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Investigation of microstructure, mechanical and wear behaviour of B_4C particulate reinforced AZ91 matrix composites by powder metallurgy

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In this study, AZ91 and AZ91 matrix composites reinforced with three weight fractions (10, 20 and 30 wt. %) of B_4C particulates have been produced by powder metallurgy using hot pressing. Microstructure, hardness, density and mechanical properties of the samples are investigated. Microstructure characterization revealed the uniform distribution of particulatesin matrix. The presence of Mg, $Mg_{17}Al_{12}$ and B_4C are verified by SEM and XRD. Wear tests are performed under loads of 5, 10, 20 and 30 N. Wear tests show that wear performance of the composites is improved with increasing particulate content. Observed wear mechanisms are oxidative and abrasive. The addition of B_4C particulates led to significant increase in hardness, 0.2% compressive yield strength, ultimate compressive strength and failure strain.

Keywords: Powder metallurgy, B_4C particulates, Wear

Magnesium alloys are attractive materials for aerospace and automotive industry because of their low densities, high specific strengthsand good damping capacities[1,2]. However, compared to other structural metals (iron andaluminium), magnesium alloys have lower wear resistance and mechanical properties[3]. Magnesium metal matrix composites (Mg-MMCs) are gaining in importance in order to improve these deficiencies. For example, SiC[3], Al_2O_3[4], TiC[5] and CNT[6] reinforced Mg-MMCs were fabricated and wear behavior and mechanical properties of the composites were investigated by researchers. B_4C is another important reinforcement which has low density, high hardness and extreme abrasion resistance[7].

Among the manufacturing methods of Mg-MMCs, powder metallurgy enables to produce lower production temperature and thus reducing the interfacial reaction between matrix and reinforcement[8]. Hot pressing method used in this study provides higher sintered density which leads to increase in mechanical properties and wear performance[9]. AZ91 is one of the most used magnesium alloys. Therefore, enhancement of the mechanical properties and wear resistance is a critical issue for AZ91 alloys[5]. However, study on AZ91/B_4C composites by powder metallurgy is quite limited.

This study investigates the producibility the AZ91 MMCs (10, 20 and 30 wt. % B_4C) and reveals the effect of B_4C on microstructure, mechanical properties and wear behavior. Furthermore, hot pressing method was used for production of the samples. The density, hardness and wear mechanisms of the samples were also discussed.

Experimental Section

In this study, AZ91 (~120 µm) and B_4C (~45 µm) powders were used for production of MMCs. The chemical composition of the AZ91 powder is given in Table 1. AZ91 powder with 10, 20 and 30 wt.% B_4C powders were mixed in a turbulamixer for 5 h. AZ91 and AZ91 MMCs were pressed into cylindrical compacts at pressure of 45 MPa. Then, samples were sintered at 525°C during 1.5 h under an argon atmosphere with same pressure. The theoretical density of the samples was calculated using the rule of mixtures. The actual density of the samples was measured using Archimedes principle. Microstructure and phase characterization of the materials were investigated using scanning electron microscopy (SEM) (Carl Zeiss Ultra Plus) and X-ray diffraction (XRD) (Rigaku Ultima IV). Hardness tests were carried out using a hardness device(Qness, Q10 A+) and

Table 1 — Chemical composition of the AZ91 powder.

Elements	Al	Zn	Mn	Fe	Mg
Wt.%	8.143	1.015	0.356	0.027	Balance

a load of 0.5 kg. The reciprocating wear tests were performed using tribometer (UTS T10/20) at loads of 5, 10, 20 and 30N. The sliding distance was 500 m. The worn surfaces of the samples were investigated using SEM to understand mechanisms of wear. Compression tests were performed in accordance with ASTM E9 standard using a Zwick/Roell 600 kN test machine.

Results and Discussion

Density results and microstructure characterization

The theoretical density, actual density and porosity of the samples are given in Table 2. As seen in Table 2, porosity values of MMCs increased with the addition of B_4C particulates. This can be attributed to the presence of fine micro-pores. However, these micro-pores could not be observed in the microstructure images due to low porosity content.

Figure 1 shows the SEM micrographs of the AZ91 and AZ91 MMCs. $Mg^{17}Al^{12}$ intermetallic structure was observed in AZ91 (Fig. 1a). The micrographs reveal the uniform distribution of B_4C particulates through AZ91 matrix. However, partial agglomeration of B_4C particulates was seen in AZ91/wt. % 30 B_4C.

Figure 2 shows the high magnification SEM micrograph of AZ91/wt. % 10B_4C and EDS point scans. From the EDS scans, it is concluded that B_4C particulate is present (black area) due to high B and C content. It is worth to say that low O content can be attributed to the realization of production under protective argon atmosphere.

Figure 3 shows the XRD patterns of the samples. From the XRD results, it can be seen that Mg and $Mg_{17}Al_{12}$ phases are present in AZ91 sample. B_4C diffraction peaks were also identified in AZ91/wt. % 20 B_4C and AZ91/wt. % 30 B_4C.

