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FABRICATION AND CHARACTERISATION OF Mg-B_4C COMPOSITES

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Abstract

The aim of the present investigation was to demonstrate the potential of pressureless infiltration in production of Mg-B_4C composites with a high fraction (>30 vol. %) of fine B_4C particles, to characterize fabricated composites by investigating their microstructure and mechanical behaviour as a function of B_4C particle size and the applied wetting agents (silicon an titanium powders added to boron carbide) and to identify the commercially most important comparative advantages of the composites obtained.

Key words: Mg-B_4C composites, infiltration, mechanical properties, chemically assisted wetting, the comparative advantages of Mg-B_4C composites

Introduction

Magnesium-based metal matrix composites (Mg-MMCs) are emerging as advanced engineering materials for applications in the aerospace, defence, automotive and consumer industries (sports goods etc.). The use of magnesium alloys as the matrix phase in metal matrix composites (MMCs) is of interest as an alternative to aluminum-based composites for advanced structural applications and for components in engines with the advantage of high specific strength and stiffness. As has been demonstrated [1-5], magnesium MMCs (Mg-MMCs) have mechanical properties basically similar to those of Al-MMCs and can be used for similar lightweight structural and functional parts.

The main advantage of Mg-MMCs in comparison to Al-MMCs and alloys is that they allow, in equivalent applications, a further (15-25%) weight saving, which is particularly attractive for extreme weight saving in transportation.

However, due to the high cost of the magnesium matrix, the cost of Mg-MMCs currently produced at the semi-industrial level was found to be typically 50-80% higher than the cost of Al-MMCs, thus limiting the application of Mg-MMCs to just a few military and aerospace products.

To manufacture Mg-MMCs with optimum properties and an acceptable cost of the end-products, the manufacturing process to near net shape has to be performed in an industrially-friendly single step.

Pressureless infiltration (spontaneous, in the absence of an external pressure), which can be practiced when good wetting conditions are achieved for self-infiltration (self-permeation or “wickling”) of the molten metal into the perform, is one of the most competitive techniques of MMC production, combining internal simplicity, cost-effectiveness, near-net shaping and significant flexibility in composition [6,7]. Additional advantages of the process are a more homogeneous distribution of particulate reinforcement within the matrix compared to the cast counterparts and an easy tailoring of the volumetric fraction of ceramic reinforcement.

Another important advantage of pressureless infiltration lies in the possibility of fabrication of composites with a high volume fraction of fine ceramic reinforcement. Actually, discontinuously reinforced MMCs with ceramic reinforcement near or above 50 vol. % and an average particle size below 1 μm could only be prepared by powder metallurgy or by infiltration. Such composites enable an additional tailoring of various physical and mechanical properties of commercial importance and better economy, allowing a high volume fraction of reinforcement to be obtained in near net shapes. At ambient temperature the elastic modulus, tensile strength and 0.2% tensile yield strength increase with the addition of reinforcing particles, whereas the tensile elongation decreases rapidly. Additional improvements of tensile properties are possible by reducing the particle size of the ceramic reinforcement. The attraction of composites with a high volume fraction of fine ceramic reinforcement is their superior performance to cost ratio, providing the maximum strength without a substantial price penalty to be paid for the extra benefits.

Hence, the aim of the present investigation was threefold: (i) to demonstrate the potential of pressureless infiltration in production of Mg-MMC samples with a high volume fraction of fine B_4C particles; (ii) to characterize fabricated composites by investigating their microstructure and mechanical behaviour as a function of B_4C particle size and the applied wetting agents (silicon and titanium powders added to boron carbide); and (iii), to identify the commercially most important comparative advantages of such a fabrication route and the composites obtained.

Experimental procedure

Materials

The composite system used in this study was based on the formulation Mg/B_4C. An unalloyed 8 kg magnesium ingot (ASTM B92/B92M 9980), as well as magnesium (with some traces of Si) internal turnings and chips (supplier: Dead Sea Magnesium, Israel), were applied as the infiltrant while two refractory grade B_4C powders: **powder A** (grade S93-0509 with d_{50}=44 μm; supplier: H. C. Starck) and **powder B** (grade HD15 with d_{50}=0.8 μm; supplier: H. C. Starck) were used for preform fabrication.

