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Influence of TiC on Microstructure, Mechanical and Wear Properties of Magnesium alloy (AZ91D) Matrix Composites

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This paper deals with the wear and mechanical (tensile, compressive, and microhardness) properties of Mg/TiC composites over magnesium alloy (AZ91D). Magnesium based metal matrix (AZ91D) composites were synthesized by using TiC particles varying wt % from 0% to 20% with a step of 5% by stir casting. The mechanical properties shows there is significant improvement of ultimate tensile strength (UTS) & % elongation, compressive strength, and microhardness with % increase of TiC content in Mg alloy. The fracture mechanism of the tensile and compressive specimen was investigated by Scanning Electron Microscope (SEM). A Pin-on-Disk (POD) tribotester was used to determine the wear rate (WR) and specific wear rate (SWR) of the composites. The test was carried out in a dry sliding condition of varying load of 10N, 30N and 50 N corresponding to a constant sliding distance & sliding speed of 1000 m and 1 m/s respectively and the worn surface of the pin is examined by SEM after the test.

Keywords: MMC, Mg alloy, TiC, XRD, SEM, Wear

Introduction

The specific strength of the material, high corrosion resistance, easy to fabricate, good thermal and electrical conductivity, and low density are important criteria for any material for the ease of acceptance in industries. In this regard, various light weight materials and alloys have been explored by several researchers. Recently, investigation pertinent to Magnesium and its alloys have gained significant attention in an era where weight saving in engineering application or industries is of paramount importance. As the pure magnesium is not strong enough, various ceramic and/or metallic materials are reinforced in magnesium to obtain desired properties.

Materials

Titanium carbide is being used as reinforcing material in AZ91D due to its better intermolecular interaction, high-melting, heat-resistant material, and its corrosion resistance. The recent years saw the emergence of a new generation of such composites. Chelliah *et al.*[1] made (MMC) by reinforcing 12 wt% of TiC in AZX915 through the stir-casting then author was carried out in as-cast, as well as at treated composites. The wear rate of HTC has higher as compared to as-cast composite. Zhang *et al*.[2] fabricated MMC, both the theoretical and experimental results indicate the improvement in tensile strength compared to the AZ91 matrix. The reduction of particle size of reinforcement the mechanical properties such as elastic modulus, yield strength, Vickers hardness strength, and UCS are significantly enhanced[3]. The mechanical and tribological properties of hybrid composites containing B_4C and Gr as reinforcement in an AZ91D matrix were investigated. With the increase of load, the coefficient of friction (COF) increases in case of AZ91D and AZ91D–B4C composites. With increase of load increase the COF decreases because presence of graphite. The wear loss also increases with an increase in load for all the material[4]. The addition of TiC shows mixed mode (ductile-brittle) fracture [5]. Nguyen *et al*.[6] used DMD technique to synthesize the Mg-AZ31B alloy and AZ31B/nano- Al_2O_3 (0.66, 1.11 & 1.50 vol %) composites and wear characteristics were investigated.

Narayanasamy *et al*.[7] characterized the microstructure, physical, mechanical and wear properties of Mg based composite in which Gr (5% &

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10%) & MoS_2 (5% & 10%) are reinforced in base metal. Garcia-Rodriguez *et al*.[8] have investigated the wear behaviour of abrasion; oxidation delamination and melt wear are identified as wear mechanism that leads to material wear of worn surface. In general, various fabrication methods such as disintegrated melt deposition technique[9], powder metallurgy[10–12], in-situ technique[13], rheocasting technique[14]. An extensive literature review carried out on magnesium based MMCs. The study reveals that a lot of work has been reported to enhance the properties magnesium based MMCs by using various reinforcement materials. Little research work is available in view of TiC/AZ91D composites with miniature variation of TiC. Hence, TiC reinforced magnesium alloy (AZ91D) matrix composites with larger variation of TiC should be explored