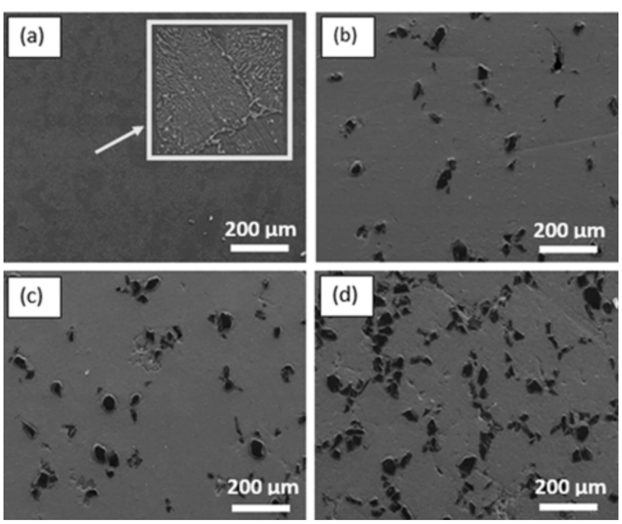


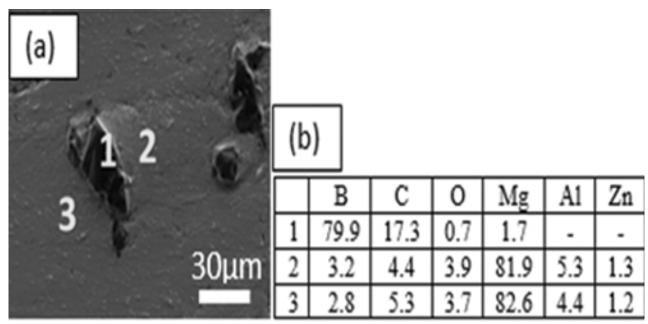
Fig. 1 — SEM (secondary electron) Micrographs of (a) AZ91, (b) AZ91/10 wt.% B_4C, (c) AZ91/20 wt.% B_4C and (d) AZ91/30wt.% B_4C.

Hardness and Wear Results

Figure 4 shows the hardness of the samples versus different reinforcement percentages. It is clear that the hardness values significantly increased with increasing particulate content. As compared with AZ91, the hardness values of AZ91 MMCs reinforced with 10, 20 and 30 wt.% B_4C particulates were

Table 2 — Density and porosity values of the samples.

Material	Theoretical density (g/cm^3)	Actual density (g/cm^3)	Porosity (%)
AZ91	1.864	1.815	2.6
AZ91/wt.% 10 B_4C	1.929	1.874	2.8
AZ91/wt.% 20 B_4C	1.995	1.931	3.2
AZ91/wt.% 30 B_4C	2.060	1.982	3.7



	B	C	O	Mg	Al	Zn
1	79.9	17.3	0.7	1.7	-	-
2	3.2	4.4	3.9	81.9	5.3	1.3
3	2.8	5.3	3.7	82.6	4.4	1.2

Fig. 2 — (a) High magnification SEM (secondary electron) micrograph of AZ91/10 wt. % B_4C and (b) EDS point scans (wt.%).

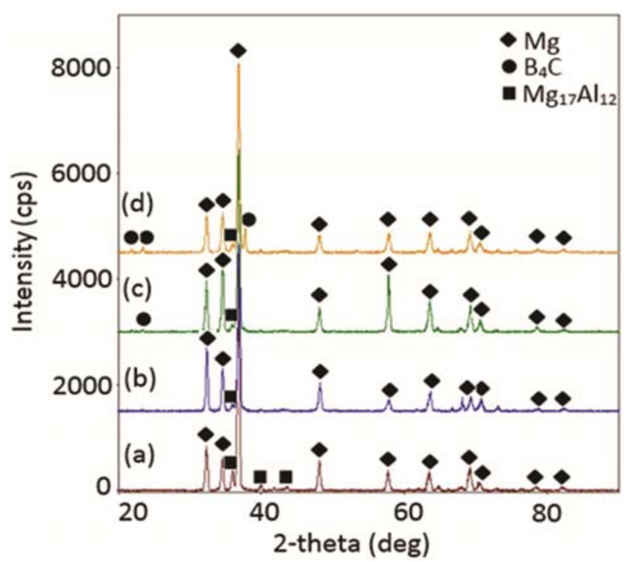


Fig. 3 — XRD patterns of (a) AZ91, (b) AZ91/10 wt.% B_4C, (c) AZ91/20 wt. % B_4C and (d) AZ91/30wt.% B_4C.

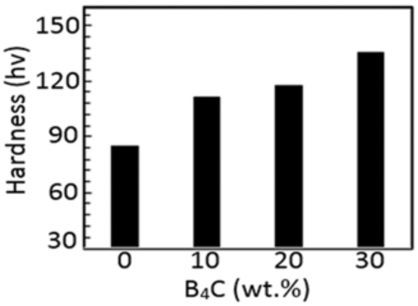


Fig. 4 — Hardness of the samples versus B_4C percentages.