All B_4C powder mixtures were also doped with a powdered wetting agent – a small amount of Si (d_{50}= 0.1µm, supplier: Alfa AESAR) or Ti (d_{50}= 20µm, supplier: Alfa AESAR).

Preform Preparation

The B_4C powder was pretreated in an equimolar mixture of HF and H_2SO_4 for 5 min, air dried at room temperature for 6 h, additionally dried at 150 °C for 24 h and calcined at 400°C for 3h, both in an Ar atmosphere.

Various mixtures (Table 1) of B_4C powders A and B doped with different amounts (1 or 5 vol. %) of powdered wetting agent were homogenized in acetone in a planetary ball mill, dried and isostatically pressed without binder into cylindrical rods at 20MPa in a 25 mm diameter by 80 mm long rubber mould. The isopressed green bodies were machined to final dimensions of: 20±1 mm diameter and 50±1 mm long performs for infiltration trials.

The pore size and porosity of preforms were measured with a mercury porosimeter.

Table 1. List of completely infiltrated samples, with corresponding initial perform composition and infiltration parameters

Sample	Preform composition (vol. %)				Infiltration parameters	
	Boron carbide grade		Wetting agent		Temperature (°C)	Time (min)
	A	B	Si	Ti		
1	98		2		750	120
2	70	26	4		800	90
3	65	30	5		830	60
4	50	45	5		850	60
5	98			2	750	60
6	72	25		3	800	20
7	50	45		5	830	30
8	35	60		5	850	60

Infiltration

Pressureless infiltration was performed as a spontaneous self-infiltration process, under a flowing oxygen-free nitrogen atmosphere.

As sources of molten metal (infiltrant) two Mg plates machined from ingot and Mg chips were used. The first Mg ingot was placed in a 12 cm diameter by 25 cm high nickel-free low-alloy steel crucible. The preform was fixed in it using upper and lower perforated steel plates and after that upper Mg ingot was placed on it. The space in between the preform and crucible was completely filled up with magnesium turnings and chips. The filled crucible was closed with a cover plate to reduce the loss of Mg and placed inside a vacuum furnace (Degussa).

The volume of Mg ingots and chips was calculated to be approx. 50% higher than the volume of the preform. Hence, during infiltration the preform was immersed in molten metal.

Prior to heating, the furnace was evacuated to 1-2 Pa at room temperature by a rotary pump and back-filled with high purity nitrogen (O_2< 5 ppm, H_2O< 2 ppm) until a positive flow was obtained.

Pressureless infiltration was conducted under a slightly positive pressure of high purity nitrogen that was achieved by bubbling the exit gas through a 30 mm column of oil. The assembly was heated at a rate of 900 ºC/h to the selected temperatures of 750±10 ˚C, 800±10 ˚C, 830±10 ˚C and 850±10 ˚C and held isothermally for 15 to 120 min under the flowing nitrogen atmosphere.

After completion of the infiltration, the assembly was cooled to 675 ºC, at which time the infiltrated preform was removed from the furnace and cooled to room temperature.

All samples prepared and characterized in this work are listed in Table 1, with the corresponding initial preform composition and infiltration parameters.

Secondary Processing

The infiltrated preforms were machined to a diameter of 20 mm and a length of 50 mm. Machining was performed on a vertical CNC lathe (Mori SEIKI VL-25) using an SPG-422T square CVDD coated insert for rough cuts and a TPG-322T CVDD coated insert for the finish cut. Both types of insert (supplier: sp^3 Inc., Mountain View, CA, USA) were with complete CVDD coverage on one side providing four cutting edges. All machining was made dry. Typical machining parameters for rough cutting were as follows: cutting speed 7.7 m/s, feed rate 0.5 mm/rev and depth of cut (DOC) 2.5 mm. The cutting parameters for finish cutting were: cutting speed 7.7 m/s, feed rate 0.125 mm/rev and depth of cut 1.3 mm.

Quantitative Assessment of B_4C Particulates

To quantitatively determine the volume percentage of ceramic particles (including secondary formed particulates) in machined Mg-B_4C composite bars, optical and scanning electron (SEM) micrographs of infiltrated composites were analysed using the point counting method and image analysis and processing software.

