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*Research article*

# Production of $B_4C_p$ reinforced magnesium metal matrix composites by powder metallurgy

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## Abstract

Metal Matrix Composites (MMCs) are modern engineering materials which have more advantages when compared to conventional materials. Magnesium based MMCs among the MMCs have become an important research subject because of their low density and high strength/weight ratio in recent years. The aim of the current study was to produce magnesium based MMCs with different amount of boron carbide ($B_4C_p$) addition (3 wt.%, 6 wt.%, 9 wt.%) by the powder metallurgy (P/M) method and to examine the mechanical properties of the produced MMCs. Hardness of the samples sintered in the vacuum atmosphere was characterized by the Brinell hardness testing method. Density of the materials was determined according to Archimedes principle. Scanning electron microscope (SEM) was used for examination of microstructure and X-ray diffraction technique (XRD) was used for the phase analysis. Sintered density of magnesium based MMCs was reduced with $B_4C$ particle reinforcement. MgO, $Al_2O_3$ and $MgB_2$ phases was detected in the samples as a result of XRD analysis. The best flexural strength was obtained at MMCs with 3 wt.% $B_4C$ reinforcement.



***Keywords***: *Powder metallurgy, magnesium based metal matrix composite, $B_4C_P$*

## 1. Introduction

MMCs represent a group of composite materials. MMCs contain at least two phases that are chemically and physically different. This composite aims to reveal the properties which cannot be obtained by monolithic metals. Generally MMCs are constituted by distributing reinforcement phases (that are in the form of fibre or particle) in the metal matrix. MMCs that are ceramic reinforced to metal matrix have a great mechanical performance [1]. MMCs are an essential material group for the aviation and aerospace industry for their requirement of material that has high specific resistance and rigidity [2]. When compared to the fibre reinforced composite materials, particle reinforced MMCs come into prominence because of their low cost [3], high wear resistance and thermal stability [2]. The general matrix materials are Al, Mg, Fe, Ti, Ni, Cu, Ag, Co and Nb [3]. Among them Al, Ti and Mg are used commonly [1]. Magnesium is the matrix material that has the lowest density among the matrix materials with its density, 1.74g/cm$^3$. Magnesium is 35% lighter than aluminum and has density 4 times lower than steel (7.86g/cm$^3$) [4, 5]. Requirement for the lighter materials in the automotive and aviation industry has risen with the increase in the prices of petroleum [6]. Usage of magnesium especially in the automotive industry attracts great attention and usage of magnesium

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alloyed automotive parts has an effect both on increasing the fuel efficiency and on decreasing greenhouse gas emissions [5]. With the decrease of $CO_2$ emissions substantially and protection of the few fuel reserves, magnesium alloyed products have gained an increasing importance in respect of solving the problems of the raise in weight resulted from the additional factors such as light, sound, security, comfort, entertainment equipments etc. in the vehicles [7].

Limited properties of monolithic magnesium have been improved with the additions of variety reinforcements [8]. Most of the research has been carried out to increase the strength of monolithic magnesium [9]. These studies have concentrated on the SiC [6, 10-13] and TiC [14-17] particle reinforced magnesium based MMCs. Especially the studies related to the $B_4C_p$ reinforced magnesium based composites are more limited when compared to the studies about $SiC_p$ and $TiC_p$ reinforced magnesium based MMCs.

MMCs are produced with various techniques. The choice of suitable method is depended on properties needed by the MMCs, cost, number of productions, distribution of the reinforcement member (particle or fibre), matrix alloy and field of application [1]. MMC production with the P/M method is one of these methods. P/M method is a method of production that aims to transform various metal powders and ceramic particles into practical engineering parts by combining them in different thermal and mechanical deformation conditions [18]. MMCs produced with the P/M method have higher qualities than the ones produced with other production methods. Because the materials are produced in lower temperatures in P/M method, undesirable compounds in interfaces come into existence less often, and accordingly they have superior mechanical properties. They are cheaper than the materials produced with other methods. A homogenous reinforcement distribution can be provided with the P/M method [2].

In this study, it was aimed to produce magnesium based MMCs with various amount of $B_4C_p$ addition (3 wt.%, 6 wt.%, 9 wt.%) and to investigate the mechanical and microstructural properties. Characterizations of the composite materials were carried out by examining microstructure, phase analysis, density and hardness properties.

