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Fabrication and Analysis of Mechanical Properties of Aluminium-Magnesium Composite

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ABSTRACT
Increasing demand for the superior material properties have turned our thinking from a single material to composite. Traditionally composite material consists of continuous phase of the matrix bearing the discontinuous phase of the reinforcement that carry the main load. Commonly used matrix materials for Metal Matrix Composites (MMC) are aluminum, magnesium, titanium, copper etc. Among various MMCs, aluminum metal matrix composites (AMMC) have distinct properties like better strength, lightweight corrosion resistance. Addition of reinforced metals in the pure aluminum improves the mechanical properties of aluminum. This paper focuses on the casting of aluminum metal matrix composite where Magnesium (Mg) of two different weight fraction is used as reinforced metal. The Al-Mg metal matrix with 1wt% and 2wt% Mg is fabricated using the stir casting method. Initially, aluminum and magnesium are preheated in two separate furnaces before being mixed. Then the preheated aluminum matrix is poured into the furnace whose temperature is elevated to 670^0C. When the aluminum is completely melted, preheated magnesium is added with manual mixing. Afterwards, the stirring is performed at a speed of 600 rpm to accomplish the mechanical mixing. Finally, the mixture of matrix and reinforcement material is transferred into the molds. The mechanical tests are performed to check the properties like tensile strength, impact strength, and hardness. With the addition of magnesium, hardness and impact strength are increased gradually while the ultimate tensile strength and ductility shows a different trend. Initially the tensile strength and ductility are reached to the highest value for 1wt% Mg and then it is decreased at the next weight percentage due to the brittleness of the material. Therefore, these properties have the significance to apply this material where the seeking properties are hardness and impact strength.

Keywords: MMC, AMMC, Stir Casting, Al-Mg Metal Matrix.

1. Introduction

The combination of two or more materials for specific unique properties which are not available in a single material is the composite material. Composite materials have two components which are called matrix and reinforcement. Matrix is the continuous phase that holds the discontinuous reinforcement phase. Reinforcements are the main load-carrying elements and matrix transfer load from an external source to reinforcements [1]. According to the matrix material, composite materials can be classified into three categories. Polymer matrix composites (PMC) where thermoset or thermoplastic matrix holds discontinuous reinforcement phases like carbon, glass, metal, Kevlar fibers, etc. Ceramic matrix composites (CMC) are based on ceramic matrix-like SiC, Al_2O_3, SiN, etc. The metal matrix composites are composed of a continuous metallic matrix and a reinforcement phase. MMCs are classified based on the metal used as a matrix. Aluminum, Magnesium, Titanium, Copper, etc. can be used as matrix material in MMCs [2]. MMCs are largely used due to high thermal conductivity, lightweight, high tensile strength, high corrosion resistance, high-temperature resistance, high strength to weight ratio, and so on [3]**.** Aluminum metal matrix composites have high hardness, stiffness, wear resistance, specific strength, thermal conductivity [4]. Aluminum-based metal matrix composites reinforced with magnesium have very lightweight and high strength. Aluminum matrix reinforced with Silicon carbide increases wear resistance highly. Al-Si carbide composites have high hardness than pure aluminum [5]. Boron carbide reinforced in the aluminum matrix has high bending strength, compressive strength, and hardness [6]. Nafsin et al. established the relationship between microstructure and cold deformation behavior of Al-Cu-Mg alloys, showed that with the increase of deformation, hardness increases for different percentage of magnesium addition [7]. Deformation increases the dislocation density which improves the hardness of the material. Rana et al. reported the effects of increasing magnesium content on the mechanical properties and wear behavior of LM 6 aluminum alloy [8]. Hardness increases and wear rates decreases with the increase in Mg content. Prem Shankar Sahu et al. investigated the fabrication methods used in aluminum-based metal matrix composites (AMMC) [9]. Stir casting method can be used due to cost-effectiveness, high hardness, easy portability, mass production, uniform distribution of reinforcement materials and which is the commercial method of fabricating AMMCs. LM25 (aluminum alloy) metal matrix composite reinforced by alumina, boron carbide and silicon carbide was explored by B. Vijaya Ramnath et al. to evaluate mechanical properties such as tensile strength, flexural strength, impact strength, and hardness [10]. Tensile strength and flexural strength were higher in LM25. Hardness and impact strength were higher in 2% alumina and 3% boron carbide reinforced composites. Microstructures had shown that the reinforcements were non-uniformly distributed in the matrix material, which gives less strength. For more

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uniform distribution, a two-step stir casting method can be applied and thus avoid internal fracture. Velugula *et al.*[11] characterized the Al-Cu MMCs fabricated by die casting process. The tensile strength, hardness, and impact strength of Al with Cu MMC increases with increasing wt% of Cu particulate up-to 8 wt% and then decreases with further addition of Cu. Above the percentage of Cu, the strength decreases due to the interaction of Cu with each other and settling down. The microstructural analysis has shown the uniform distribution of Cu in the Al matrix material.