Measurement of Composite Density and Calculation of Retained Porosity

Composite density measurements were carried out in accordance with Archimedes' principle [13] applying distilled water as the immersion fluid. The retained porosity was calculated based on the theoretical density of the samples taking into considerations the volume fraction of ceramic reinforcement (as B_4C) and the metallic matrix (as unalloyed magnesium).

Microstructural Characterization

Microstructural characterization studies were conducted on sub-samples of Mg-B_4C composite bars which were the same as sectioned for composite density measurement. Optical microscopy was used to determine B_4C morphology. Optical micrographs were taken and analysed using an image analysis system. Scanning electron microscopy was used to investigate the grain morphology, distribution of reinforcement, and the interfacial integrity between the Mg matrix and B_4C particulates. Energy dispersive spectroscopy (EDS) and X-ray diffraction analysis (XRD) were used for identification of phases present in the magnesium matrix.

Mechanical Behaviour

The mechanical behaviour of machined Mg-B_4C samples was assessed in terms of their microhardness, macrohardness and tensile properties.

Microhardness measurements were made on polished samples of Mg-B_4C. These measurements were made on an automatic digital microhardness tester using a pyramidal diamond indenter with a facing angle of 136 deg, a 0.025 kg indenting load, 50 μm/s load applying speed, and a 15 second load holding time.

Macrohardness measurements on the polished composite samples were accomplished using the Rockwell 15T superficial scale. Superficial Rockwell hardness measurement (HR15T) were made on a Rockwell hardness tester with a 1.59 mm steel ball indenter with a 2-second application of a total test load of 147.15 N, in accordance with ASTM standard E18-94.

The tensile properties (tensile strength, 0.2% tensile yield strength and elongation) of the Mg-B_4C specimens were determined in accordance with ASTM test method E8M-96. The tensile tests were conducted on round tension-test specimens of 5 mm in diameter and a 25 mm gauge length using an automated servo-hydraulic tensile testing machine with a crosshead speed of 0.254mm/60 s.

Results

B_4C particle morphology

The morphology of B_4C powders applied in this study is presented in Figs. 1 and 2. As evident, the refractory grade B_4C powder A consisted of coarse, polycrystalline aggregates while fine boron carbide powder B is composted of a fraction of individual particles having an average particle size about 1 μm and very fine agglomerated particles with an average particle size of a few tenths of a micrometre.

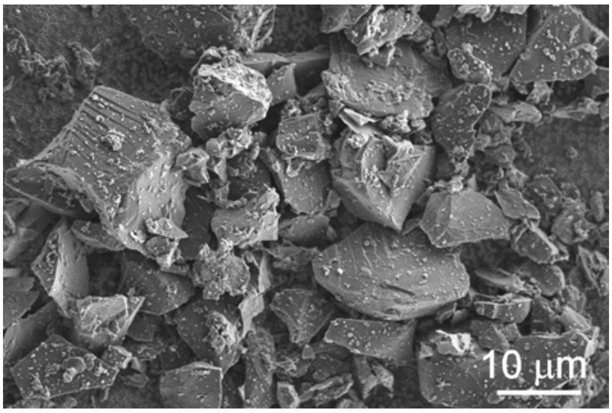


Fig.1. SEM photograph of B_4C powder A

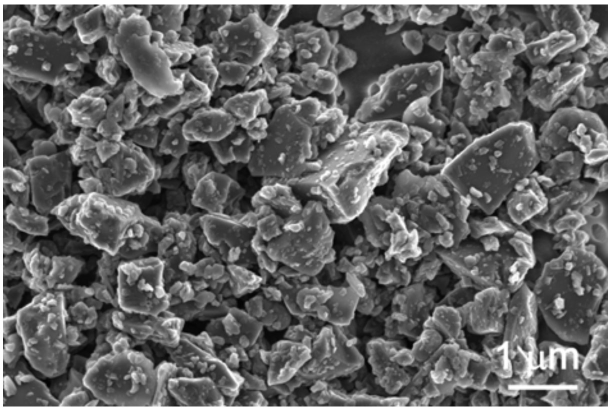


Fig.2. SEM photograph of B_4C powder B

Macrostructure

The machined performs of Mg-B_4C were 20 mm in diameter and 50 mm in height. Visual inspection of machined specimens revealed the minimal presence of solidified sludge. There was no evidence of blowholes and macropores.

