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Mechanical and Tribological Behavior of Mg-Matrix Composites Manufactured by Stir Casting

R. Praveenkumar[a, c], P. Periyasamy[a], V. Mohanavel[b] and M.M. Ravikumar[b]

[a]*Dept. of Mech. Engg., St. Peter's Institute of Higher Education and Research, Chennai, Tamil Nadu, India*
[b]*Dept. of Mech. Engg., Kingston Engineering College, Vellore, Tamil Nadu, India*
[c]*Corresponding Author, Email: pk29031991@gmail.com*

ABSTRACT:

In the recent decades, magnesium matrix composites present a plenty of applications to automotive, marine and aerospace industries. In this work, AZ31B is selected as Mg matrix material and hard Tungsten carbide (WC) particles as reinforcement material. Mg/WC composites reinforced with different weight proportions (0, 5, 10 and 15 wt.%) were made through stir casting method. The worn surface of manufactured Mg/WC composites and base Mg material were examined by scanning electron microscope (SEM). The wear test results denoted that the AZ31B/15 wt% WC composites have excellent tribological behaviour when compared to the base magnesium matrix AZ31B alloy. The yield strength, flexural strength, tensile strength and micro-hardness of the manufactured composites are improved by increasing the WC reinforcement content. SEM images reveal the homogeneous distribution of WC particles throughout the Mg matrix.

KEYWORDS:

Wear metal matrix composites; Tribological properties; Stir casting.

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1. Introduction

Titanium, copper, magnesium, aluminium alloy based hard ceramic particulates reinforced metallic matrix composites (MMC) are highly active area of research for last twenty years. The important reason behind widely acceptance of MMC as advanced engineering materials is the outstanding sequences of properties which are more complicated to attain by individual alloy phase or ceramic particulates. Most number of literatures [1-4] reveal that aluminium and magnesium alloy based metallic matrix composites have shown outstanding impact strength, yield strength, tensile strength, flexural strength, hardness and wear resistance when compared to other matrix alloy i.e. Titanium alloy, Copper alloy based metal matrix composites. The mechanical, corrosion, erosion, machining and tribological properties of the composites largely depends on manufacturing method, size, weight proportion of reinforcement and matrix alloy of the composites. The foremost goal involved in developing of metal matrix composite (MMC) materials is to merge the desirable ascribed of ductile matrix metals and hard ceramic particles. The incorporation of ductile and brittle matrix characteristics, MMCs have an enormous potential for being tailored for several applications and qualified for replacing the conventional materials [5, 6]. Mostly, metal matrix composites (MMCs) reinforced with particles like BN, ZrO_2, B_4C, SiC, Al_2O_3, TiC, ZrB_2 and graphite to get different preferred properties [7-9]. In the recent days, ceramic particles reinforced magnesium matrix composites have a huge number of applications in ship building, transportation, aerospace, structural and non-structural applications like shaft, connecting rod and piston [10].

For manufacturing of magnesium based metal matrix composites (Mg-MMCs), stir casting is more preferable process because of higher production rate. The application of Mg is inadequate because of its light strength, poor room temperature ductility and toughness. Magnesium has hexagonal closed-packed (HCP) structure which leads to low ductility and toughness. The density of magnesium (1.74 g/cm^3) is 35.6% lower when compared to aluminium which makes it ideal for light weight applications. But low ductility, toughness and stiffness are the foremost limitations of magnesium based materials when compared to aluminium based materials. It was stated that the work of fracture and ductility of Mg can be improved by employing filler materials [11-13]. Kumar et al [14] manufactured AZ91/ (0, 3, 6, 9, 12wt%) SiC particle composite via vaccum assisted stir method. It was discovered that the tensile strength of the composites enhanced with the increasing of 12wt% SiC particles (AZ91/12wt%SiC, 193.96 MPa).

