Microstructure and Mechanical Behaviour of AZ91d Magnesium Composite Reinforced With B₄C and Graphite by Casting Process

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Abstract. In this study, we have manufactured AZ91D magnesium-based alloy and its composite reinforced with boron carbide (B₄C) and Graphite (Gr) at various weight percentages by bottom pouring stir casting process. The work is aimed at comparing the microstructure and mechanical properties of developed composites with its matrix AZ91D magnesium alloy. The B₄C reinforcement particles were added 1.5, 3, 4.5 weight percentage respectively to the matrix material and also solid lubricant graphite was added 1.5 weight percentage into composite. Density, Porosity, Rockwell hardness test, tensile test, and Optical Microstructure were evaluated. The developed composites reveal increased 11.18% hardness value when compared to base material, which could be accredited to the occurrence of B₄C particles. Also, this study indicates that increase in percentage addition of B₄C and graphite leads to increase in density and tensile strength of the developed composites. Optical microstructure images show the uniform distribution of particles into matrix.

1. Introduction
In current era there is a massive require of the materials that are lighter in weight, have superior strength, further durable and have superior wear resistance. Elevated anxiety on material for enhanced on the complete recital has led to widespread research and enlargement effort in the composite fields. Considering this in the model few decades, general research has been carried out into metal matrix composites (MMC) [1-3]. Al-MMCs, Mg-MMCs are some of the composites that are lighter in weight than erstwhile metals and their alloys. As a consequence of this they discover enormous appliance in sectors like Automobiles and Aerospace [4-6]. As a result, magnesium alloys warm incredibly elevated specific strength amid predictable engineering alloys. In adding together, magnesium alloys posses’s admirable damping capacity, excellent castability, and superior machinability. Further research done in this field says that Mg-MMCS were nearly 17-22% lighter than the Aluminium composites and are also used in defence systems like missiles and their components etc [7-10]. A small decrease in hardness is observed for the hybrid composite when compared to Mg–SiC composite due to the presence of soft Gr particles [11]. Adding of B₄C into AZ91D magnesium matrix composite mechanical properties were slightly increased as compared to AZ91D magnesium alloy. Graphite particles act as a solid lubricant in AZ91D magnesium hybrid composite [2]. It might be observed that
there is less amount of work reported on the use of B\textsubscript{4}C and graphite particulates on the mechanical properties of magnesium AZ91D alloy. The current effort expected to examine the result of addition of B\textsubscript{4}C and Graphite on the microstructures and mechanical properties of AZ91D magnesium alloy at room temperature.

2. Experimental procedures

2.1. Sample Making

The magnesium composites are made-up by bottom pouring stir casting process. The materials used for stir casting are magnesium, aluminium and zinc as the base matrix alloy metals with reinforcements such as ceramic material boron carbide and solid lubricant graphite in composites for the same. Table 1 shows the composition of the samples. The raw materials were cut down into smaller pieces for easy melting and for materials to properly accommodate in the furnace pot. Figure 1 shows the image of bottom pouring stir casting machine. Then the stir casting machine is switch on and a temperature is set to a particular value i.e. 850°C. All the components are cleaned properly before starting the furnace and graphite paste is applied to all the components through which the molten material is departing to flow. Once furnace reaches 800°C raw materials were added slowly into the furnace. After melting the raw materials preheated reinforcement were added into the furnace. Simultaneously, the die and the runner were heated with die heater and runway heater respectively. Molten metal were mixed properly with help of stirrer at a speed of 500rpm. After proper stirring, the molten metal was passed through furnace bottom open to die (50mm diameter and 250mm length) via heated runway. After molten metal are inside the die then we allow it to solidify and remove it from the die later. Figure 2 shows the image of developed sample after stir casting process.