Quantitative Assessment of Ceramic Particulates

The results of quantitative assessment of ceramic particulates in fully infiltrated samples are presented in Table 2.

Table 2. The initial porosity of fabricated preforms and the volume percentage of particulate reinforcement in fully infiltrated samples

Sample	Initial porosity in preform (vol. %)	Volume fraction of ceramic reinforcement in Mg matrix* (vol. %)
1	46±5	44±5
2	48±5	42±5
3	45±5	40±5
4	44±5	40±5
5	48±5	48±5
6	48±5	49±5
7	47±5	51±5
8	45±5	50±5

*including secondary ceramic phases formed during infiltration

Density Measurement and Calculated Retained Porosity

The measured density of infiltrated preforms and the calculated percentage of retained porosity are listed in Table 3.

Table 3. Measured density and calculated retained porosity of the fabricated Mg-B_4C composite samples[*]

Sample	Density (g/cm^3)	Retained porosity (%)
1	2.06±0,025	3.8±0.035
2	2.04±0,025	3.2±0.035
3	2.02±0,025	2.2±0.035
4	2.02±0,025	2.0±0.035
5	2.09±0,025	2.9±0.035
6	2.10±0,025	2.8±0.035
7	2.11±0,025	2.5±0.035
8	2.10±0,025	1.9±0.035

[*] values are averages of 5 different measurements

Microstructural Characterization

SEM-EDS micrographs of various infiltrated samples are shown in Figs. 3-5. In Fig. 6 the XRD of the phases detected is also presented.

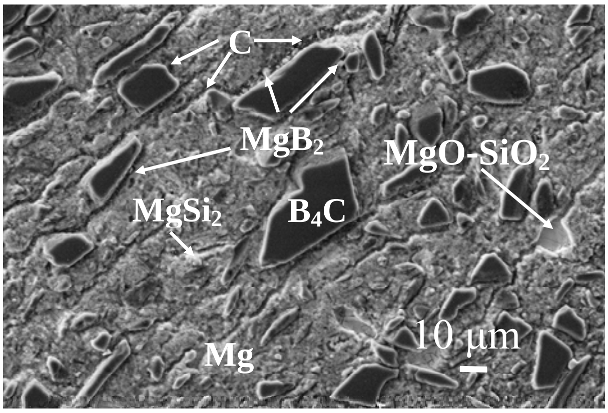


Fig.3. SEM-EDS of composite sample 2 (Table 1)

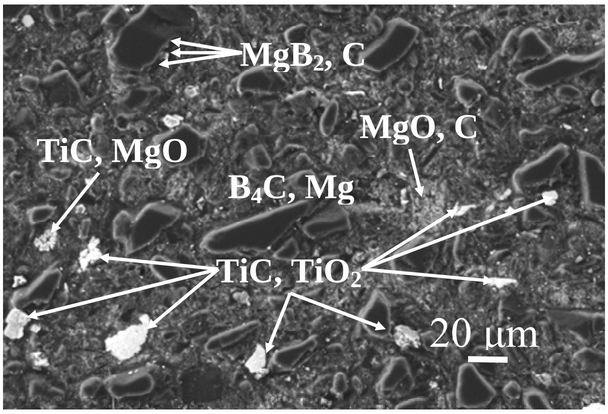


Fig.4. SEM-EDS of composite sample 6 (Table 1)