Wang et al [15] prepared the composite through ultrasonic technique for adding SiC nanoparticles in mg matrix. An increase in the wt% of reinforcement particles embedded in the matrix reduced the grain size. They concluded that the grains of the prepared composites are refined and revealed improved mechanical properties. Kaviti et al [16] fabricated Mg/BN composites using powder metallurgy process and investigated the effect of BN particle on the tribological behavior of the composites. Aatthisugan et al [17] stated that the preparing of AZ91B/B_4C/Gr mg matrix composite via stir casting method and they revealed the mechanical and tribological properties of prepared composite are superior to the AZ91D base alloy. Prakash et al [18] stated in magnesium alloy/silicon carbide/graphite composite that matrix microstructure refinement was better in comparison with the base alloy made via stir casting method. In this work, the AZ31B magnesium alloy was reinforced with a various wt% of tungsten carbide (WC) to prepare the composite and compared the microstructure, mechanical and tribological properties with base alloy.

2. Experimental procedure

AZ31B magnesium alloy was chosen as a matrix material and the WC particles of size 40-60 microns are used as the reinforcement material. Mg alloy has been melted in a bottom pouring electrical resistance furnace. WC ceramic particulates were incorporated in various weight proportions like AZ31B+0% WC, AZ31B+5% WC, AZ31B+10% WC and AZ31B+15% WC. The measured weight proportions of WC particles were incorporated to the molten magnesium. The temperature of the melt was maintained at 65C. The melt was stirred constantly at 400 rpm and it was being continued for 4 min. Finally, the Mg-WC melt was poured into preheated mould. The manufactured composite and unreinforced Mg alloy was subjected to micro-hardness test, ultimate tensile test, flexural test and microstructure characterization. The micro-hardness was measured using Vicker's hardness tester at a load of 0.5kgf applied for duration of seconds at three different locations on all samples. The flexural test and tensile test was conducted on the base alloy and manufactured composite using the computerised universal tensile machine. The tensile test was conducted at a strain rate of 1 mm/min and 2.5 mm/min. The testing sample was machined as per the ASTM standard shown in Fig 1. Fig. 2 shows the pin on disc apparatus. Wear properties were examined using a pin-on-disc apparatus. The wear was measured by weight loss, as a difference of weights of the wear pins, before and after wear tests to an accuracy of 0.0001 g. The wear test was conducted at a sliding distance of 1500m, the normal force of 10N, 20N and 30N and sliding velocity of 1m/s. The counter disc was made of EN32 steel having a hardness of HRC 60.

Fig. 1. Dimensions (mm) of tensile test specimen

Fig. 2. Pin on disc apparatus

3. Results and discussions

3.1. SEM analysis of AZ31B/WC composites

Fig. 3 shows the SEM images of the Mg-MMCs. SEM micro structural analysis show the uniform distribution of tungsten carbide particles and also show the fine, clean and clear interface between the Mg matrix (AZ31B) and the reinforcement (WC). It should develop the load bearing capacity of the final Mg-MMCs. The addition of WC particle content in the Mg matrix alloy can quite notably rework the microstructure and the properties of the WC particulates reinforced Mg-MMCs [7, 13].

