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Critical Review on processing & properties of magnesium matrix composites

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ABSTRACT
In the recent era most of the industries focus on the fact that the ratio of strength to weight should be maximised i.e. the strength of the material should be increased along with decrease in its weight. Magnesium is one of the lighter materials; therefore, from last few years, its light-weight matrix composites have become the significant matter of concern in the field of metallurgy. Magnesium mixed with ceramic, forms the composite materials which are having extremely good mechanical and physical properties, e.g., good resistance towards wear and tear, excellent damping properties and high specific strength. In this review paper the stress is given on explaining the various processing techniques that how the composites are being reinforced into the metal matrix and also what are the effects of these reinforced ceramic particles on the properties of material. The great bonding ability between the ceramics and the magnesium matrix can be used to fabricate magnesium matrix composites. Description of microstructure and the changes in physical and mechanical properties of the material is summarized in the paper together with creep behaviour, damping capacity and resistance towards wear and tear.

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Introduction

The alloys of magnesium are taken into observation by many of the industries dealing with materials due their light weight and machinability properties [1]. Magnesium is not used in its pure form because at elevated temperatures it starts losing its strength and moreover magnesium is having poor resistance towards corrosion and thus provides hindrance to its applications [2]. In aerospace industries where high strength to weight ratio is the major concern, such types of composites are used. The magnesium matrix composites comprise of ceramic material, which is reinforced into the magnesium. Magnesium in combination with ceramics can exhibit the properties of high tensile strength, high resistance to corrosion and better damping properties. For example, if SiC_p is reinforced into the magnesium matrix composite it will reveal better resistance towards wear by almost 15% to 30% as compared to standard alloy [3]. The reinforced particles may be fibres, particulates or whiskers. Out of these, the particulates are cost effective and can be machined easily. There are wide varieties of techniques available for the processing of such types of composites which makes their progress increasingly attractive. Magnesium can be used as advanced structural material but it is also indispensable to have appropriate knowledge of selecting the correct processing method for a particular type of ceramic system.

Processing routes for magnesium matrix composites

The processing methods developed for optimizing the mechanical properties and microstructure of magnesium matrix composites can be classified into two categories: Conventional and Special processing routes.

Conventional processing

There are three methods which have been widely adopted for formation of metal matrix composites: Stir casting, Powder metallurgy (PM) and Squeeze casting.

Stir casting

The process of stir casting was started by Ray in 1968 [4]. It involves the process of introducing reinforcements into molten magnesium with the help of mechanical stirring. The fabrication of submicron SiCp-reinforced AZ91 composites of magnesium matrix is shown in Fig. 1.

The ratio of submicron SiCp has a great impact on the strengthening effect and grain refinement of composites [5, 6]. Amongst all the processing methods stir casting is the most economic one. It has capability of mass production. Stir casting also has some disadvantages: (1) a uniform distribution of reinforcements in metal matrix composites is tough to find; (2) trapping of unwanted inclusions and gases is possible in stir casting.

Powder Metallurgy

In the process of powder metallurgy, magnesium and reinforcements are uniformly mixed, degassed and sintered at required atmospheric conditions. Figure 2 shows the schematic method of fabrication of composites of magnesium matrix reinforced with boron carbide particulates. By changing the ratio of B_4C particulates, the mechanical properties can be altered [7]. There are various other applications of powder metallurgy process; for example, the fabrication of ball milled Al + CNT into magnesium matrix composites is also done by PM route. Powder metallurgy has many advantages: (1) since this process can minimize the reaction between matrix and reinforcements, any type of alloy and reinforcement can be

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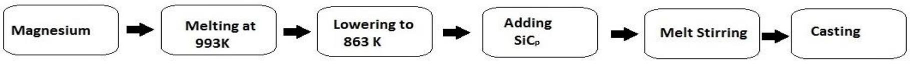

Figure 1: Fabrication of magnesium matrix composites reinforced with submicron SiC_p with the help of stir casting [10, 1]