## 2. Material and Method

### 2.1. Powder Preparation, Pressing and Sintering

The size of commercial pure magnesium and aluminum powders (3% by weight) constituting the matrix and $B_4C_p$ used as reinforcement with average particle size of 61μm. Sizes of reinforcement particle and matrix powders were determined with the sieve analysis. $B_4C$ particle reinforcement was used at different ratio such as 3%, 6%, 9% by weight in the experiments. A homogenous distribution of reinforcement particles in the matrix was provided by mixing the powder mixtures prepared for each sample group in the mixer for 60 minutes at 50rpm homogenously. After the mixing procedure, green samples were obtained by cold pressing uniaxially under the pressure of 500MPa. Lubricant was used to make pressing easier. Sintering was carried out for 30 minutes at 150°C, 300°C, 450°C, and then for 3 hours at 590°C in vacuum atmosphere. Temperature profile in the process of sintering was indicated in Fig. 1.

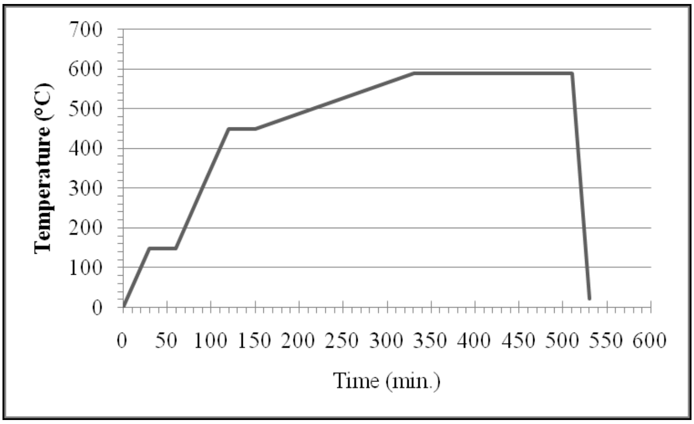


**Fig. 1** The furnace cycle for $B_4C_p$/Mg-MMCs

## 2.2. Microstructure Examinations, Phase Analysis

Samples were ground evenly with 400, 600, 800, 1000 and 1200 numbered water-proof SiC papers respectively by being rotated 90° at each time. Ground samples were polished with 6μm, 3μm and 1μm diamond paste suspensions, respectively. Metallographically prepared samples were cleaned with ethanol, and scanning electron microscope (SEM) (EVO 40) was used for the microstructure characterization of the samples that were polished metallographically. Shimadzu XRD 6000 X-ray diffractometer with Cu-X-ray tube was used for the phase analysis. Phase analyses were carried out with X-rays produced with CuKα (λ= 1.5405A°) radiation.

## 2.3. Hardness and Density Measurements

Hardness value of metallographically prepared samples was measured with the Brinell hardness measurement method by using load at 62.5 kg and balls in 2.5mm diameter. With Brinell hardness measurement method, 12 different measurements were carried out for each sample, minimum and maximum values were not evaluated. Mean Brinell hardness values were determined by averaging the measurement values. Weights of the samples in air were measured with analytical balance, and weights of them in water were measured with a suspension kit attached to the analytical balance at room temperature. Density measurements of the sintered samples were calculated with Archimedes principle based on buoyancy of water.

## 2.4. Three–point Flexural Strength Test

Three-point flexural test was carried out with the Shimadzu AG-IS computer controlled tensile testing device with 10tons capacity. The size of the test samples are 35×15×8 mm. A force was applied from the midpoint with 0.5mm/min rate of feed to determine the flexural strength values of the samples. The distance between the supports was arranged as 25.4mm. The flexural test was continued until the sample was broken, and maximum strength value at the time of breaking was calculated.

## 3. Test Results and Evaluations

## 3.1. Microstructure Characterization and Phase Analysis

Scanning electron microscope (SEM) images of the samples produced by adding $B_4C_p$ 3%, 6%, 9% by weight into the matrix are given in Fig. 2. It was seen that reinforcement particles came together in heaps especially in the sample of Mg-$B_4C_p$ (9% by weight) (Fig. 2).