Experimental Details

The stir casting process is used for this fabrication of composites. The matrix material i.e., magnesium alloy (AZ91D) and reinforcing material as TiC particles. The average size of the particles of the TiC is 22 µm. For cylindrical composites, mould is used as steel and for rectangular composites sand casting mould was used. After solidification the casted cylindrical bar of 250 mm length and 22 mm diameter and rectangular composites 150 × 150 × 10 mm^3 were removed from the moulds. The micro structural studies of composites were analyzed in a metallurgical optical microscope (De-wintor Inverted Trinocular Metallurgical Microscope). An X-ray diffractometer (RIGAKU ULTIMA IV) is being used for XRD analysis of the phases of composites. The scan speed of 03 deg/min. was taken during the test in a radiation source of Cu-Kα (λ=1.54059Å).The phase analysis is determined by using the Match-2. For the tensile test, the casted bars were machined in a lathe.to gauge diameter 6 mm as per ASTM B557M – 15 standards. A servo controlled UTM (Model-F 100) was used for tensile test at room temperature at a cross-head speed of 1mm/sec. SEM was used to analysis the fractography of the broken tensile specimen of TiC particles (0, 5, 10, 15, & 20 wt %) reinforced/AZ91D magnesium composites. The samples for uniaxial compression test were prepared according to ASTM E 9 – 89a standard. The compression test was carried out in a UTM (servo controlled machine) having a capacity of 600 kN. The fracture mechanism of compression specimen was examined by SEM. The micro Vickers hardness tester 401 MVD (Wilson Wolpert – Germany) was used for measurement of hardness at an indenting load of 0.5kgf for a dwell time of 10 seconds. As per ASTM G99 –05 standard test specimens were prepared for wear test. A POD Tribotester (TR-20LE) was used for wear test at room temperature condition with varying load of 10N, 30N and 50 N corresponding to a sliding speed & distance of 1 m/s and 1000 m respectively. The test pin (stationary) is then pressed against the rotating EN 31 steel disc having hardness 62 HRC in a fixed diameter of 120 mm. After each wear test, the volumetric wear loss was calculated and the pin surface was examined through SEM to determine the possible wear mechanism.

Results and Discussion

Micro structural Analysis

Figure 1(a-c) shows the 100X magnification of etched Mg-TiC (0, 15 and 20 wt %) of the composite metal matrix which shows the formation of dendritic net-work of grains. The bright regions are the primary alpha magnesium phase and the grain boundaries show the precipitation of eutectic alpha $Mg_{17}Al_{12}$. These precipitates have not dissolved as they are slowly cooled from the sand cast moulds. The distribution of the composite particle TiC at the grain boundary cavities is depicted in Figure 1(b)-(c). The

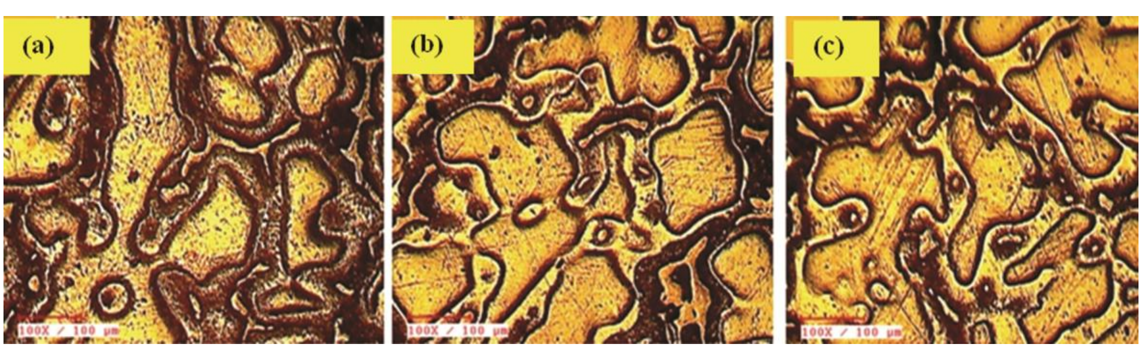

Fig. 1 — Optical Micrograph of 100X magnification of (a) Mg alloy (b) Mg-15% TiC(c) Mg-20% TiC composites

higher percentage addition of the TiC particles showed higher concentration in the metal matrix with fair distribution. The grain boundaries are better resolved and the precipitates of eutectic components are present at the grain boundaries. The composite particles also occupy the grain boundary cavities. The particles present and distributed at the grain boundaries are better resolved at 200X. The particles can be identified as globular. The investigation of optical microscopy showed that there is well bonded between TiC particles and magnesium metal matrix composites.

