Fabrication and characterization of Magnesium Metal Composite by Stir Casting

A Razal Rose*, I Aatthisugan

Department of Mechanical Engineering, SRM Institute of Science and Technology, Chennai, India

*Corresponding author: razalroa@srmist.edu.in

Abstract. In Automotive and Aerospace industries, the demand for lighter materials is increasing exponentially. The main advantage of Magnesium Metal Matrix Composites over Aluminium Metal Matrix Composites, there is an additional 15-20% weight saving without having to compromise on properties. Metal matrix composites reinforced with Boron carbide and molybdenum disulphide have significant advantage over conventional materials. Generally, these reinforcements are used to improve the hardness and tensile strength of metal matrix composite. In this study, we have performed three castings each on magnesium alloy (A14Z1, A17Z1, and A19Z1) and composites with reinforcements of 2.5% Boron Carbide by stir casting method. Mechanical test like Rockwell hardness were conducted to find hardness of the specimen. The Microstructure was observed through an Optical Microscope. The comparative study of these samples with and without reinforcement were carried out and analyzed. The results showed that there is an appreciable increase in mechanical and metallurgical properties of new magnesium novel composite material used in this investigation.

Keywords: Magnesium, Alloy, Composite, Casting, Hardness

1. Introduction
In present times a huge demand of the materials that are lighter in weight, have better strength, more durable and have better wear resistance. There are some metals and alloy that have high strength but are heavier and so are much prone to failure because of the crack propagation. Seeing this in the past few decades, extensive research has been carried out into (MMC) metal matrix composites. Mg-MMCs, Al-MMCs are some of the composites that are lighter in weight than other metals and their alloys [1-5]. As a result of this they find a huge application in sectors like Automobiles and Aerospace. As a result, magnesium alloys tender incredibly soaring specific strength amid predictable engineering alloys. In adding together, magnesium alloys posse’s excellent damping capacity, admirable castability, and better machinability [6-7]. Further research done in this field says that Mg-MMCs were nearly 17-22% lighter than the AI composites and are also used in defence systems like missiles and their components etc. The automobile industry holds up to 80-85% of the casting
demands. And it is because their thermal properties can be altered, they are widely used in this industry [8-10]. Magnesium and its application require critical properties like ductility, creep resistance, energy absorption etc. Mg and its composites are used in steering wheel, frames, wheel design etc [11-14]. As of the narrative, it is obviously apparent that there is not much effort reported on the influence of B\textsubscript{4}C particulates into the mechanical behaviour of various magnesium alloys and it’s composite. Consequently the purpose of this exertion is to produce various magnesium alloys and it’s composite by bottom pouring stir casting method and to cram the mechanical properties of developed samples.

2. Experimental Work

2.1 Specimen groundwork

The composite were fabricated by bottom pouring type stir casting process. The materials used for casting were magnesium, aluminium and zinc as the base alloy metals with reinforcements such as boron carbide and molybdenum disulphide in composites for the same. Figure 1 shows the image of used materials. Table 1 shows the density and rockwell harness of purchased raw materials. The raw materials purchased were cut down into smaller pieces for easy melting and for materials to properly accommodate in the furnace pot. Figure 2 shows the image of bottom pouring stir casting machine. Table 2 shows the composition of the samples. 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 going to flow. Then the furnace is switch on and a temperature is set to a particular value i.e. 850°C, through a laptop that is connected to the control panel of the equipment. Then we check melt temperature that has been set to 800°C.Next the die and the runner are heated with die heater and runway respectively. When the furnace is heated to the required temperature then the metals are added slowly into the furnace. After all the metals are melted putting the stirrer into the furnace so that everything mixes properly. After proper stirring the metals in the furnace, making sure that the runner is properly aligned to the die, the furnace is opened to let the metals flow through it. After the metals are inside the die then we allow it to solidify and remove it from the die later. Meanwhile, the runner is taken out from the heater and tapped rigorously to remove excess metal. After the die is cooled down, the specimen is taken out.
Figure 1. Raw materials.  
Figure 2. Stir casting machine.