In this study, an Al metal matrix composite reinforced by magnesium is fabricated using the stir casting method and tested the mechanical properties like tensile test, hardness test and impact test, and then compared the mechanical properties with different reinforcement metal-matrix.

2. Materials and Methods

2.1 Materials

To fabricate Al-Mg composite, Aluminum bar has been used as the source of matrix material in this metal matrix composite due to its lower density, excellent specific strength and hardness, low cost, good thermal properties, good wear and corrosion resistance. 1-wt% and 2-wt% Magnesium from magnesium ribbon is used as a reinforcement material in the aluminum matrix phase to increase hardness and strength.

2.2 Fabrication Method

The Al-Mg composite is fabricated through the stir casting method. Before mixing reinforcement into the molten matrix material, aluminum and magnesium are preheated at 450^0C for 3 to 4 hours in two separate furnaces. The furnace temperature is raised to 670^0C (above the liquidus line) and then poured with the preheated aluminum matrix into the furnace. When aluminum is melted fully, then preheated magnesium is introduced into the molten aluminum and manual mixing is done.

After manual mixing, mechanical mixing is done by the mechanical stirrer at a stirring speed of 600 rpm for 10 minutes. The furnace temperature has been risen to 760 ± 10^0C and continued for several minutes [12].
Finally, the mixture of aluminum-magnesium material is placed in the molds that are made according to sample size and shape specifications. Properly fabricated samples are used for testing mechanical properties like tensile, hardness, and impact tests have been done.

Two samples have been fabricated where sample 1 has 99% aluminum and 1% magnesium, and sample 2 has 98% aluminum and 2% magnesium.

3. Mechanical Properties

The following tests have been conducted for the analysis of the mechanical properties of the fabricated Al-Mg composite.

3.1 Tensile Test

The maximum axial load that can be applied without breaking the composites is determined by the tensile test. The tensile test is done by using the universal testing machine (UTM) and the specimens are cut as per the ASTM: B-557M standard with a diameter of 5mm and gauge length of 50mm. Load is gradually applied to the specimen at one end until failure occurs, and the deflection is measured simultaneously with a gauge meter. Both the original and final lengths are properly measured. The cast samples for tensile test are shown in fig.1. The sample did not fail at the center because of the local compression under the grips, which results in a smaller local cross-sectional area than the tensile section. Furthermore, localized constriction at the grip ends can result in stress concentrations that enhance failure here.

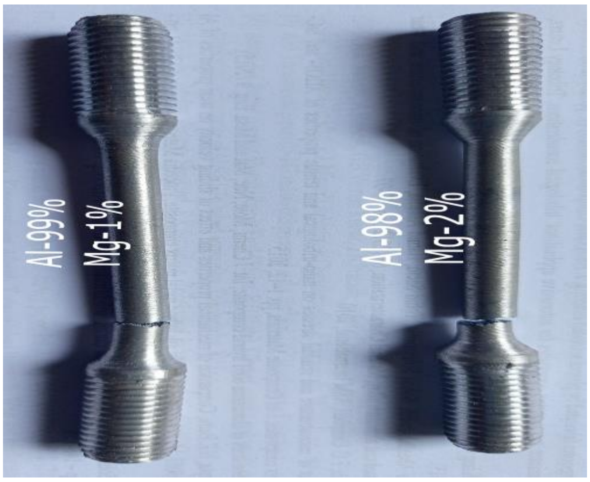

Fig.1 Tensile test specimens.

3.2 Impact Test

This test is used to measure the amount of energy that the composites absorb by impact load. It measures the relative toughness. The Charpy impact test is done by the digital impact testing machine where load is adjusted at 80 cm height and inclined at 140^0 horizontally. The mass of the applied load is 24 kg about 235.2 N. The specimens are cut using as per IS 1757 standard. The cast samples for impact test are shown in fig.2.