Figure.1 Optical Micrograph of 100X magnification of (a)Mg alloy (b)Mg-15% TiC(c)Mg-20% TiC composites

XRD Analysis

The XRD pattern of casted Mg alloy and the different wt % of TiC reinforced in Mg alloy are shown in Figure 2 (a-e). From the XRD pattern, it is revealed that Mg and TiC are present within the composites as the peak achieved. The larger peaks indicate the existence of Mg whereas the smaller peaks show the presence of TiC in XRD. XRD analysis also shows that casting is free from the presence of oxygen as it cast in an argon gas atmosphere. The intensity of TiC increases as the wt % of TiC increases from 5% to 20%. Figure 2 XRD and influence of TiC on hardness (a-e) XRD of various composite from 0-20 wt% TiC (f) and influence of TiC on hardness

Effect of TiC on Micro-hardness

The results obtained from Vickers micro-hardness test for magnesium alloy and magnesium with different wt% of reinforcement of TiC. From the result, it has been found that the micro-hardness value increases with the addition of TiC as the reinforcement as observed by previous researcher[10]. Figure 2(f) shows the influence of TiC on the Mg alloy it shows that increase in percentage of TiC particles into the Mg matrix increases the hardness of the Mg composite; this is mainly due to the resistance offered by the hard particle of TiC and also due to the evidence that TiC particle hold off major load conveyed by the Mg.

Effect of TiC on Tensile test and compressive test

The tensile test of the composites is carried out in a universal testing machine. For each composition, three numbers of samples were tested and the average value was taken. Figure 3(a) shows the effect of %