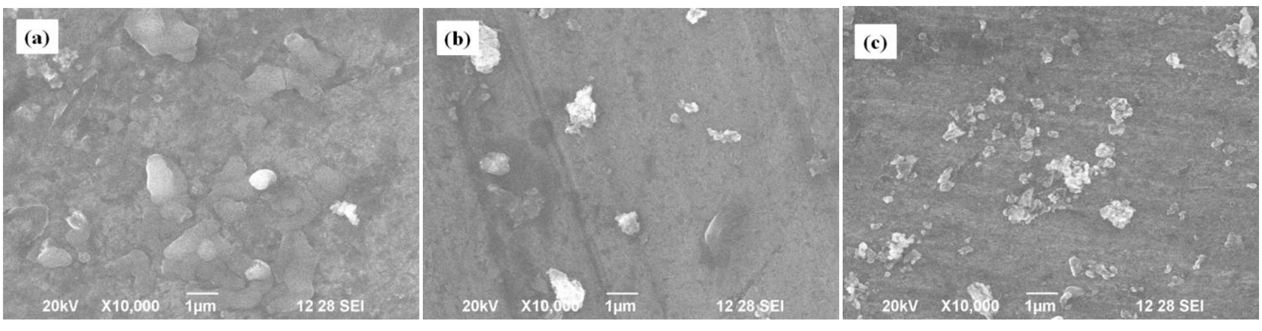

Fig. 3: SEM micrographs of (a) AZ31B+5wt% WC, (b) AZ31B+10wt% WC and (c) AZ31B+15wt% WC

3.2. Hardness of the AZ31B/WC composites

Fig. 4 shows the Vickers micro-hardness of AZ31B/WC Mg-MMCs. The hardness of AZ31B/15 wt% WC MMCs is 76 HV which is 31.95% higher than AZ31B matrix material. The development of hardness can be ascribed to the uniform distribution of WC particles in the Mg matrix. Furthermore, the important reason for the increase in micro-hardness of the MMCs containing WC particles is more enriched resistance against plastic deformation [2, 9 and 18]. AZ31B Mg alloy with 15 wt% of tungsten carbide MMCs revealed the higherd hardness.

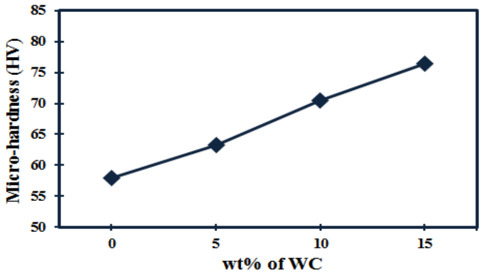

Fig.4. Influence of WC particle on Vickers hardness of MMCs

3.3. Tensile and yield strength of the AZ31B/WC composites

The tensile and yield strengths of the Mg-MMC are shown in Fig 5. The tensile and yield strength are noted to rise with the increase in WC particles. They are extensively higher than the strength of the unreinforced Mg matrix alloy. The strength of the composites is on the strain rate of 1 mm/min when compared to the strain rate of 2.5 mm/min. The AZ31B/15 wt.% WC composites exhibit the maximum tensile strength at a strain rate of 1 mm/min. The presence of WC particles in the Mg-MMCs acts as barrier to the movement of dislocation which leads to further increase in tensile strength and yield strength. The increased dislocation caused by thermal coefficient mis-match also increases the yield and tensile strength of the MMCs. Moreover, the fine interface between the magnesium AZ31B and the WC reinforcement remarkably transfers the load from the Mg alloy to the WC content. Therefore the tensile strength and yield strength of the composite are improved at the 15% weight proportion of tungsten carbide content.