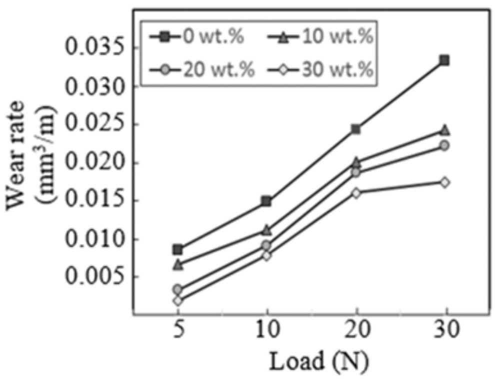


Fig. 5 — Wear rates of the samples versus different loads and particulate percentages.

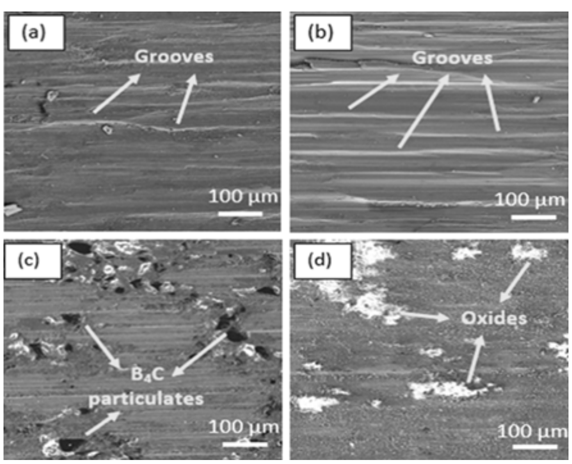


Fig. 6 — Worn surface images of AZ91 under (a) 5N and (b) 30N; AZ91/wt. % $30B_4C$ (c) 5N and (d) 30N.

increased by 30, 38 and 58%, respectively. The increase in hardness can be mainly attributed to the presence of hard B_4C particulates which leads to localized matrix deformation during indentation[4].

Figure 5 shows the wear rates of the samples versus different loads and particulate percentages. As compared to AZ91, AZ91 MMCs exhibited the lower wear rates under all loads. Additionally, wear rates of the samples increased with increasing wear load.

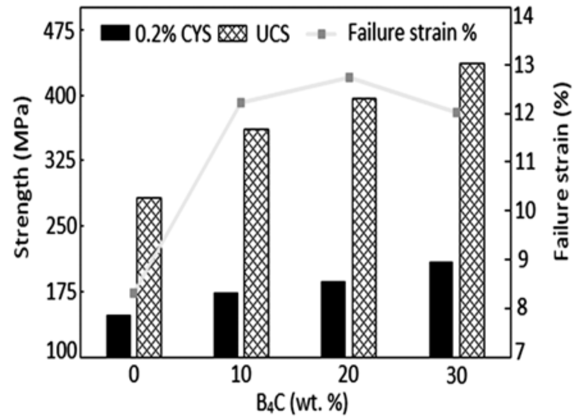


Fig. 7 — Compression test results of the samples versus B_4C Percentages.

Wear results of this study is consistent with Archard's law which explains a material with high hardness has low wear rates[10].

Figure 6 shows the worn surface images of the samples under loads of 5 and 30 N. It is concluded that abrasive wear is dominant mechanism due to the presence of grooves (AZ91). However, these grooves are distinct for AZ91 under load of 30 N. It is possible to say that wear mechanism changed to severe abrasive. AZ91/wt. % 30 B_4C shows the mild abrasive wear. The reason of this behavior is attributed to the presence of B_4C particulates, which resists to wear. Under high load (30 N), partly oxidative mechanism is dominant for AZ91/wt. % 30 B_4C.

Compressive properties

Figure 7 shows the compression test results of the samples. The results show that increase in both compressive yield strength (CYS) and ultimate compressive strength (UCS) was achieved with increasing B_4C content. The increase in CYS and UCS can be attributed to (a) load transfer (from matrix to reinforcement), (b) generation of dislocations due to thermal and elastic mismatch between the matrix and the reinforcement[11]. It is worth to mention that failure strain values of the MMCs are higher than that of AZ91. The reason of this is mainly attributed to the presence of homogenous distributed B_4C particulates.

Conclusion

AZ91 MMCs reinforced with B_4C particulates have been successfully produced by powder metallurgy using hot pressing. Uniform distribution of B_4C particulates is achieved. The addition of B_4C particulates leads to significant improvement in hardness, wear resistance and compression strength. The investigation of worn surfaces shows that wear mechanisms are abrasive and oxidative. Consequently, it is believed that AZ91/B_4C composites are possible candidate for automotive and aerospace industry due to their good mechanical properties and wear resistance.

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