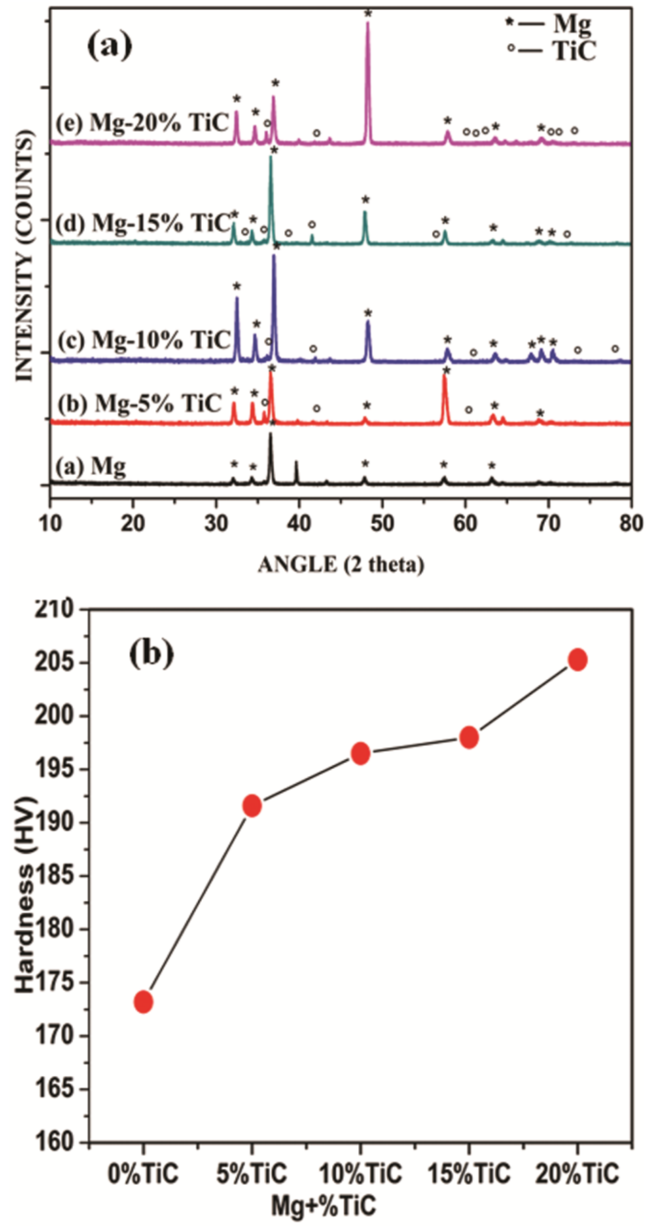

Fig. 2 — XRD of Mg /TiC and influence of TiC on hardness of Mg alloy (a) XRD of various composite from 0-20 wt% TiC (b) and influence of TiC on hardness

TiC particle on yield stress, ultimate tensile and compressive strength. The result shows that the UTS and % of elongation increase with an increase in wt% addition of reinforcement i.e., TiC. The similar observations have been reported in the works[11,16]. The stress-strain diagram reveals the ductile fracture of the composites without an apparent yield point. The tensile of the fracture surface of magnesium alloy and Mg/TiC composites is analyzed by Scanning Electron Microscope (SEM) is shown in Figure 3(b-c). The fractography of magnesium alloy and Mg/TiC

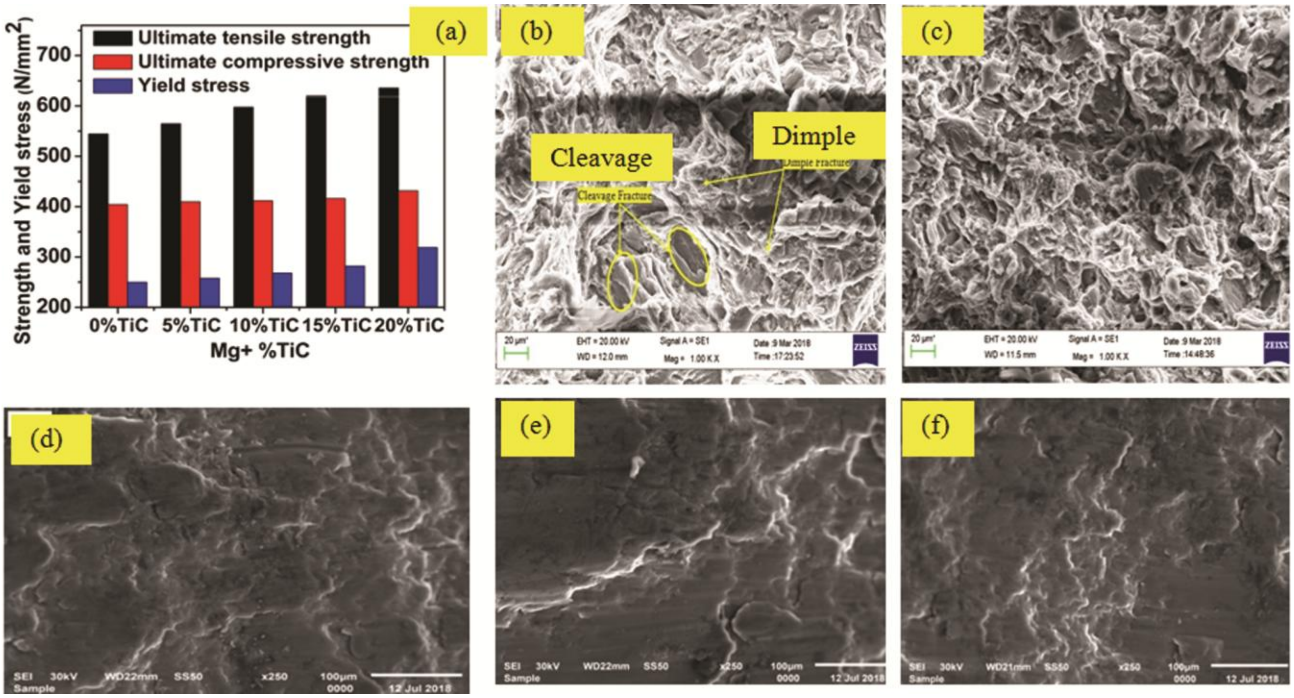

Fig. 3 — Influence of %TiC on strength and SEM images of tensile and compressive fracture surface (a) Influence of %TiC on strength (b)&(c) Tensile of 0%TiC, 20%TiC respectively (d),(e)&(f) compressive of 0%TiC, 15%TiC,20%TiC respectively