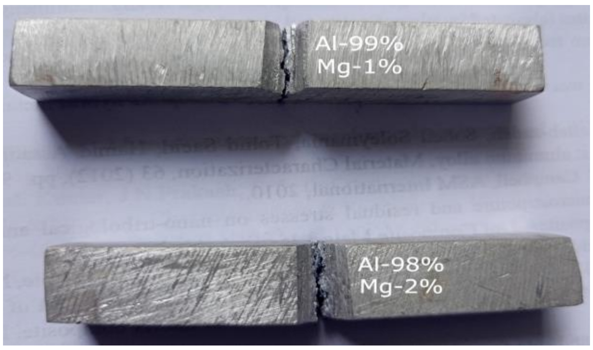

Fig.2 Impact test specimens.

3.3 Hardness Test

It is the measure of the resistance of a material against the static load applied by an indenter. The Brinell hardness number is determined by a compression hardness test. The indenting tool through which force is applied is a ball with a diameter of 5mm. The sample is placed on the compression pad of the lower cross member and applying load of 250Kgf. The cast samples for hardness test are shown in fig.3.

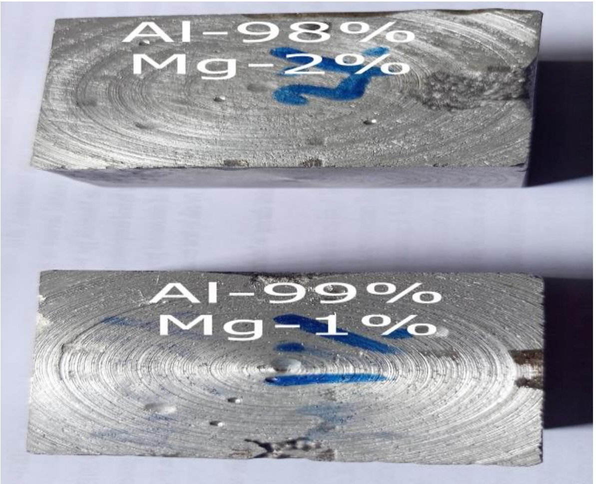

Fig.3 Hardness test specimens.

4. Results and Discussion

The results of different mechanical tests are discussed in this section using graphical representation.

4.1 Tensile Test

Table 1 shows the results of the tensile test for the two samples. Breaking load, maximum displacement, ultimate tensile strength, and percentage of elongation are shown here, and these properties are decreased with the increase in magnesium content.
Sample 1 has a greater ultimate tensile strength than sample 2. Tensile strength decreases with the increase in magnesium percentage.
Rana et al.[8] fabricated LM6 metal matrix with 1.18wt% Mg which possessed greater tensile strength than that of tested samples 1 and 2 as shown in fig.4. Aluminum alloy has greater strength than pure aluminum. Mg reinforced aluminum alloy MMC has larger tensile strength than Al-Mg composites.

Table 1 Tensile properties of composites.

Sample	Breaking load (kN)	Max. displacement (mm)	Tensile strength (MPa)	Elongation (%)
$Al_{99}Mg_1$	4	0.75	174.65	1.5
$Al_{98}Mg_2$	3.4	0.65	143.16	1.3

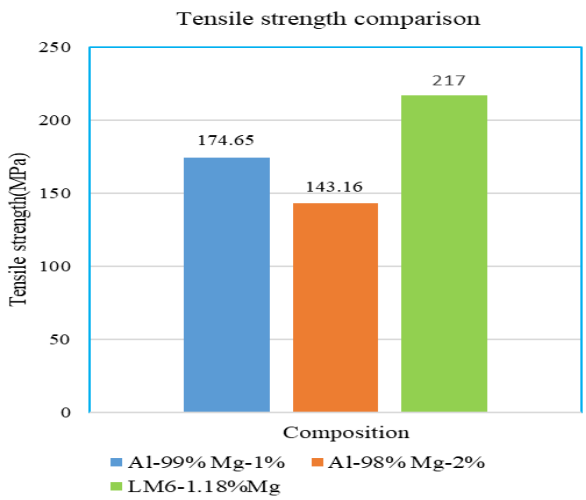

Fig.4 Tensile strength comparison for different MMC.

4.2 Impact Test

The energy absorbed and impact strength for the two samples are shown in fig. 5. It is clear that sample 2 absorbs more energy than sample 1. Impact strength and energy absorbed increases with the increase in magnesium percentage.

