Evaluation Of Microstructural And Mechanical Behavior Of Some Magnesium Metal Matrix Composites

1Amandeep Singh, 2Niraj Bala
1 Research Scholar, Mechanical Engineering Department IKG PTU Kapurthala-144603 (Punjab) India
2 Associate Professor, Mechanical Engineering Department BBSB Engg College Fatehgarh Sahib-140407 (Punjab) India

Abstract
Magnesium based metal matrix composites reinforced with different content of boron carbide (B\textsubscript{4}C) particles were prepared using stir casting route. Microstructure study was done to see the particle distribution in the T4 heat-treated state using optical microscope and SEM analysis. The fabricated composites showed nearly uniform distribution of B\textsubscript{4}C particles however some agglomerated regions were also found. The significant grain size reduction was observed with the addition of B\textsubscript{4}C particles. Mechanical properties of cast composites i.e. tensile strength and macro hardness were investigated. The Mg composites showed an increase in hardness, yield strength and ultimate tensile strength as compared to unreinforced Mg.

Keywords: Stir casting, Magnesium, Hardness, Tensile strength

1. Introduction
Magnesium and its alloys have occupied the status of one of the lightest structural materials which have substantial applications especially in the transportation industry. It is paid close attention, due to its inherent characteristics like low density, good damping capacity, excellent castability and its availability in the global market [1, 2]. The density of magnesium is approximately two thirds of that of aluminum and one fifth of steel. As a result, magnesium alloys offer a very high specific strength among conventional engineering alloys. Magnesium casting production has experienced an annual growth between 10 and 20% over the past decades and is expected to continue at this pace. During the last two decades lot of work has been carried out to utilize magnesium alloys in manufacturing of the gear box housings, wheels, seat frames, steering wheel and power train applications [3, 4]. But relatively low strength, low elastic modulus and low hardness restricts its applications over wide range. However, these limitations can be compensated by developing metal matrix composites (MMCs) with the incorporation of harder ceramic particulates reinforcements in the magnesium matrix. To obtain optimum properties of these metal matrix composites, the selection of the type, size and volume fraction of reinforcement is a major concern. The processing techniques for magnesium are similar to those of aluminum counterparts, but due to reactive nature of magnesium with oxygen, special attention regarding melting, casting and mechanical processing is required. As reported in the literature, extensive research work has been performed on development of aluminum-based MMCs. But very less literature has been found for development of magnesium matrix composites. The major reason may be related to the difficulty in synthesizing Mg-matrix composites due to its high chemical activity. In general, protective gases such as SF\textsubscript{6}+Argon are used to avoid burning of magnesium melt. Magnesium based metal matrix composites (MMMCs) have attracted considerable interest because of their attractive mechanical properties over monolithic alloy [5]. Particulate reinforcement Mg-based composites fabricated with different techniques like molten metal infiltration [6], powder metallurgy [7], squeeze casting [8], stir casting [9] and spray forming [10] have been developed. Among these various techniques stir casting technique is the most simple, flexible and economic for large scale production. An additional benefit of this technique is the near-net shape formation of the composites. The need for lightweight and high-performance materials for automotive and aerospace sector has led to extensive research and development work in the production of magnesium matrix composites and cost-effective fabrication technologies. Stir casting is a liquid state method of composite materials fabrication, in which reinforcement is mixed with a molten matrix metal by means of mechanical stirring. Mechanical stirring in the...
furnace is a key element of this process. The final molten magnesium alloy, with ceramic particles, can then be used for sand casting, permanent mold casting or die casting. [9,11]. Magnesium metal matrix composites with various matrix compositions, such as Pure Mg, AZ31 and AZ91 have been successfully fabricated by using this method [9, 12-14]. In the present work pure Mg/ B₄C particulate reinforced MMCs were prepared by the stir casting technique. Microstructural analysis was done using SEM and optical microscope. Macro-hardness and tensile properties were determined on as cast composites.

2. Experimental detail

2.1. Composite fabrication

Commercially available pure Mg of purity 99.8% was used as matrix for composite preparation. Automatically controlled bottom pouring stir casting setup as shown in Fig. 1 was used for composite fabrication. Pure Mg ingots were firstly cut into small pieces as shown in Fig. 2. The melting of Mg pieces was done in a mild steel crucible which was placed in a resistance furnace, under the controlled atmosphere of SF₆ gas and high purity argon gas. Magnesium metal matrix composites reinforced with 6 wt % and 9 wt% of micron size B₄C particles were produced by the stir casting process. Small pieces of pure Mg (1Kg) were placed in a mild steel crucible and then preheated upto 400°C. Thereafter, SF₆+argon gases were supplied in the crucible to prevent any burning of Mg during melting stage. Then the furnace temperature was raised to approx.700°C and the melt was homogenised for about half hour and stirrer was started. Separately preheated (350°C) B₄C particles were added into the molten Mg during stirring. The stirring was done with stainless steel impeller at 400 rpm for 20 min. Finally the composite melt was poured into a permanent steel mould to form ingot of 80mm×80mm×80mm size. Pure Mg pieces were also melted under similar processing conditions and similar ingot was also prepared for pure Mg. Unreinforced Mg and B₄C reinforced Mg ingots were then subjected to T4 heat treatment at 688K (415°C) for 86400 sec. (24 hrs) [15]. Designation and compositions of prepared samples are shown in Table 1.