composites depicts the mixed mode of cleavage and dimple fracture. However, due to the addition of TiC the ductility increases due to which the fracture strain is also increased. Figure 3 Influence of %TiC on strength and SEM images of tensile and compressive fracture surface (a) Influence of %TiC on strength (b) & (c) Tensile of 0%TiC, 20%TiC respectively (d),(e) & (f) compressive of 0%TiC, 15%TiC,20%TiC respectively. The compressive test is carried out in a UTM (Model No.: HL 5902). From the fracture specimen it is observed that the diagonal shear failure of the specimen takes place i.e. fractured plane makes an angle nearly 45^0 to the compressive load axis. It is also found from fig 3(a) that the compressive strength increases as % TiC increase in Mg-TiC composites as compared to Magnesium alloy and similar results were obtained by[11,17]. Figure 3(d-f) shows the compressive fractograph of fracture surface Mg and Mg-TiC composites. The SEM fractograph of the compressive specimen shows the shear band is present in the image of fracture surface magnesium alloy and Mg-TiC composites. Besides the shear band some crack is also seen at the fracture surface which may lead to the failure of composites.

Effect of TiC on Wear test

The wear rate is shown in Figure 4(a). The result shows that the wear rate increases as applied load increases from 10N to 50N for each composition of composites. The comparative wear rate decreases from magnesium alloy to Mg-20% TiC as because of the reinforcement of TiC. It has also been observed that due the addition of reinforcement in magnesium alloy the specific wear rate decreases when the applied load increases from 10-50 N for all the composites from magnesium alloy to Mg-TiC composites. Figure 4 Influence of %TiC on wear and SEM images of worn surfaces during various load (a) Influence of %TiC on wear (b)&(c) worn surface 0%TiC at 10 & 50N respectively (d-1),(d-2) & (d-3) worn surface 20%TiC at 10, 30, 50N respectively. The SEM fractograph of wear surface with reinforced TiC composites at a load 10N, 30N and 50N is shown in Figure. 4(b to d-3). At a lower load of 10N and there is a relative motion (dry sliding) between the protuberances (asperities) of disc and pin- head. The asperities of disc surface result in the shallow grooves, micro-cutting, and scratches in the sliding direction of wear track indicating the abrasion wear pin. As the load increases from 10N to 30N, the asperities over the disc surface impact larger force onto the pin surface which results in deep grooves as ridges are clearly visible through SEM. At a high load of 50N, the delamination takes place at pin surface in the form of sheets. Before the delaminating, the crack is initiated and as the time increases, the crack growth