Table 1. Raw material properties.

| Material Name       | Density (g/cm³) | Rockwell Hardness (HRB) |
|---------------------|-----------------|-------------------------|
| Magnesium (Mg)      | 1.739           | 71.4                    |
| Aluminum (Al)       | 2.712           | 78.2                    |
| Zinc (Zn)           | 7.151           | 81.6                    |

Table 2. Composition of the samples.

| Sample No. | Aluminium (%) | Zinc (%) | Magnesium (%) | B₄C (%) |
|------------|---------------|----------|---------------|---------|
| 1          | 14            | 1        | 85            | 0       |
| 2          | 17            | 1        | 82            | 0       |
| 3          | 19            | 1        | 80            | 0       |
| 4          | 13.65         | 0.975    | 82.875        | 2.5     |
| 5          | 16.575        | 0.975    | 79.95         | 2.5     |
| 6          | 18.525        | 0.975    | 78            | 2.5     |

2.2 Density and Porosity measurement

The actual densities (ρₐ) of the samples were calculated using Archimedes’ principle and the theoretical densities (ρₜ) of the samples was calculated using the rule of mixtures. The porosity of each sample can be premeditated according to Eq. (1) [1]

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

(1)

Where, P is the porosity of the material, \( \rho_a \) is the actual density and \( \rho_t \) is the theoretic density. Table 3 shows the value of density and porosity of the samples.
Table 3. Density and porosity values.

| Sample No. | Actual Density (g/cm³) | Theoretical Density (g/cm³) | Porosity (%) |
|------------|------------------------|-----------------------------|--------------|
| 1          | 1.85                   | 1.878                       | 1.48         |
| 2          | 1.79                   | 1.876                       | 1.46         |
| 3          | 1.853                  | 1.88                        | 1.42         |
| 4          | 1.846                  | 1.898                       | 1.46         |
| 5          | 1.781                  | 1.886                       | 1.44         |
| 6          | 1.853                  | 1.889                       | 1.41         |

2.3 Hardness Measurement

The preferred hardness test for light material is Rockwell Hardness B scale. These hardness tests were performed with Digital Rockwell hardness apparatus and 1/16” ball type indenter. Table 4 shows the value of hardness of the samples.

Table 4. Hardness values.

| Sample No. | Rockwell Hardness (HRB) |
|------------|------------------------|
| 1          | 73.5                   |
| 2          | 65.1                   |
| 3          | 54.46                  |
| 4          | 84.52                  |
| 5          | 76.52                  |
| 6          | 65.22                  |

2.4 Optical microstructure

The metallographic studies of alloys were done on the samples after machining from the cast ingot. Specimens were ground with 600#, 1000#, 1200#, and 2000# grit-Silicone Carbide abrasive. After that with 1-μm diamond paste and disc polishing for finer finish. To visible grain structure prepared specimens were etched using Keller’s reagent for 7 seconds and then washed out with water.

3. Result and Discussion

3.1 Microstructure Analysis

Metallographic investigation offers a foremost feature control as well as a significant investigative tool [5]. The grain structures and allocation of reinforced particles were experiential by using Olympus microscope. The presence of Boron Carbide can be seen in the microstructure through the dark spots. Figure 3 shows the optical microstructure images of developed magnesium alloys. Figure 4 shows the optical microstructure images of developed magnesium composites and its shows the uniform distribution of B₄C into matrix magnesium alloys.
3.2 Density and porosity

Figure 5 shows the graphical representation of density and porosity of developed samples. From fig. 5 we observed that while increasing aluminium contents in magnesium alloy and adding B₄C content into magnesium composite density of the sample slightly increased and porosity value slightly decreased. Since density of Aluminum is higher than magnesium [Table 1.].

![Figure 5. Variation of Density and Porosity.](image-url)
3.3 Hardness

Figure 6 shows the graphical representation of hardness of developed sample. From fig.6 we observed that while increasing aluminium contents in magnesium alloy hardness values slightly decreased and adding B$_4$C content into magnesium composite hardness of the sample slightly increased. This is because of ceramic reinforcer B$_4$C content into composite [1].