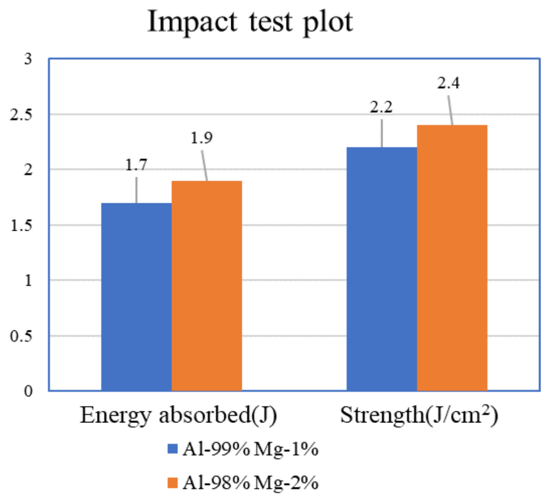

Fig.5 Energy absorbed and strength comparison.

4.3 Hardness Test

Five measurements were taken at different locations of the sample and the average hardness value of two samples are shown in fig.6. The Brinell hardness number for sample 2 is higher than sample 1 due to the increased magnesium percentage.
The hardness values of different aluminum magnesium composites vary with different percentages and are shown in fig.7. Nafsin et al. reported the variations of hardness with different percentage of Al-Cu-Mg composites [7]. The variation of hardness values of the aluminum composites reinforced by magnesium with and without copper addition cleared that LM6-1.18wt%

Mg[8] has largest hardness and $Al_{98}Mg_2$ has the second largest hardness value.

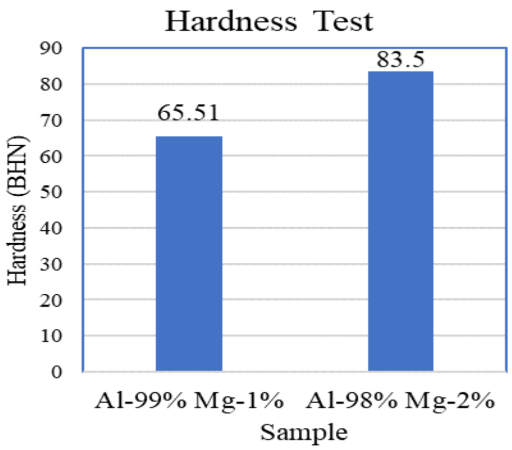

Fig.6 Brinell Hardness Number(BHN).

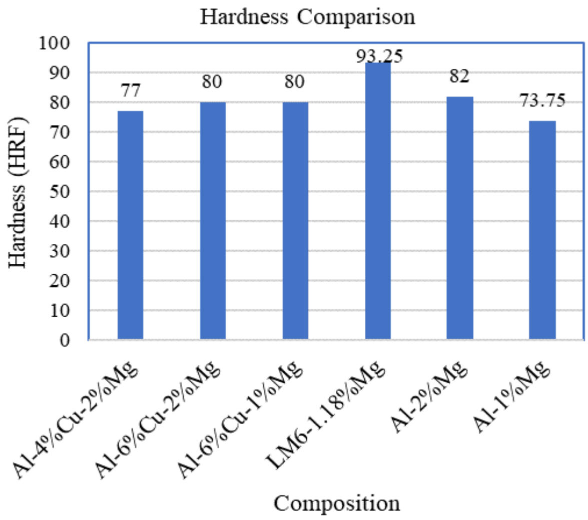

Fig.7 Hardness comparison for different MMC.

5. Conclusion

Aluminum metal matrix composites are fabricated by reinforcing 1-wt% and 2-wt% of magnesium. Fabrication is done by the stir casting method, which is cost-effective and applicable for mass production. Uniform distribution could be achieved by proper stirring through a mechanical stirrer. Hardness and impact strength have been increased gradually with the increase in magnesium content because of a solute effect. Ultimate tensile strength and ductility is increased for 1-wt% Mg and then decreased for 2-wt% Mg. Different phenomena in tensile strength and ductility have been identified due to the brittleness of reinforced material. These properties have the significance of applying this material where the sought properties are hardness and impact strength. It is the driving force behind the use of Al-Mg composites in a wide range of structural, non-structural, and functional applications in various engineering sectors, with performance, economic, and environmental benefits. Because of their appealing isotropic mechanical properties and low cost, market demand for AMMCs has gradually increased. AMMCs are the most used MMC in the automotive and aerospace industries due to their higher strength, improved wear resistance, lower density, and so on.

During the fabrication, some precautions should be taken, like controlling porosity. It can be decreased by the optimization of pouring temperature, pouring time, and different types of gating system design. In Al casting, porosity can also be decreased by degasification technique, degassing flux tablets, etc.

This work can be further extended by the addition of copper with different percentages in the Al-Mg composite. Mg can be added to different aluminum alloys for different fabrication methods. With an increasing amount of deformation, the hardness of Al-Mg composites can be increased. Microstructural analysis can be done to find the structural growth in the casting of Al-Mg.

6. References

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