Table 1. Composition of the samples.

| Sample No. | AZ91D (%) | B\textsubscript{4}C (%) | Gr (%) |
|-----------|-----------|----------------|--------|
| 1         | 100       | 0              | 0      |
| 2         | 98.5      | 1.5            | 0      |
| 3         | 97        | 3              | 0      |
| 4         | 95.5      | 4.5            | 0      |
| 5         | 97        | 1.5            | 1.5    |
| 6         | 95.5      | 3              | 1.5    |
| 7         | 94        | 4.5            | 1.5    |

Figure 1. Stir casting machine.  
Figure 2. Developed cast sample.
2.2. Porosity and Density measurement

The theoretical density ($\rho_t$) was calculated using the rule of mixtures and the actual density ($\rho_a$) were calculated using Archimedes’ principle. The porosity of each sample can be premeditated according to Eqn. (1) [2]

$$P = 1 - \left( \frac{\rho_a}{\rho_t} \right)$$

Where, ‘P’ represents porosity of the material, $\rho_a$ represents actual density and $\rho_t$ represent theoretic density. Table 2 demonstrate porosity and density value of the developed samples.

**Table 2. Mechanical Properties of the samples.**

| Sample No. | Density (g/cm$^3$) | Porosity (%) | Hardness (HRB) | Ultimate Tensile Strength (N / sq mm) |
|------------|--------------------|--------------|----------------|-----------------------------------|
| 1          | 1.8091             | 1.42         | 49.2           | 81                                |
| 2          | 1.8197             | 1.34         | 51.8           | 97.9                              |
| 3          | 1.8241             | 1.31         | 53.4           | 109.1                             |
| 4          | 1.8296             | 1.29         | 54.7           | 117                               |
| 5          | 1.8249             | 1.11         | 49.2           | 85.4                              |
| 6          | 1.8371             | 1.08         | 50.8           | 96.3                              |
| 7          | 1.8593             | 1.07         | 52.3           | 107.4                             |

2.3. Hardness and Tensile strength Measurement

These hardness tests were performed with Digital Rockwell hardness apparatus with 1/16” ball type indenter. Ultimate Tensile Strength (UTS) was calculated as per ASTM A370-E8 by tensometer. Table 2 demonstrate hardness and UTS values of the developed samples.

2.4. Specimen Preparation for Optical microstructure analysis

The microstructure studies of developed sample were done on after machining into 10mm diameter and 15mm length from the cast ingot. Specimens were ground with 600, 1000, 1200, and 2000 #grit-Silicone Carbide abrasive emery paper. After emery polishing with 1-μm diamond paste and disc polishing were performed for better finish. To visible grain structure primed specimens were etched using Keller’s reagent for 6 seconds and then washed out with water.

3. Result and Discussion

3.1. Porosity and Density

Figure 3 shows the graphical illustration of porosity and density of developed samples. From fig.3 we observed that whereas increasing B$_4$C and graphite content into magnesium composite density of the sample slightly increased and porosity value faintly decreased.

![Figure 3. Variation of Porosity and Density.](image-url)
3.2. Hardness and Tensile strength
Figure 4 shows the graphical representation of hardness and UTS of developed samples. From fig.4 we observed that whereas increasing B₄C contents in AZ91 magnesium alloy hardness values and ultimate tensile strength values faintly increased, also increasing Graphite content into AZ91D magnesium composite hardness of the sample faintly decreased. This is because of hard ceramic B₄C and soft lubricant graphite elements.

![Figure 4. Variation of Hardness and UTS.](image)

3.3. Microstructure Analysis
Microstructure investigation offers a primary characteristic control as well as a momentous exploratory tool. The circulation of B₄C and Graphite particles and grain structures were observed using Olympus microscope. The occurrence of Boron Carbide can be seen in the microstructure all the way through the dark spots. Figure 5 shows the optical microstructure images of developed magnesium composites and its shows the even distribution of B₄C and graphite into matrix magnesium alloys.
Figure 5. Microstructure of (a) Sample-1 (b) Sample-2 (c) Sample-3 (d) Sample-4 (e) Sample-5 (f) Sample-6 (g) Sample-7.

4. Conclusion
AZ91D magnesium alloy, AZ91D–B₄C composites and AZ91D–B₄C-Gr hybrid composites have been productively developed by bottom pouring stir casting method. The porosity, density, ultimate tensile strength, hardness, and optical microstructure were estimated. Optical microstructure images show the grains structure and uniform distribution of particles into matrix. As match up with pure AZ91D magnesium alloy, density of AZ91D composite and hybrid composite were slightly increased. Hybrid composite porosity slightly decreased compared with AZ91D alloy and AZ91D composite. The developed composites reveal increased 11.18% highest hardness value when compared to base material. AZ91D composite has better ultimate tensile strength compared to AZ91D matrix alloy.

5. References
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