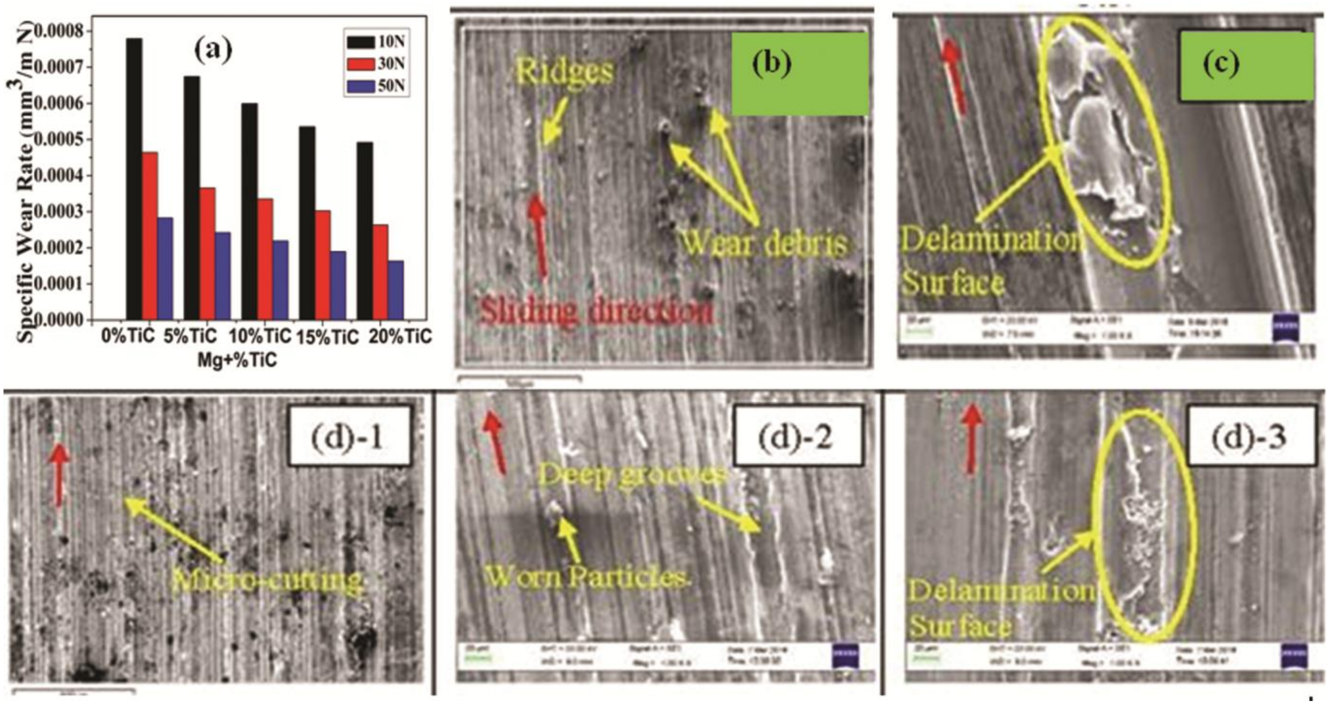

Fig. 4 — Influence of %TiC on wear and SEM images of worn surfaces during various load (a) Influence of %TiC on wear (b)&(c) worn surface 0%TiC at 10 & 50N respectively (d-1), (d-2)&(d-3) worn surface 20%TiC at 10, 30, 50N respectively

and finally detached from the worn surface. In some cases the void at pin surface has been observed as the asperities of disc surface penetrate into the pin surface and results ploughing of the pin surface. There is a dry sliding between the pin and disc surface resulting in temperature rise at the pin surface. The Energy dispersive X-ray spectroscopy (EDS) indicates the presence of oxides and magnesium pick-up on the worn surface as the test as carried out in dry sliding condition. The frictional heat between the disc and pin surfaces results in oxidation at the pin surface and repetitive relative motion between the disc and pin surfaces, the oxide layer was broken by the asperities of the disc and may fill on the wear surface of pin.

Conclusions

In the present study, Mg (AZ91D) alloy/TiC (0, 5, 10, 15, & 20 wt %) MMC is fabricated through stir casting method leads to the following conclusions:

- There is a significant improvement in UTS and compressive strength of Mg/TiC composites upon the addition of TiC. Mg /TiC (0, 5, 10, 15, & 20 wt %) are 544.518N/mm^2 and 404.2 N/mm^2, 564.738N/mm^2 and 409.86 N/mm^2, 597.498N/mm^2 and 411.86 N/mm^2, 620.24N/mm^2 and 416.1 N/mm^2, 635.8N/mm^2 and 431.66 N/mm^2 respectively.
- The micro hardness of Mg-TiC composites increases uniformly with an increase in % of TiC compared to Mg alloy matrix. Mg /TiC (0, 5, 10, 15, & 20 wt %) are 173.2HV, 191.6HV, 196.5HV, 198HV, 205.3HV respectively.
- The wear test reveals that the wear resistance increase with the applied load from 10N to 50N. However, due to the addition of TiC the wear rate decreases from Mg alloy to Mg/TiC composites. The SEM image of wear surface analysis shows the abrasion, oxidation and delamination wear are leading wear mechanism.

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