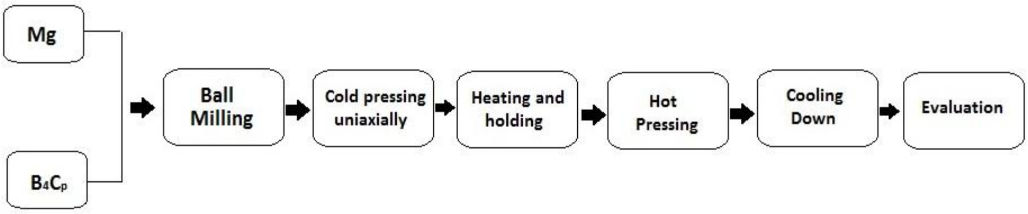

Figure 2: Fabrication of magnesium matrix composites reinforced with B_4C_p with the help of powder metallurgy

Figure 3: Schematic of squeeze casting process to produce $Mg_2B_2O_{5w}$ + B_4C_p reinforced hybrid [8]

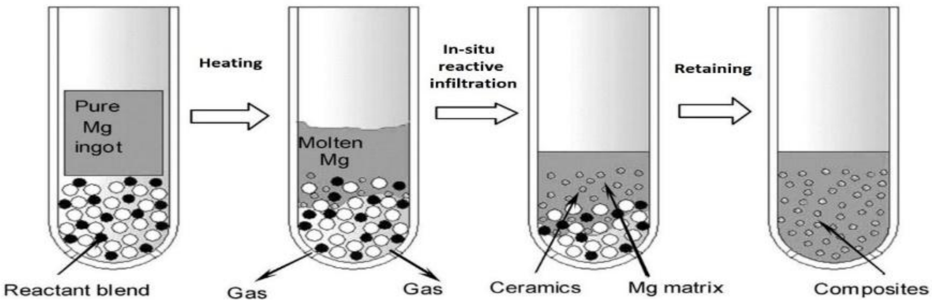

Figure 4: In-situ reactive infiltration process for fabrication of magnesium matrix composites [1]

used. (2) unlike stir casting process, this method provides a uniform distribution of reinforcements but the cost factor of PM process cannot be ignored. This process requires costly material (alloy powder) for the fabrication of materials.

Squeeze Casting

Squeeze casting also known as pressure infiltration, is the process for the preparation of metal matrix composites in which the reinforcement materials are preheated before placing them in casting mould, then the magnesium alloy is poured into the mould in molten form and is allowed to solidify. The use of this process to produce B_4C_p + $Mg_2B_2O_5$ hybrid is shown in figure 3. With the help of this process, it was observed that B_4C_p plays an important role in increasing the flexure strength of composite materials [8].

Although the process of squeeze casting is less suitable for mass production yet it is more advantageous over stir casting due to the reason that this method gives an even distribution of reinforcements into the composite and there is no scope for gas formation as the metal is pressurized throughout the solidification [9]. There must be a proper control over applied pressure as excess of pressure may result in the turbulent motion of molten magnesium which may further cause its oxidation.

Special Processing Routes

In-situ reaction, pressure less infiltration, spray forming, mechanical alloying etc. are some of the other important techniques for the fabrication of magnesium matrix composites in addition to above discussed methods.

In-Situ Reaction Synthesis

In-situ reaction synthesis method is one of the recently adopted methods which aim at directly synthesizing the reinforcements in the magnesium matrix composites with the help of certain chemical reactions between elements and compounds. This method founds a great advantage as it gives thermodynamically stable reinforcements and provides good mechanical properties to the material [10].

The most important requirement for the application of this process is the desired thermodynamics of the foreseen reactions. In-situ reactive infiltration process is a new technique for the formation of magnesium matrix composites that combines pressure less infiltration with in-situ synthesis. A uniform arrangement of reinforcements and clean interface between them and matrix can be obtained by this technique [1, 2]. The fabrication of magnesium matrix composites using in-situ infiltration process is shown in Fig. 4.

Mechanical alloying

Mechanical alloying is the method which can provide a material with unique microstructures and properties. It was found in late 1960s [11]. It is a solid state processing method in which there is repeated fracture and welding of particles due to the collision of high energy ball samples [4, 5]. Mechanical alloying method finds an edge over other techniques when the nano-composites with large ratio of reinforcements are taken into account [6]. The only drawback of mechanical alloying is that it consumes long time and thus contamination of milled powder occurs.

