Development of Magnesium Composite Material by the method of Stir Casting for applications in Automotive and Aerospace Industries

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Abstract

In Automotive and Aerospace industries, the demand for lighter materials is increasing exponentially. The main advantage of Magnesium Metal Matrix Composites (Mg-MMCs) over Aluminium Metal Matrix Composites (Al-MMCs) is that, there is an additional 15-20% weight saving without having to compromise on properties.Metal matrix composites reinforced with Boron carbide and Multi Walled Carbon Nano Tubes have significant advantage over conventional materials. Generally, these reinforcements are used to improve the hardness and tensile strength of metal matrix composites. In this project, we have performed three castings on Magnesium ZE-42 alloy with reinforcements of 2% Boron Carbide, 2% Boron carbide with 1% Multi Walled Carbon Nano Tubes and 2% Boron Carbide with 3% Multi Walled Carbon Nano Tubes using Stir Casting method. The samples were subjected to Mechanical tests like Micro Vickers Hardness test and Tensile test. The Microstructure was observed through an Optical Microscope and Scanning Electron Microscope. In addition to this, we obtained composition via Energy Dispersive Spectroscopy. The comparative study of these samples with and without reinforcement were carried out and analyzed. The study showed that Magnesium ZE-42 alloy reinforced with 2% Boron Carbide and 3% Multi walled Carbon Nano Tubes showed an increase of 200% in tensile strength and a 70% increase in hardness in comparison to the base metal.The novel composite obtained has a potential to replace the existing aluminium alloys used in the automobile and aerospace industry without compromising on its properties.

Keywords: Stir Casting, Magnesium alloy, Boron Carbide, Multi Walled Carbon Nano Tubes, Hardness, Tensile Strength, Scanning Electron Microscopy, Energy Dispersive Spectroscopy

1. INTRODUCTION

In the past few decades, the advances in the field of engineering materials has been rapid as scientists and researchers all across the globe are pushing the limits in optimizing the properties of materials according to the particular field of use or application. In addition, the materials for such applications needs to be light in order to facilitate flight in the case of aerial vehicles and mobility in the case of land vehicles. Some metals and alloys had high strength, but were heavier and more failure prone due to crack-propagation. As a result, by the mid-20th century, scientists began extensive research into metal matrix composites (MMCs) as some MMCs like Al-MMCs and Mg-MMCs were significantly lighter than metals and alloys[6]. This resulted in weight saving and a higher strength to weight ratio. Hence, these materials are now being increasingly used in Automotive and Space technologies and have become one of the important areas of research and development.[3] They are also capable of replacing traditionally used heavy metals. Further, using Mg-MMCs resulted in a 15-20% weight saving in comparison to Al-MMCs. They arebeing used in the Defense industry as the structural material in missile hulls, rudder bodies etc. Mg-MMCs are also starting to be used in the automobile industry as their thermal properties can be altered. Mg-MMCs are being used in alloy wheels, seat frames and steering wheels. Mg-MMCs reinforced with boron carbide and Multi-walled Carbon Nano Tubes could be a useful material in such applications. The idea of using Boron Carbide powder as reinforcement agent was because of its higher hardness similar to that of diamond than the conventionally used reinforcement such as Silicon carbide and aluminium tri oxide.It was also chosen to utilize the beneficial effect of Mg so as to improve the property of wettability between boron carbide particles and the alloy melt [5].In addition to this magnesium is also a lighter metal.Multi-walled Carbon Nano Tubes have excellent elastic modulus, tensile strength and load-bearing capabilities[4].Further, multi-walled CNTs have excellent Electrical and thermal properties [7].An important factor which is to be considered in producing MMCs is cost of production. The costs involved should be as economical as possible. Also, casting technique is used for the manufacture of complex parts. Hence, stir casting a simple and cost effective technique is used in this study, followed by squeezing, under the pressure from a hydraulic ram in an enclosed die. This is done to minimise casting defects like blow holes and porosity. Though the costs involved in production of Magnesium metal matrix composites are relatively higher when compared to that of aluminium metal matrixcomposites, the benefits accrued more than compensates the costs involved.The main parameters involved in stir casting method are stirring speed, stirring time, holding time and size of reinforcement particles[2,3]. The particle size distribution hinges on stirring rate and cooling time. Defects like blow holes, porosity, inadvertent addition of impurities, improper interfacial bonding may arise during the process. In order to provide sufficient wetting and to ensure even distribution of reinforcement particles in the metal matrix,the reinforcement particles have to be first pre-heated and then to be added in steps of small quantities