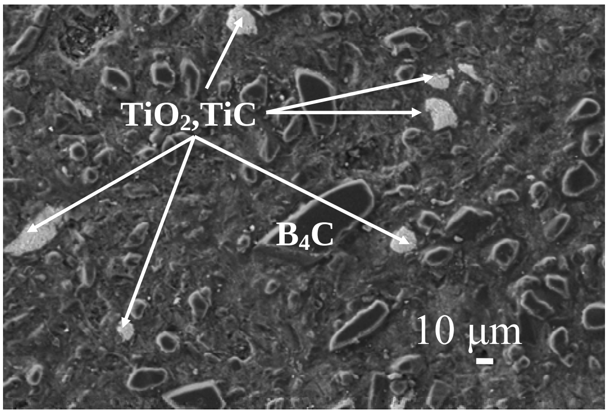
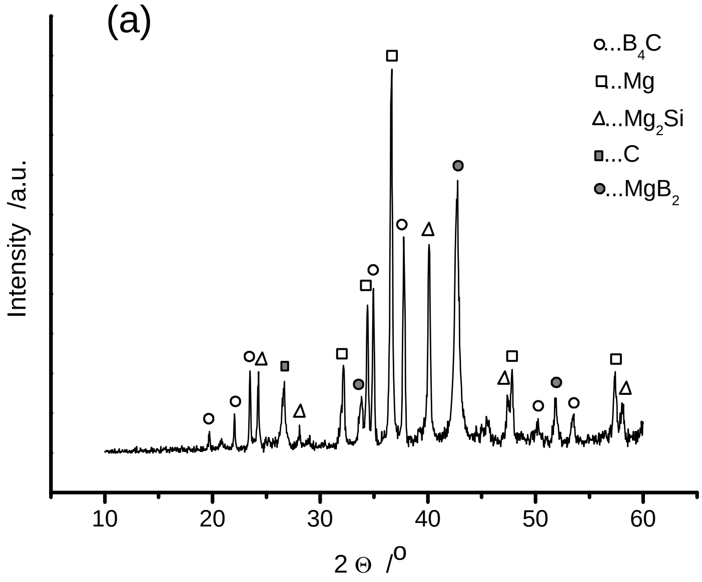


Fig.5. SEM-EDS of composite sample 7 (Table 1)



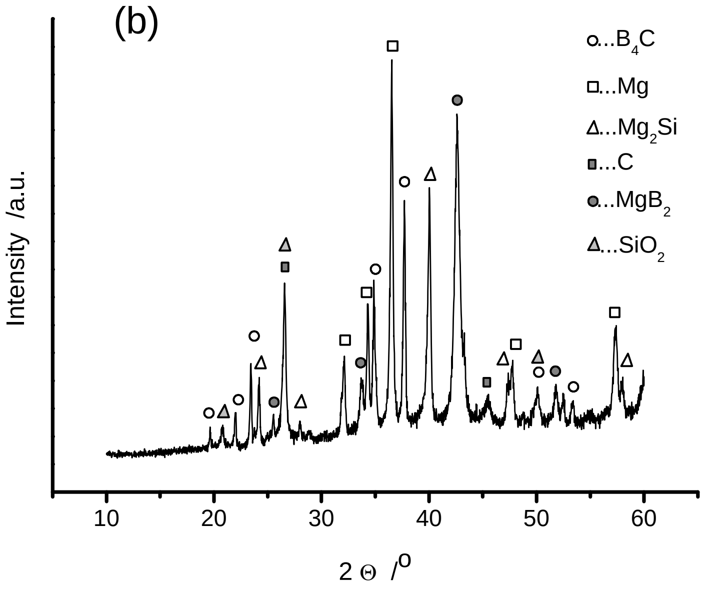


Fig.6 a, b. XRD of composite samples: (a) sample 4 (Table 1)-wetting agent Si, (b) sample 8 (Table 1)-wetting agent Ti

Mechanical Behaviour

The microhardness and macrohardness measurements of the as-infiltrated and machined samples of Mg-B_4C are summarized in Table 4.

In Table 5, the elastic modulus (E) of the as-infiltrated and machined composite samples, as well as results of ambient tensile testing are summarized.

Table 4. Summary of hardness measurements

Samples	Microhardness (GPa)		Macrohardness (HR15T)
	Matrix	B_4C	
Unalloyed magnesium	5±0.05		39±1
1	5±0.05	30±2	76±3
2	5±0.05	30±2	78±3
3	5±0.05	30±2	79±3
4	5±0.05	30±2	81±4
5	5±0.05	30±2	77±3
6	5±0.05	30±2	80±4
7	5±0.05	30±2	82±4
8	5±0.05	30±2	84±4

Table 5. Average mechanical properties of various laboratory prepared composite samples

Sample	E (GPa)	Tensile strength (MPa)	0.2 % tensile yield strength (MPa)	Elongation in 50 mm (%)
Unalloyed magnesium	41±1	216±3	125±13	7±3
1	81±2	403±6	287±25	0.8±0.1
2	89±2	443±6	304±25	0.8±0.1
3	91±2	453±6	308±25	0.8±0.1
4	96±2	478±6	318±25	0.8±0.1
5	83±2	416±6	303±25	0.8±0.1
6	94±3	462±6	326±25	0.8±0.1
7	100±3	501±7	347±25	0.8±0.1
8	108±3	535±7	364±25	0.9±0.1

Discussion

Infiltration

One of the main purposes of this work was to investigate the possibility of producing B_4C-Mg composites with a high volume fraction of fine particulate reinforcement (above 50 vol. % of particles with an average particle size below 5 µm).