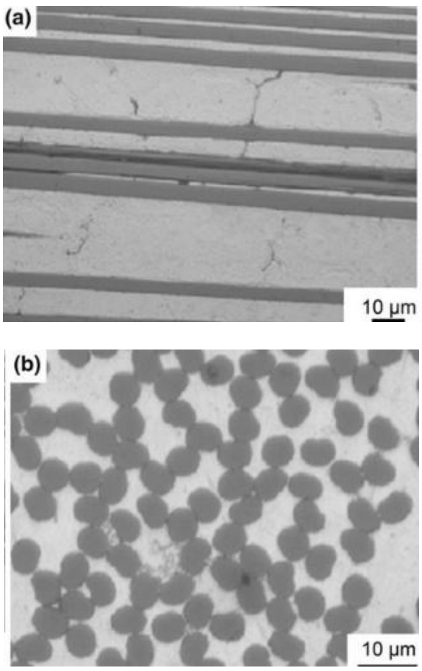

Figure 5: Microstructure of magnesium matrix composite reinforced with carbon fibres; (a) longitudinal section; (b) transverse section [7]

Microstructural characterization

Owing to the fact that there are number of fabrication techniques used for reinforcing the material into metal matrix and thus the microstructure formed will also differ according to the technique used. For example, in stir casting the particles are in random fashion of aggregation and segregation which in result, limits the amount of the reinforcements added to the metal matrix. There are some reinforcements which may react with the metal matrix to form a new microstructure. In this section the issue of concern will be the microstructural characterisation of composites.

Morphology of Reinforcements

As the different types of reinforcements are integrated into the metal matrix, so the distribution of these reinforcements will also vary accordingly. For example, if the carbon fibre is incorporated into the magnesium matrix composites, they will form the microstructure in longitudinal as well as transverse section as shown in the Fig. 5. Such types of composites formed, generally possesses anisotropic properties. The ceramic particles are widely used as reinforcements, because they tend to form a variety of microstructure depending upon the shape and size of the matrix and reinforcement particles. The microstructure will also vary depending upon the processing conditions like surrounding pressure, temperature and other factors. For example, if the matrix particles are larger than the reinforcements then there is a tendency that reinforcing particles may gather in the voids of matrix resulting in heterogeneous distribution in the final composite [10]. In recent years, the attention is given towards in-situ magnesium matrix composites as compared to ex-situ, because the particles which are reinforced within the metal, forms a more uniformly distributed structures as compared to those formed with ex-situ processing as they are more uniformly distributed when processed in in-situ reaction method. If the whiskers are used as reinforcements, then they tend to form a random orientation. Figure 6 depicts the SEM graph of $Mg_2B_2O_5$ whiskers in the matrix of magnesium [9].

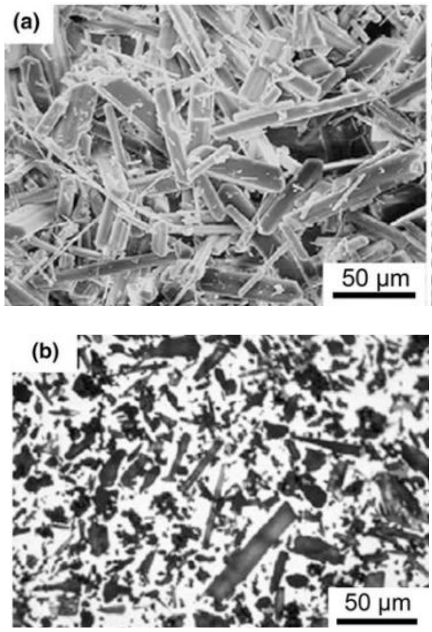

Figure 6: (a) SEM micrograph of Mg_2B_2 whiskers (b) optical image of the as-cast magnesium based composite with 50% vol $Mg_2B_2O_5$ with whiskers [9]

Mechanical properties of magnesium matrix composites

In comparison with the unreinforced matrix material, the metal matrix composites are gaining much importance due to high tensile strength, good wear resistance and damping properties. The concern is also shown towards the homogeneity of composite as inhomogeneous type of distribution will result in lower ductility and toughness of the composite [12]. Thus a symposium of mechanical properties of the magnesium matrix composite is provided below.