2. EXPERIMENTAL SETUP & FABRICATION

The most cost-effective and simplest method of liquid state fabrication is stir casting. In this work stir casting technique is employed to fabricate the casted ingots. The reinforcement particles are in dispersed phase and is mixed with a molten metal by means of stirring for a particular period of time[2].The Magnesium alloy (ZE-42) is melted at 650^{0}C in an electric

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furnace. At this high temperature boron carbide and multi walled carbon Nano Tubes are subsequently added into the molten alloy to increase the wettability[2]. An appropriate amount 20 grams of Boron Carbide powder was preheated (250^{0}C) and then added slowly to the molten magnesium alloy. Simultaneously, the molten metal was stirred thoroughly at a constant speed of 500 rpm with a stirrer for a period of 15 min. For an even dispersion of B_4C particles in the molten magnesium alloy, the high temperature Magnesium Metal Matrix Composite was poured into cast iron mould and subsequently pressed by a ram.

3. MICROSTRUCTURE IDENTIFICATION

Microscopic analyses of the Magnesium base metal and the Magnesium Metal matrix composites were performed using Optical Microscope and Scanning electron microscope(SEM).The mechanical properties of reinforced metal matrix composites basically dependsupon the size of particles, its flaws, distribution, surface irregularities and matrix bonding. The etchant used was a mixture of100ml ethanol, 2.5g of Picric acid, 25ml of Acetic Acid & 25ml of Water for the microscopic analysis and subsequently EDS test was carried out in order to obtain the confirmation of the composition.

4. RESULTS AND DISCUSSION

4.1 Hardness Test

The hardness tests revealed that there was an increase in the hardness value with increasing percentage of Multi Walled Carbon Nano Tubes being added to the ingot and at the same time keeping a constant composition of Boron Carbide powder being incorporated into the matrix.

The hardness values of Boron Carbide and MWCNT reinforced composites are higher than only Boron Carbide reinforced composites because of strong interfacial adhesion between the metallic matrix and the carbon nanotubes.

Hence from the below table we can conclude that the hardness property of Magnesium (ZE-42) alloy is increased by addition of

Boron Carbide & Multi Walled Carbon Nano Tubes. The hardness of the composite is augmented from 39.3 VHN to 65.61 VHN which can be seen in Table 1.

Table 1. Hardness Comparison

Base Material ZE-42 (VHN)	2% Boron Carbide(B4C) reinforced MMC (VHN)	2% B4C and 1 % MWCNT reinforced MMC (VHN)	2% B4C and 3% MWCNT reinforced MMC (VHN)
39.3	48.25	56.125	65.61

4.2 Microstructure& EDS Spectrum Analysis The properties of particulate composites are mainly dependent on its morphology, density, type of reinforcing particles and its distribution within the material casted [8].The specimens were observed under an optical microscope and Scanning Electron Microscope for studying the microstructure.

The microstructure of the base metal in Fig.1 viewed through an optical microscope showcased the presence of carbon through dark spots along with the presence of dominant magnesium throughout the material along with patches of oxygen and zinc. Microstructure of the composites presented in Fig.2 clearly reveals the homogeneous distribution of B_4C while Fig.3 and Fig.4 reveals homogenous distribution of both B_4C and Multi Walled Carbon Nano Tubes in the Magnesium alloy matrix and there is no evidence of porosity and cracks in the castings. This might be related to the various parameters which are used in the process of producing castings.The microstructure of cast Magnesium composites reinforced with Boron Carbide and Multi Walled Carbon Nano Tubes are entrapped at the edges of Carbon and Boron randomly as shown in Fig.2, Fig.3 and Fig.4.