| Sample No. | Matrix | Wt % of B₄C added |
|------------|--------|-------------------|
| 1          | Pure Mg| 0                 |
| 2          | Pure Mg| 6                 |
| 3          | Pure Mg| 9                 |

2.2. Microstructural characterization

Microstructural analysis was done on the T4 heat treated cast samples in order to see the distribution of the hard phase reinforcement particles. Small pieces were cut to 0.01m x 0.01m size pieces for microstructural analysis. The samples were metallographically polished firstly and then etching was done on prepared composite samples using acetic glycol [Distilled H₂O 19ml + ethylene glycol 60 ml + aetic acid 20ml+ HNO₃ 1 ml] for 30 seconds. Microstructural characterization was carried out using optical microscope and SEM analyses. The distribution of B₄C particles and grains size changes was checked.
2.3. Mechanical characterization

Mechanical properties such as macrohardness and tensile properties were evaluated for prepared composite samples. The macrohardness test was carried out on Rockwell hardness tester, at a load of 100 kgf. The tensile samples having gauge length 25mm, width 6mm and thickness 5mm were prepared from ingots as per ASTM E8M-03 standard. The tensile tests were conducted on Tinus Olsen table top tensile tester. Further tensile fracture surface were also investigated using SEM.

3. Results and Discussion

3.1 Microstructural Analysis

3.1.1 Optical analysis
The microstructure images of as cast pure Mg and Mg/9wt% B₄C composite after etching are represented in Fig. 3 and Fig. 4 respectively. The B₄C particles were found to be located both at the grain boundaries and inside the primary pure Mg grains. As seen from optical images the grains in pure Mg were coarse in comparison to Mg/9 wt% B₄C composite sample. The refinement in grain size in composites may be attributed to the pinning effect due to the presence of harder reinforcement particles. Similar type of microstructure images were seen by Kumar et al. [16] in AZ91 magnesium based composite reinforced with silicon carbide particles.

3.1.2 SEM analysis
SEM micrographs of 9wt% B₄C composite is presented in Fig. 5. The micrograph shows the reinforcement to be well distributed in the Mg matrix and strongly bond with the pure Mg matrix; however, some agglomerated region were also observed in cast composites. Similar results were obtained by Deng et al. where they observed same images for Mg composites reinforced with different sizes of SiC particles [17].
3.2 Mechanical analysis

3.2.1 Hardness Results

The mean value of macrohardness of pure Mg matrix and Mg/B4C composites samples was calculated and shown in Fig. 6. The hardness of the composites was found to be remarkably improved as compared to the Mg matrix. Further, hardness of the cast composite increases significantly with increasing B4C reinforcement content. The increase in the hardness results of the composites may be attributed to the addition of harder B4C reinforcement which prevent localized deformation of the matrix and grain refinement of the Mg matrix with the addition of reinforcement. Kumar et al. [16] observed similar trend in increase of macrohardness in AZ91 magnesium based composite reinforced with silicon carbide particles.

3.2.1 Tensile Results

The yield strength (YS) and ultimate tensile (UTS) strength of the pure Mg and Mg/B4C composites are presented in Fig. 7 and Fig. 8. Results indicated that YS and UTS of the composites increased with the reinforcement content and was higher than the pure Mg matrix. Similar increase in tensile properties was observed by Saravanan and Surappa [9]. The fracture surfaces of tensile tested samples were analyzed using SEM testing. Figure 9 and Fig. 10 shows the typical SEM image of fracture surfaces of the Mg matrix and the Mg/B4C composite sample. Circular dimple were seen in pure Mg, which depict ductile fracture failure in pure Mg matrix whereas cleavage type brittle failure was seen in Mg/B4C composite sample. [18]
4. Conclusions

1. Magnesium based metal matrix composites were successfully prepared by stir casting technique.
2. The uniform distribution of B₄C reinforcement particles and good interface bonding between Mg/B₄C particles was observed in cast composites.
3. A significant grain refinement was observed with the addition of B₄C particles in the composite material.
4. The significant improvement in hardness, yield strength, and ultimate tensile strength was obtained with the addition of B₄C particles.
5. The unreinforced Mg exhibits ductile type of failure, whereas the fracture surface of composites shows brittle failure.

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