Tensile Behaviour

The ultimate tensile strength of reinforced matrix composite is highly improved as compared to unreinforced metal alloys; as a result, composites are selected as high performance materials which are used in aerospace industries [13]. In some cases, the improvement of the tensile strength results in poor ductility of the material [2]. Table 1 indicates increase in the ultimate strength of composite as compared to unreinforced magnesium alloy at the cost of its ductility [14].

Wear Resistance

The property of the material to resist its wearing rate is known as wear resistance. There are many materials which exhibit such type of property. Owing to the fact that magnesium alloys are having poor resistance thus cannot be used in tribological conditions. The reinforcement of ceramics, fibres or particulates into the metal matrix has improved wear resistance of magnesium alloy [15]. For example, the wear resistance of composite material incorporated with 1.11 vol % of Nano- alumina particles has improved to 1.8 times than the unreinforced material [16].

Damping Capacity

The tendency of a material to absorb the vibrations or shocks is known as damping capacity of material. Magnesium in its pure form exhibits high damping capacity but due to low tensile strength and poor wear resistance properties, pure magnesium fails to find its applications. Thus magnesium matrix composites having high tensile strength, high damping capacity and good wear resistance properties are used in place of pure magnesium [17]. The addition of SiC particulates into magnesium matrix can increase the damping capacity of the material.

Table 1: Density and room temperature tensile properties of magnesium alloy and (TiB2+TiC)/Mg composites [8]

Materials	Density (g/cm3)	Modulus (GPa)	0.2%YS (MPa)	UTS (MPa)	Ductility (%)
Mg	1.81	45 ± 2	82 ± 3	233 ± 0	6.0 ± 0.5
Mg/(TiB2 ? TiC)	1.93	53 ± 2	95 ± 2	298 ± 2	2.4 ± 0.4

Table 2 depicts the wear mechanism of Mg-Al alloy and the composites formed by reinforcing SiC_p [11]. From table 2 it is clear that the softening and melting of metal will occur when the material is tested under severe conditions of high speed and high load. Contrastingly, the abrasion will decrease in the severe conditions due to smooth and featureless operating conditions.

Conclusions

This review paper presents some important aspects related to magnesium matrix composites along with different methods of synthesis, study of microstructures and various physical and mechanical properties. The addition of different types of reinforcements results in different micro-structures which plays an important role in controlling the mechanical and physical properties of material.

The magnesium matrix composites are having high affinity towards oxygen and thus gets oxidised easily; therefore, conventional machining processes which includes high temperature rise are restricted for such type of composite material. Great efforts are required on how to increase both the ductility and strength of the magnesium matrix composites. Although some demur still exists but the magnesium matrix composites, on the account of its light weight offers attractive potential to be utilized commercially.

Table 2: Wear mechanisms for each combination of sliding condition and magnesium-based pin material [11]

Sliding speed (m/s)	Load (N)	Pin material	Wear mechanisms		Delamination	Adhesion	Softening/melting
			Abrasion	Oxidation			
0.2	10	MgAl	**	*	*	-	-
		SiC_p/MgAl	**	*	**	-	-
	30	MgAl	**	-	**	-	-
		SiC_p/MgAl	**	*	***	-	-
0.5	10	MgAl	*	**	**	-	-
		SiC_p/MgAl	*	***	*	-	-
	30	MgAl	**	-	**	-	-
		SiC_p/MgAl	**	*	***	-	-
1	10	MgAl	*	**	**	-	-
		SiC_p/MgAl	*	***	*	-	-
	30	MgAl	**	-	**	*	-
		SiC_p/MgAl	**	*	**	-	-
2	10	MgAl	**	-	**	*	-
		SiC_p/MgAl	*	**	*	-	-
	30	MgAl	*	-	*	**	*
		SiC_p/MgAl	*	-	*	**	*
5	10	MgAl	*	-	*	**	*
		SiC_p/MgAl	*	-	*	**	*
	30	MgAl		-	-	-	***
		SiC_p/MgAl	*	-	-	-	***

The relative extent of each wear mechanism: * slight, **moderate, ***heavy

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