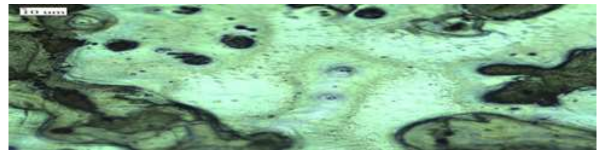

Fig.1 Mg (ZE-42) alloy

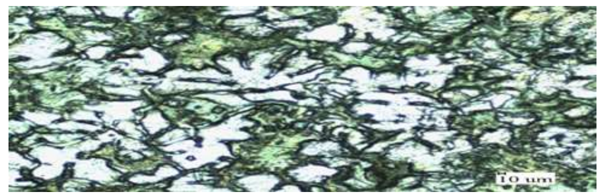

Fig.2Mg-MMC with 2% B_4C by wt.

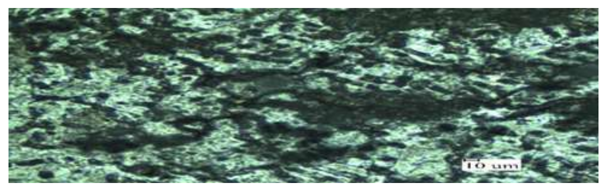

Fig. 3Mg-MMC with 2% B_4C & 1% MWCNT by wt

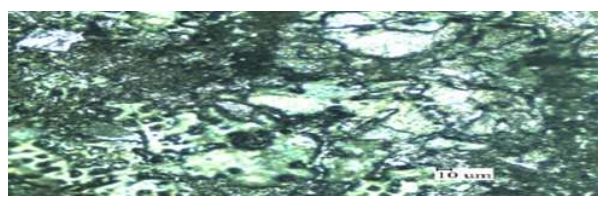

Fig.4 Mg-MMC with 2% B4C & 3% MWCNT by wt

The presence of reinforced particles in the composite redefined the primary boron crystals while its morphology is relatively unaffected and its clearly seen there is good interfacial bonding between the base metal and reinforcements. Fig.9, Fig.10, Fig.11 and Fig.12 below shows the SEM micrographs of base metal (ZE-42) and its reinforcements. From the Scanning Electron Microscope micrograph, the matrix element Magnesium and Reinforcement of Boron Carbide Multi Walled Carbon Nano Tubes can be easily viewed.The EDS test was carried out at various locations of Magnesium Metal Matrix composite which was produced by the method of stir casting.Fig.5, Fig.6, Fig.7, Fig.8 shows the composition of the base metal and the reinforced casted ingots.The various composition tables below confirms the reinforced particle infiltrating within the cracked structure of the base metal and thus showcasing the formation of elements such as Carbon, Boron and Magnesium as one of its major components.

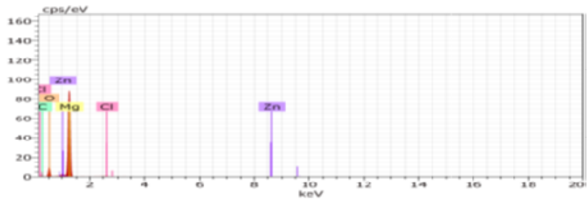

Fig. 5 EDS spectra and SEM Image Results at the particle matrix interface in Mg (ZE-42) alloy

Table 2: Composition – Base metal

Element	AN	Series	Norm. C [wt.%]	Atom. C [at.%]
C	6	K-series	13.36	21.73
O	8	K-series	24.36	29.74
Mg	12	K-series	59.00	47.41
Zn	30	K-series	2.75	0.82
Cl	17	K-series	0.53	0.30
		TOTAL	100	100