The reasons rationale for such a study is the optimization of composite economy and improvement of mechanical properties. The spontaneous infiltration used in this work was found to be a suitable method for achieving these goals, allowing at the same time near net shaping and composite species production in a single processing step.

Although the systematic investigation of the infiltration rate of various preforms under different processing conditions was outside the scope of this work, it was found that the process of spontaneous infiltration of boron carbide porous preforms with molten magnesium proceeds rapidly with average infiltration rates of about 2-5 mm/min.

When successfully initiated, the spontaneous infiltration of porous preforms was completed in 15-20 min, demonstrating its valuable industrial potential. However, the successful initiation of spontaneous infiltration was found to be influenced by several experimental parameters.

The first one is the morphology of the boron carbide particulate. According to the collected experimental data, in preforms with more than 60 vol. % of fine B_4C powder A spontaneous infiltration was not achieved, even with further increase of the infiltration temperature and concentration of wetting agents. In contrast, preforms containing exclusively coarse B_4C powder B were spontaneously infiltrated with a significantly lower addition of wetting agents. Attempts to initiate spontaneous infiltration without adding wetting agents were unsuccessful.

Temperature is another important parameter in actuating spontaneous infiltration. As was confirmed by experiments, below 750 °C spontaneous infiltration was not achieved nor by prolonging the holding time or by applying coarse boron carbide powder B.

Chemically assisted wetting

From the point of view of wetting, the B_4C-Mg system is a non-reactive one. The low chemical reactivity between pure molten magnesium and B_4C is also the main reason for pore wetting behaviour and, also in this study, the experimentally confirmed inability of performing spontaneous infiltration in this system without addition of some wetting agents.

The enhanced wetting conditions necessary for spontaneous infiltration were achieved in this study by doping boron carbide powders with Si or Ti wetting agents. Addition of Ti and Si improve wetting mainly by forming a metal-like carbide more stable than B_4C. In addition, Si has an affinity for dissolving B, whereas Ti helps in stripping and inter-penetrating the oxide film from the molten magnesium.

Molten magnesium and boron carbide react forming magnesium borides (MgB_2 and less stable MgB_4) at the same time liberating elemental carbon. The presence of both borides and carbon was confirmed in composite samples by XRD (Fig. 6 a, b). MgB_2 is stable until 1047 °C, whereas MgB_4 decomposes completely at 827°C. Carbon remains in elemental form due to the fact that Mg does not form carbides.

Both wetting agents react with molten magnesium forming bright intermetallic (Mg_2Si, MgTi) and agglomerated phases (MgO-TiO_2-TiC, SiO_2-MgO, TiO_2-TiC), whose presence was confirmed by SEM-EDS (Figs. 3-5) and XRD (Fig.6 a, b).

Comparing the efficiency of the wetting agents used in this work, it was found that under the same conditions the addition of 5 vol. % of Ti enables spontaneous infiltration in preforms consisting of 60 vol. % of fine B_4C particles (powder A), whereas the addition of the same amount of Si leads to the spontaneous infiltration of preforms with a max. of 45 vol. % of fine B_4C particles. Ti as a wetting agent reacts with B_4C forming TiC. The experimental findings confirm that TiC appears in a mixture with oxide phases (Fig. 5). This is because Ti also removes the oxide film on the surface of molten magnesium, facilitating the formation of an oxide-free infiltration front.

Contrary to expectations that Ti should also react with boron forming TiB_2, the presence of a TiB_2 phase was not observed. A possible explanation is that TiC is thermodynamically more stable than TiB_2, which favours its formation in the system.

Mechanical properties

The results of the hardness measurements in Table 4 indicate an increase in macrohardness of the composite in comparison with non-reinforced magnesium. Also, the results of tensile property characterization revealed that Mg-B_4C composites fabricated by spontaneous infiltration exhibit superior mechanical properties (elastic modulus, tensile strength and 0.2% tensile yield strength) when compared to of non-reinforced magnesium. At the same time, the addition of ceramic particulates to the magnesium matrix led to a significant degradation in ductility.