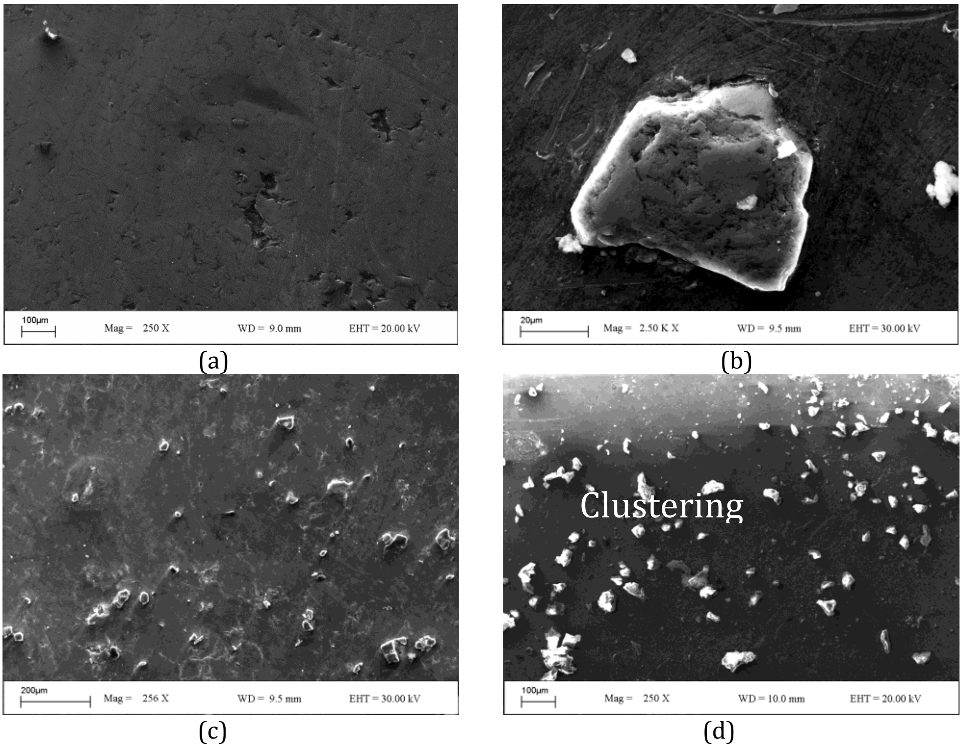


**Fig. 2** SEM micrographs of unreinforced Mg (a) and $B_4C_p$/ Mg-composite reinforced with (b) 3 wt.% $B_4C_p$, (c) 6 wt.% $B_4C_p$, (d) 9 wt.% $B_4C_p$

X-rays diffraction (XRD) patterns of Mg-$B_4C_p$ (6% by weight) sample are seen in Fig. 3. It was detected with the XRD analyses that MgO, $MgB_2$ and $Al_2O_3$ phases was found in the structure with the Mg and $B_4C_p$ principal components.

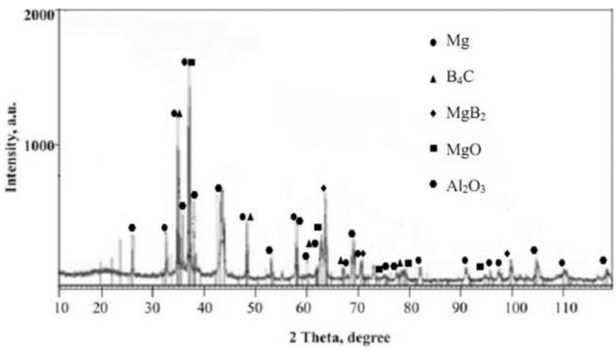


**Fig. 3** X-ray diffraction (XRD) pattern $B_4C_p$ 6 wt.% reinforced Mg composite

The existence of MgO and $MgB_2$ phases in the spectra is believed to be caused by oxidation of $B_4C$ reinforcement particles during the sintering process [19]. When the studies taking part in the literature were examined, it was seen that MgO and $MgB_2$

reaction productions were constituted in the previous studies as a result of the reactions stated below [19-20].

$$2Mg_{(s)} + O_{2(g)} = 2MgO_{(s)} \quad (1)$$

$$Mg_{(s)} + 2B_{(s)} = MgB_{2(s)} \quad (2)$$

$$B_4C_{(s)} + 4O_{2(g)} = 2B_2O_{3(l)} + CO_{2(g)} \quad (3)$$

$$4Mg_{(s)} + B_2O_{3(l)} = 3MgO_{(s)} + MgB_{2(s)} \quad (4)$$

### 3.2. Hardness and Density Measurement Results

Brinell hardness values of the samples are given in Fig. 4. The highest hardness value was obtained with 9 wt.% $B_4C$ reinforced Mg composite. The order of hardness values for the produced composite are as follows: Mg-$B_4C$ (9% by weight), Mg-$B_4C$ (6% by weight), Mg-$B_4C$ (3% by weight) and Mg (unreinforced). $B_4C$ reinforcement particle addition increased the hardness when compared to the unreinforced magnesium.