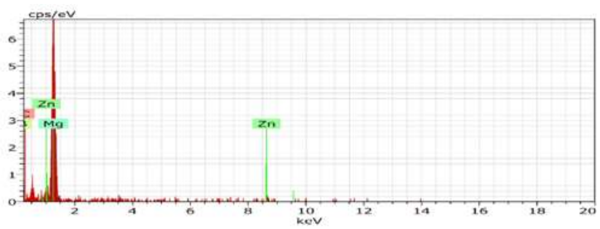

Fig. 6 EDS spectra of particle – matrix interface in Mg (ZE- 42) alloy Reinforced with 20g of B_4C

Table 3: Composition – Base metal reinforced with 20g B_4C

Element	AN	Series	Norm C [wt.%]	Atom C [At.%]
C	6	K-series	40.61	44.87
B	5	K-series	34.28	42.07
Mg	12	K-series	23.21	12.67
Zn	30	K-series	1.90	0.39
		TOTAL	100	100

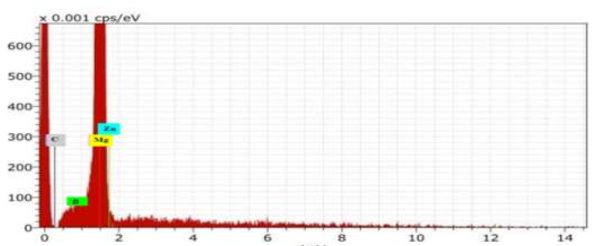

Fig. 7 EDS spectra of particle – matrix interface in Mg (ZE- 42) alloy Reinforced with 20g of B_4C & 10g of MWCNT

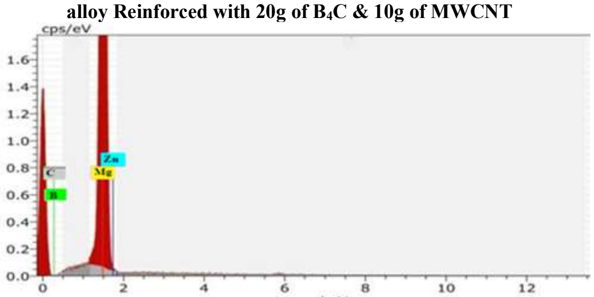

Fig. 8 EDS spectra of particle – matrix interface in Mg (ZE-42) alloy Reinforced with 20g of B_4C and 30g of MWCNT

Table 4: Composition of ZE-42 alloy reinforced with 20g $B_4C$and 10g MWCNT

Element	AN	Series	Norm. C [wt.%]	Atom. C [at.%]
C	6	K-series	45.31	46.82
Mg	12	K-series	32.22	43.91
B	5	K-series	21.52	8.81
Zn	30	K-series	0.95	0.46
		TOTAL	100	100

Table 5: Composition of ZE-42 alloy reinforced with 20g B_4C and 30g MWCNT

Element	AN	Series	Norm. C [wt.%]	Atom. C [At. %]
C	6	K-series	51.83	50.67
Mg	12	K-series	30.48	42.43
B	5	K-series	17.36	6.68
Zn	30	K-series	0.33	0.22
		TOTAL	100	100