Comparing the mechanical properties of composite samples with various ratios of fine and coarse boron carbide powders A and B, it was found that both macrohardness and tensile properties increase with increase in the portion of fine particles. For example, comparison of elastic modulus, tensile strength and 0.2% tensile yield strength in samples made of coarse B_4C (Table 5, sample 1) and samples with 30 vol. % of fine B_4C particles (Table 5, Sample 8) confirmed improvement of approx. 30% in tensile strength and modulus, as well as approx. 20% in 0.2% tensile yield strength.

The comparative advantages of Mg-B_4C composites with a high volume fraction of ceramic reinforcement

One of the great advantages of B_4C as reinforcement in magnesium-based composites is its low density (2.52 g/cm^3), slightly higher than the density of graphite fibres (2. 25 g/cm^3), frequently applied with magnesium for aerospace structures.

The density of boron carbide is actually the second lowest of all commercially used carbides, right after CaC_2 at 2.20 g/cm^3, making B_4C very attractive as reinforcement in light composites. As an example, the density of SiC, one of the most often used reinforcements in discontinuously reinforced MMCs, is significantly higher (3.21 g/cm^3). In addition, B_4C has several other advantages: extreme hardness, high Young's modulus and competitive bending as well as compressive strength.

In practice, the choice between aluminium alloys (with a density about 2.70 g/cm^3) and more expensive magnesium alloys (with a density of about 1.74 g/cm^3) as matrix in discontinuously reinforced MMCs is definitely made on the basis of weight reduction. Magnesium-based composites provide lightweight and excellent mechanical properties when reinforced with the appropriate amount of ceramic filler. However, there is a substantial price penalty to be paid for that particular combination of properties. Generally, to make magnesium-based composites the material of choice, that particular combination of properties should become competitive enough regarding alternative materials. In the case of magnesium-based composites, this is definitely not possible without the usage of low density ceramic reinforcement – preferably with a density similar to the density of magnesium and, at the same time, with appropriate morphology for achieving optimal properties. Such a ceramic filler is crucial in providing both lightening and equivalent functionality, which is of the utmost commercial importance.

Although in this work the competitiveness of magnesium-based composites was not systematically studied, the experimentally findings clearly suggested that an increasing amount of submicron particle size B_4C particles in a magnesium matrix results in improved functionality of the composite material, but not necessarily in better economy (better quality to cost ratio for a selected property).

Considering the same composite fabrication cost (cost of preform fabrication and infiltration) and the cost of magnesium metal (approx. 3.5 EUR/kg), the cost of composites with the same amount of B_4C filler (approx. 50 vol.%) will depend on the portion of low cost coarse and highly expensive submicron B_4C powders A and B, respectively. Taking into account the predicted cost of submicron and coarse boron carbide powders for mass production (about 1.5 EUR/kg for powder A and about 50 EUR/kg for powder B), one can calculate the total cost of materials for various compositions and experimentally determined properties, Table 6.

Table 6. Correlation between the cost of the material and the achieved properties in various composite samples

Material	Composition Vol.%			Cost of material (EUR/m^3)	Selected property (average from Table 4)		
	P-A	P-B	Mg		E (GPa)	Tensile strength (MPa)	0.2% tensile yield strength (MPa)
Non-alloyed magnesium			100	2000	41	216	125
Powder A (P-A)				600			
Powder B (P-B)				20.000			
Sample 1*	43		57	1.398	81	403	287
Sample 2*	29	11	60	3.574	89	443	304
Sample 3*	26	12	62	3.756	91	453	308
Sample 4*	20	18	62	4.960	96	478	318
Sample 5*	47		53	1.342	83	416	303
Sample 6*	35	12	53	3.670	94	462	326
Sample 7*	26	23	51	5.776	100	501	347
Sample 8*	18	30	52	7.148	108	535	364

* from Table 1

As evident, any application of submicron B_4C powder as composite reinforcement results in a huge (several times) cost increase from 1.342 EUR/kg for Sample 5 (Table 6) without fine boron carbide to 7.148 EUR/kg for Sample 8 (Table 6) with 30 vol. % of fine B_4C particles. However, the introduction of 30 vol. % of fine B_4C particles as reinforcement results at the same time in significant improvement of tensile properties: about 30% in modulus and tensile strength and about 20% in 0.2% tensile yield strength, which is of particular interest for very demanding applications (e.g. in the aerospace segment).