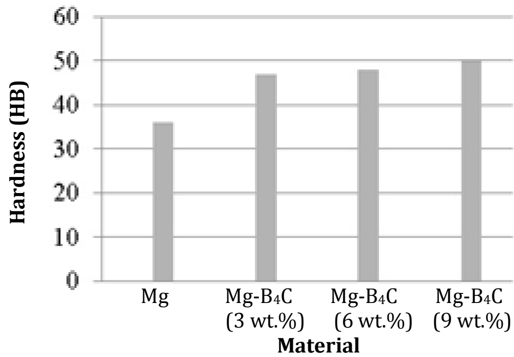


**Fig. 4** Variation in average hardness for $B_4C_p$ 3, 6, 9 wt.% reinforced Mg composite

Green density values of the samples increased with the increase in the amount of reinforcement particles, and sintered density values of them decreased (Fig. 5). Decrease in the density values that occurred after the sintering process resulted from the increase in porosity with the increase in the amount of reinforcement particles.

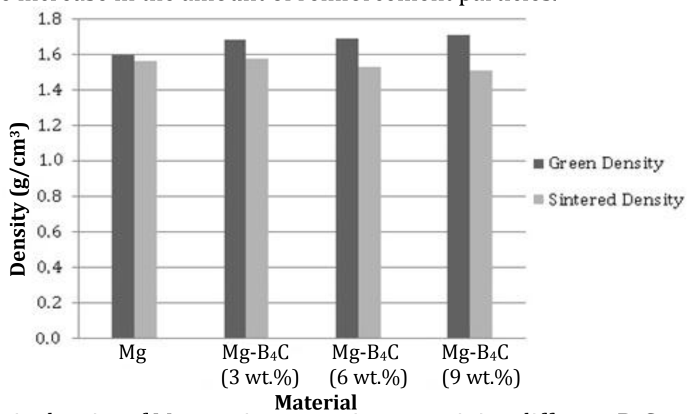


**Fig. 5** Variation in density of Mg matrix composites containing different $B_4C_p$ wt.%

### 3.3. Three–point Flexural Strength Test Results

Fracture surface SEM images of the samples subjected to three-point flexural test are given in Fig. 6a, b, c, d, e. In Fig. 6a, the image of the fracture surface of unreinforced magnesium is seen. Brittle fracture including typical cleavages was seen in this image of fracture surface dominantly due to the HCP structure of magnesium as seen in Fig. 6a. Typical image of fracture surface in the boron carbide particle reinforced composites occurred in the way of matrix deformation and particle fracture. Separation of the particles from the matrix was observed as holes (Fig. 6b, 6c and 6d). Flexural strength value of the samples is given in Fig. 7. When it is listed from the highest to the lowest, flexural resistance values of the samples are as follows: Mg-$B_4C$ (3% by weight), Mg (unreinforced), Mg-$B_4C$ (6% by weight) and Mg-$B_4C$ (9% by weight).