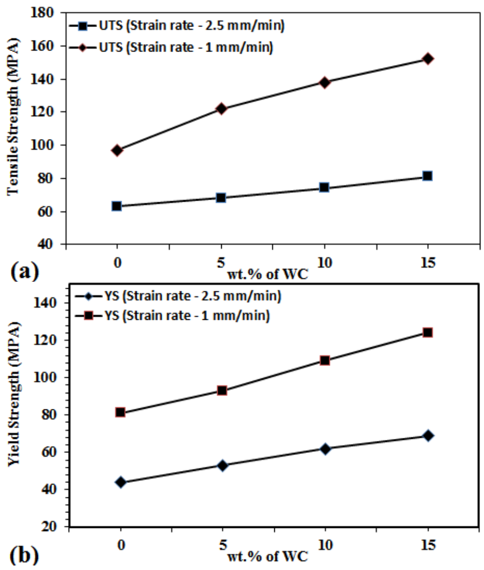

Fig.5. Influence of WC particle on strength of MMCs

3.4. Tribological behaviour of the AZ31B/WC composites

Dry sliding wear test was undertaken with applied load of 15 N under sliding velocity of 1.5 m/s for traverse distance of 1km over 10 minutes. Table 1 shows the results of dry sliding wear behaviour of composites with 0, 5, 10 and 15 wt% of WC reinforcement. It was observed that the wear loss falls with increasing tungsten carbide particle content. For a constant load, sliding velocity and sliding distance, the wear mass loss steadily decreases as a function of the amount of WC content. The wear loss decreases as the WC particulate increases. The minimum amount of wear loss in Mg-MMCs with a greater weight proportion of WC particles can be ascribed to the higher hardness and strong mechanical bonding of the Mg matrix with the WC reinforcement.

Table 1: Wear loss of the AZ31B/WC composites

Initial weight (g)	Final weight (g)	Wear loss
3.216	3.193	0.715174
3.086	3.065	0.680493
3.323	3.305	0.541679
3.02	3.009	0.364238

3.5. Worn surface morphology of the AZ31B/WC composites

The SEM images of the worn surface of AZ31B and AZ31B/WC composites are shown in Fig 6. Worn surface of AZ31B alloy shows the large amount of plastic flow of material. The worn surface of AZ31B/WC composites show parallel grooves like pattern without the presence of plastic. It is also observed that the wear debris is loose in nature and non-adherent with the matrix because of the improved hardness of the magnesium matrix due to the addition of hard WC particles in the Mg matrix.

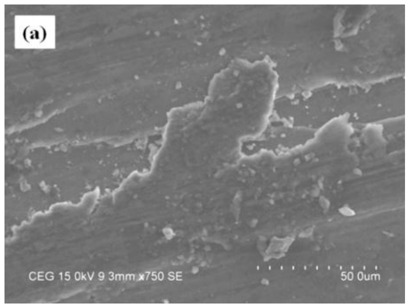

Fig. 6(a): SEM micrograph of AZ31B

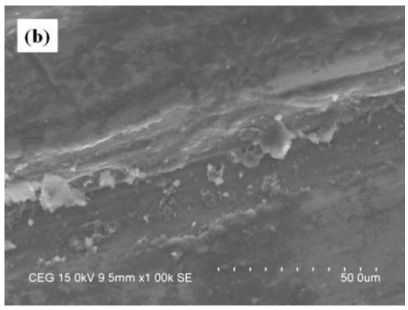

Fig. 6(b): SEM micrograph of AZ31B+5wt% WC

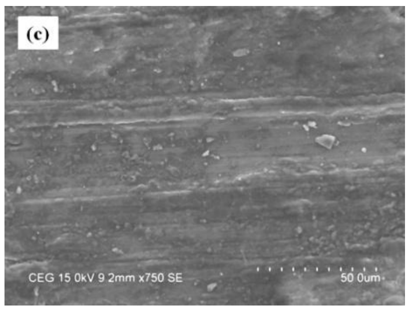

Fig. 6(c): SEM micrograph of AZ31B+10wt% WC

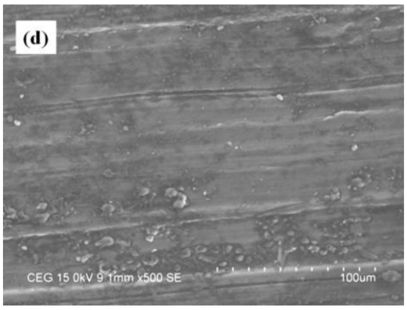

Fig. 6(d): SEM micrograph of AZ31B+15wt% WC

4. Conclusion

The main goal of this study is for estimating the mechanical and the tribological characteristics of ceramic particulate reinforced with AZ31B composites which were made via liquid state process. SEM analysis confirmed the uniform distribution of WC particles in Mg matrix. The yield strength, flexural strength, tensile strength and hardness of the composites have significantly improved by the presence of WC particle content. The wear results reveal that the wear loss decreases as the WC particulate increases. The tribological and mechanical properties of the composite are improved at the 15 wt% of tungsten carbide content.

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