A more detailed analysis based on calculation of the performance cost index (PCI) and the cost of lightening for equal functionality (e.g. stiffness, strength) [8], which is out of the scope of this paper, is necessary for a final evaluation of the economic advantages of magnesium-based MMCs with a high volume fraction of ceramic reinforcement (particularly in the submicron range). The most significant contributor to the total cost of the material is submicron B_4C powder, which, on the other hand, is also responsible for achieving the superior performance of Mg-B_4C composites.

Thus, the major limitation in further commercialization of composites with a high amount of submicron reinforcement is the extremely high price of such reinforcement. Hence, in order to improve the competitive position of Mg/B_4C composites, making them more attractive also for automotive applications, a significant price reduction of submicron boron carbide reinforcement will be necessary.

Conclusion

The main conclusions that may be derived from this work are as follows:

Doping a B_4C preform with 5 vol. % of Ti powder as wetting agent, Mg-B_4C composites with approx. 30 vol. % of fine B_4C particles (with an average particle size of 0.8 μm) and approx. 20 vol. % of coarse boron carbide particles (with an average particle size of 44 μm) were successfully prepared by spontaneous pressureless infiltration. On the other hand, the pressureless infiltration of preforms with a higher amount of fine B_4C particles was, under the same experimental conditions, unsuccessful or, in some cases, incomplete. Moreover, preforms consisting of fine boron carbide particles with an average particle size of 0.8 μm were not successfully infiltrated even at higher temperatures (up to 900 °C), a longer holding time (2 h) and a higher amount of wetting agent (10 vol. % of Ti powder) indicating that for spontaneous infiltration some volume fraction of coarse B_4C particles should be incorporated into the preform.

Addition of Ti improves wetting by forming metal-like TiC which is more stable than B_4C. On the other hand, silicon has an affinity for dissolving boron which, once dissolved, reacts with molten magnesium forming MgB_2. In addition, both wetting agents react with molten magnesium forming intermetallics (Mg_2Si and MgTi) and bright inclusions appear in the solidified matrix, consisting of MgO, TiO_2, SiO_2 and TiC combined in different molar ratios. Ti as a wetting agent also helps in stripping and inter-penetrating the oxide film on the surface of molten magnesium, enhancing the formation of an oxide-free infiltration front between the molten magnesium and ceramic reinforcement.

Regarding the geometrical quantities characterizing porous preforms, it was found that for preforms with an average particle size of the mixed B$_4$C powders less than 15µm and a volume fraction of fine, submicrone particles higher than 60 vol. %, spontaneous infiltration did not take place or proceeded only in a thin surface layer of the preform. In addition, attempts to initiate spontaneous infiltration without adding wetting agents were unsuccessful. Finally, below 750 °C, spontaneous infiltration was not attained under any other experimental conditions, most probably because of poor wetting and low chemical reactivity in the system necessary for enhancing wetting behaviour. However, once successfully initiated, the spontaneous pressureless infiltration of porous preforms of dimensions 20 mm diameter and 50 mm long was completed rapidly, in less that 15-20 min.

The hardness (HR15T), elastic modulus, tensile strength and 0.2% tensile yield strength of B$_4$C-Mg composites were more than doubled compared to unalloyed magnesium. The main limitation remained ductility, which decreased with reinforcement by one order of magnitude.

Improvement of hardness and tensile properties (except ductility) was evidently higher in samples doped with Ti as wetting agent. The increase of the volume fraction of B$_4$C particles in the magnesium matrix and the wetting agent added to the preform resulted in about 30% higher values of elastic modulus and tensile strength, about 20% improvement in 0.2% tensile yield strength, as well as slight improvement in hardness (about 5 %) of the composites.

The main advantage of B$_4$C-Mg composites with a high (50 vol. %) volume fraction of low density ceramic reinforcement is in achieving superior tensile properties (except ductility) better than in aluminium matrix composites – while not exceeding 90% of the density of aluminium. The best tensile properties were obtained by introducing 30 vol. % of submicron B$_4$C reinforcement, which also significantly increases the cost of the composite.

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