-20 seconds, and for getting an accurate hardness value, five readings were taken for each sample.

Instron UTM was used for testing the tensile behaviour of different composites. The test was conducted at room temperature at a strain rate of 1.5min^{-1}. Samples for tensile testing were prepared with the help of wire EDM as per the standard (ASTM E8).

Tinius Olsen UTM was used for the flexural (bending) strength test, as shown in Fig. 3. For the flexural test, samples were prepared according to standard (ASTM-E290-14), and flexural tests were performed at 1.5 mm/min.

Fig. 3. Flexural strength testing machine

3. Results and discussion

Micro-hardness. The hardness of a metal matrix composite is defined as the resistance to scratch and indentation. It is a surface property of the material. The microhardness of all the four composites is shown in Fig. 4. The strength of bonding (interfacial strength) between the aluminium matrix and the different reinforcement particles present in the composite tell us about the microhardness. Fig. 4 shows that adding varying % of marble dust in Al-based composite improves the hardness of composite (76 Hv to 88 Hv). The maximum hardness (88 H_v) was observed for the 6 wt. % marble dust reinforced composite, and minimum hardness (76 H_v) was observed for unreinforced marble dust composite. This shows that the hardness of AMC can be improved by using varying % of marble dust because well interfacial bonded hard particle resists the motion of dislocations.

Tensile strength. The behaviours of tensile strength with varying wt. % of the marble dust have shown in Fig. 5. It is observed from the data of the tensile test that the strength (tensile) of the marble reinforced composites has higher tensile strength as the % of marble dust particles increases from 0 to 4% (180 MPa to 249 MPa); this is because the load is transferred to the reinforcement particles which are strongly bonded with the matrix of aluminium and due to pinning effect.

It was observed that the tensile strength of the AMC sample reinforced with 6% marble dust was around 242MPa. So, on further increase in marble dust content beyond 4%, tensile strength decreased because of the aggregation of marble dust particles in the AMC sample reinforced with 6% marble dust.

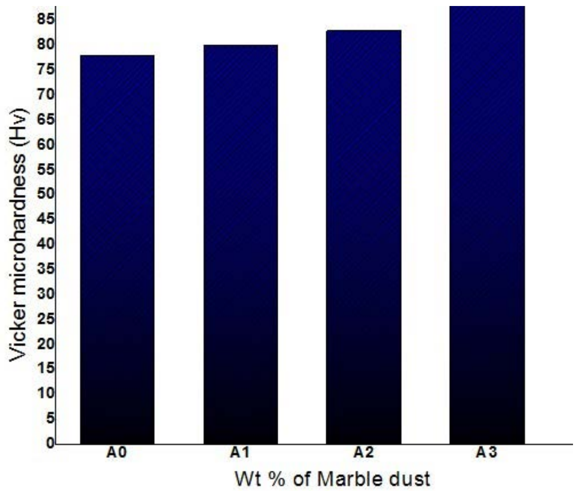

Fig. 4. Vickers micro-hardness results

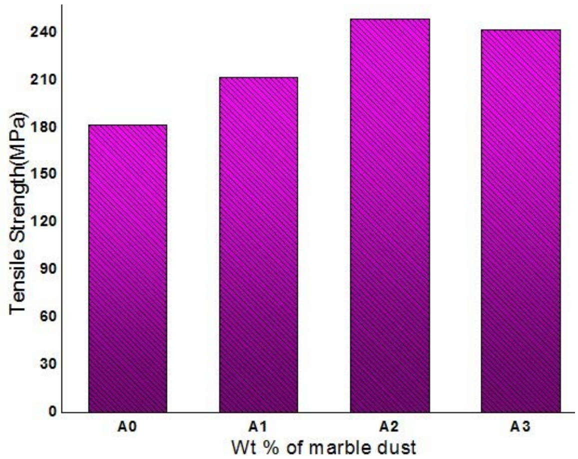

Fig. 5. Tensile behaviour of Al composites

Flexural strength. With the help of the 3-point-bend test, flexural strength has been obtained. The behaviour of the bend test for different % of marble dust has shown in Fig. 6. Marble dust reinforced composites show higher flexural strength than unreinforced marble dust composites. The maximum value of flexural strength (262 MPa) is for 4% reinforced marble dust and the minimum value of flexural strength (210 MPa) for unreinforced marble dust composite.

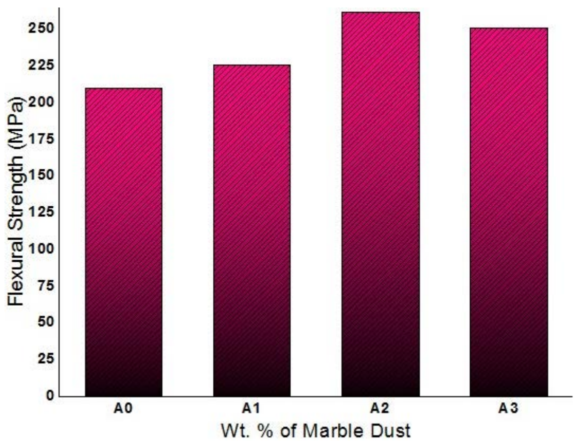

Fig. 6. Flexural behaviour of Al composites

This increase in flexural property occurs due to the good interface bonding between the hard particles and the matrix material. But it is observed that in the case of 6% reinforced marble particles; the flexural strength is equal to 251 MPa; this is less than 4% marble reinforced system because for 6% reinforced system, agglomeration of marble dust particles took place.

4. Conclusion

In this research, it is concluded that after the addition of marble reinforcement:

- The addition of varying % of marble dust in Al-based composite improves the hardness of composite (76 Hv to 88 Hv), and the maximum hardness (88 H_v) was observed for the 6 wt % and minimum for unreinforced.
- The tensile strength of the marble reinforced composites has higher tensile, and flexure strength as the % of marble dust particles increases from 0 to 4% (180 MPa to 249 MPa for tensile and 210MPa to 262 MPa for flexure).
- It is observed that for the case of 6% reinforced marble particles, the tensile and flexural strength comes to be equal to 242 MPa and 251 MPa, respectively, these values are less as compared to 4% marble reinforced system this is because agglomeration of marble dust particle takes place for 6% reinforced system.

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