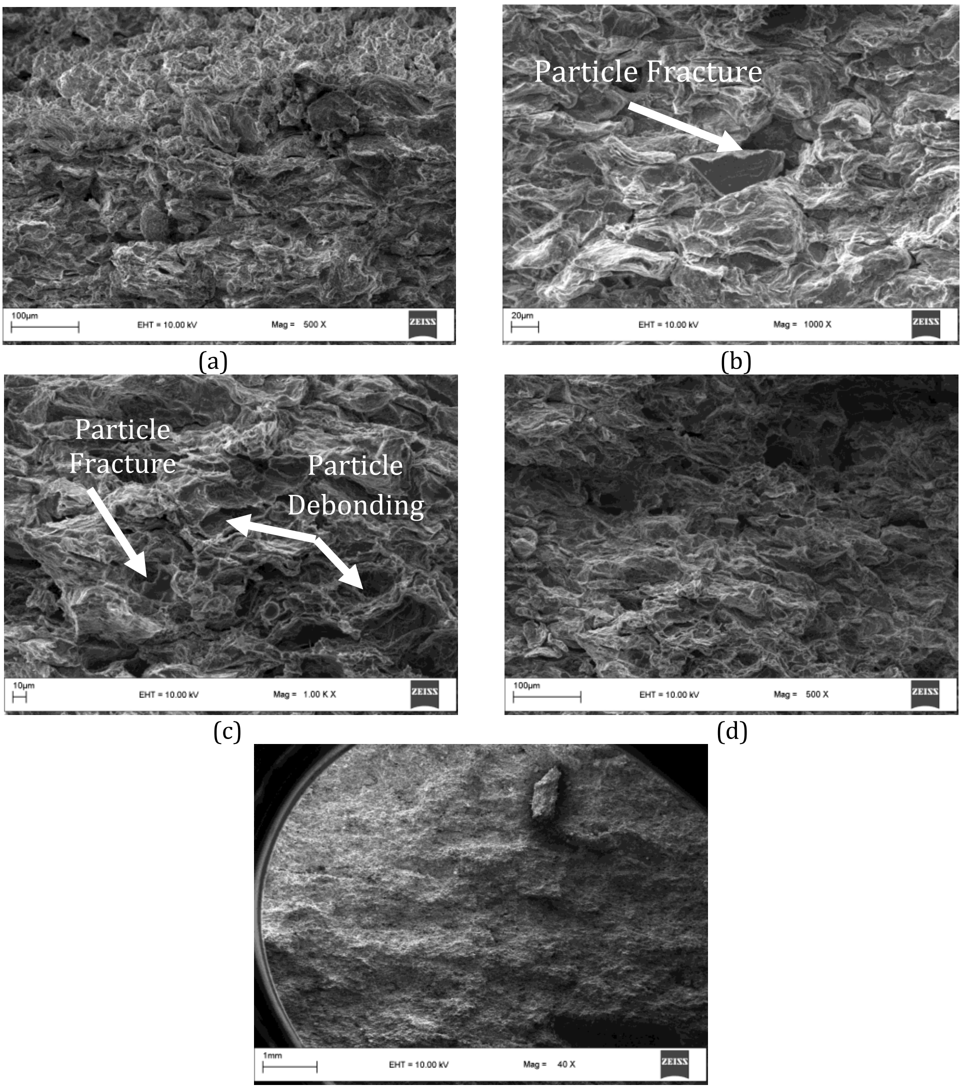


**Fig. 6** Fracture surface SEM images of the samples: (a) Mg (unreinforced), (b) Mg-$B_4C_p$ (3 wt.%), (c) Mg-$B_4C_p$ (6 wt.%), (d) Mg-$B_4C_p$ (9 wt.%), (e) Mg-$B_4C_p$ (6 wt.%)

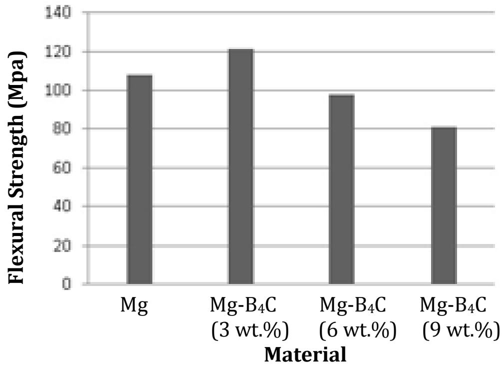


**Fig. 7** Variation in flexural strength for B4Cp reinforced Mg based metal matrix composite

## 4. General Results

Within the study, $B_4C_p$ reinforced magnesium based MMCs were produced with the P/M method. XRD analyses results showed the existence of MgO, $MgB_2$ and $Al_2O_3$ phases in the structure along with the Mg and $B_4C_p$ principle components. Green density values of the samples increased with the increase in the amount of reinforcement particles, and sintered density values of them decreased. Addition of $B_4C$ reinforcement particle increased the hardness when compared to the unreinforced magnesium. With the increase in the amount of reinforcement particles, an increase was observed in the porosity values. The best flexural strength was gained with the MMC that has 3% reinforcement ratio by weight.

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