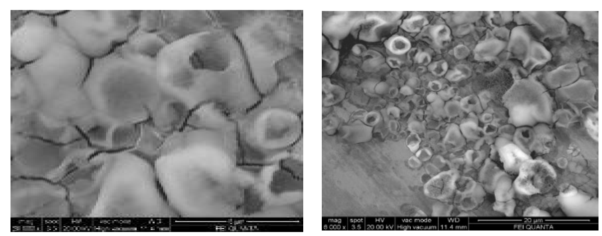

Fig. 9 SEM images of ZE-42 Base Metal alloy

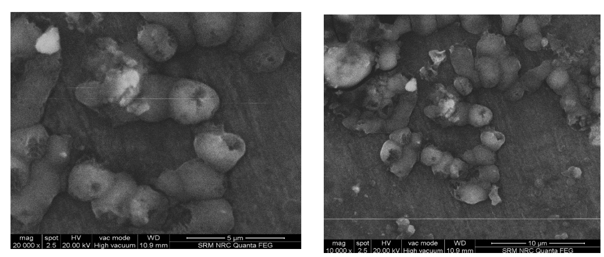

Fig. 10 SEM images of ZE-42 alloy reinforced with 20g B_4C

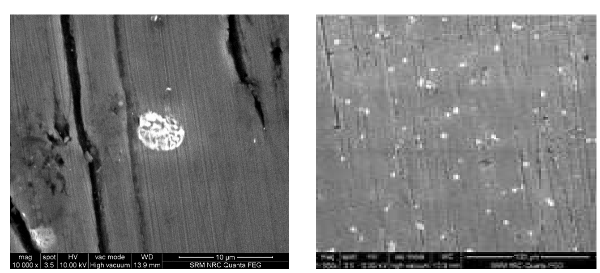

Fig. 11 SEM images of ZE 42 alloy reinforced with 20g B_4C and 10_g MWCNT

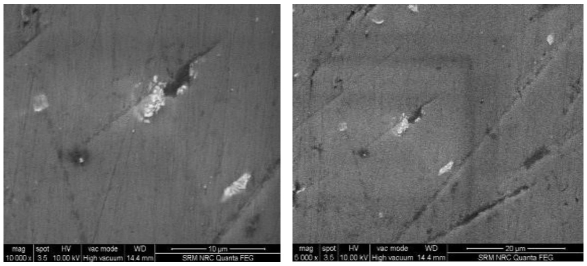

Fig. 12 SEM images of ZE 42 alloy reinforced with 20g B_4C and 30_g MWCNT

4.3 Tensile Test

The tensile strength of base metal reinforced with 30g of Multi Walled Carbon Nano tubes and 20g Boron Carbide is higher because of higher amount of Carbon content present in it when compared to other composites.

Table 6. Tensile Strength Comparison

Base Material ZE-42 (N/mm^2)	2% Boron Carbide(B_4C) reinforced MMC (N/mm^2)	2% B_4C and 1 % MWCNT reinforced MMC (N/mm^2)	2% B_4C and 3 % MWCNT reinforced MMC (N/mm^2)
67.8	115.4	145.55	192.5

5. CONCLUSIONS

Mg-MMCs composites were produced by the method of Stir casting with different weight percentage of reinforcement andthemechanical properties such as hardness and tensile strength were evaluated. Further, the microstructure was analyzed via Optical Microscope and SEM and composition was studied using EDS. The experimental investigation of reinforced magnesium composites using Boron Carbide and Multi Walled Carbon Nano Tubes produced by stir casting technique leads to the following conclusions.

The hardness of the base material is found out to be 39.3 VHN while the hardness value of The Mg-B_4C-MWCNT composites varied from 48.25 VHN to 65.61 VHN as the weight percentage of Multi Walled Carbon Nano Tubes varies from 0% to 3% keeping the weight percentage of 2% of B_4C powder constant in the matrix.Similarly, the Tensilestrength also varied from 67.8N/mm^2 to 192.5 N/mm^2 as the weight percentage of Multi Walled Carbon Nano tubes was increased from 0% to 3% and keeping the weight percentage of Boron Carbide as 2% in casted ingots.

Hence it can be concluded that the composite consisting of ZE-42 alloy reinforced with 2% of Boron Carbide and 3% of Multi Walled Carbon Nano Tubes was found out to be having the highest hardness and tensile strength value among all the samples.

Thus the addition of Boron Carbide and Multi Walled Carbon Nano Tubes to Magnesium (ZE-42) alloy had enhanced its mechanical properties.

Furthermore the novel composite material developed has a potential to replace the existing aluminium alloys used in automotive and aerospace industries with the only consideration being, the manufacturing of magnesium composite needs inert working conditions.

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