4. Conclusion

The alloys and composite were successfully fabricated using stir casting machine. The density, porosity, hardness and microstructure were evaluated. The hardness of the entire composite were found to be 10% - 15% more than that of alloys. Similarly, densities of composite show an increase from their alloy as well. A decrease in porosity can be seen when alloys are compared to composites. From the microstructure of all the composites we concluded that there is uniform distribution of reinforcements in composites throughout the ingots.

5. References

[1] Aatthisugan, I., Rose, A.R. and Jebadurai, D.S., 2017. Mechanical and wear behaviour of AZ91D magnesium matrix hybrid composite reinforced with boron carbide and graphite. *Journal of magnesium and alloys*, 5(1), pp.20-25.

[2] Dinaharan, I., Vettivel, S.C., Balakrishnan, M. and Akinlabi, E.T., 2019. Influence of processing route on microstructure and wear resistance of fly ash reinforced AZ31 magnesium matrix composites. *Journal of Magnesium and Alloys*, 7(1), pp.155-165.

[3] Karakulak, E., 2019. A review: Past, present and future of grain refining of magnesium castings. *Journal of Magnesium and Alloys*.

[4] Cavaliere, P. and De Marco, P.P., 2007. Superplastic behaviour of friction stir processed AZ91 magnesium alloy produced by high pressure die cast. *Journal of materials processing technology*, 184(1-3), pp.77-83.

[5] Karakulak, E. and Küçüker, Y.B., 2018. Effect of Si addition on microstructure and wear properties of Mg-Sn as-cast alloys. *Journal of magnesium and alloys*, 6(4), pp.384-389.

[6] Chelliah, N.M., Singh, H. and Surappa, M.K., 2016. Correlation between microstructure and wear behavior of AZX915 Mg-alloy reinforced with 12 wt% TiC particles by stir-casting process. *Journal of Magnesium and Alloys*, 4(4), pp.306-313.

[7] Aatthisugan, I., Muralidharan, S., Majumdar, S., Rose, A.R. and Jebadurai, D.S., 2018, August. Wear and mechanical properties of Al-6% Cu-X% Mg alloy fabricated by powder
metallurgy. In *IOP Conference Series: Materials Science and Engineering* (Vol. 402, No. 1, p. 012106). IOP Publishing.

[8] Chen, T.J., Ma, Y., Li, B., Li, Y.D. and Hao, Y., 2007. Friction and wear properties of permanent mould cast AZ91D magnesium alloy. *Materials Science and Technology*, 23(8), pp.937-944.

[9] Prakash, K.S., Balasundar, P., Nagaraja, S., Gopal, P.M. and Kavimani, V., 2016. Mechanical and wear behaviour of Mg–SiC–Gr hybrid composites. *Journal of magnesium and alloys*, 4(3), pp.197-206.

[10] Chai, F., Zhang, D. and Li, Y., 2015. Microstructures and tensile properties of submerged friction stir processed AZ91 magnesium alloy. *Journal of Magnesium and Alloys*, 3(3), pp.203-209.

[11] Aatthisugan, I., Vignesh Kumar, S., Razal Rose, A. and Selwyn Jebadurai, D. 2017, “Wear behavior of am60 magnesium alloy with different load and sliding distance”, *International Journal of Mechanical Engineering and Technology* 8(6), pp. 130-134.

[12] Máthis, K., Gubicza, J. and Nam, N.H., 2005. Microstructure and mechanical behavior of AZ91 Mg alloy processed by equal channel angular pressing. *Journal of Alloys and Compounds*, 394(1-2), pp.194-199.

[13] Yao, Y.T., Jiang, L., Fu, G.F. and Chen, L.Q., 2015. Wear behavior and mechanism of B4C reinforced Mg-matrix composites fabricated by metal-assisted pressureless infiltration technique. *Transactions of Nonferrous Metals Society of China*, 25(8), pp.2543-2548.

[14] Zhao, P., Geng, H. and Wang, Q., 2006. Effect of melting technique on the microstructure and mechanical properties of AZ91 commercial magnesium alloys. *Materials Science and Engineering: A*, 429(1-2), pp.320-323.