Wear Characteristics of Mg-MWCNT & AZ31-MWCNT Nanocomposites

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Abstract— The wear properties of pure Mg &Mg alloy AZ31 (Al 3%, Zn 1%, rest Mg) nano composites reinforced with multi-wall carbon nanotubes (MWCNTs) is studied by conducting experiments on pin-on-disc wear test apparatus. The composites are fabricated by stir casting technique by homogeneously reinforcing variable percentages of MWCNTs (0.33 wt%, 0.66 wt%, and 0.99 wt %) into Mg alloy AZ31 matrix. The effect of varying percentages of MWCNTs on the wear properties of Mg-MWCNT & AZ31-MWCNT composites and the mechanism behind that are investigated through Scanning Electron Microscopy (SEM) analysis. The characterization reveals that the wear rate & coefficient of friction of Mg-0.99 wt% MWCNT and AZ31-0.99 wt% MWCNT composites goes on increases as load applied increases. However by increasing the percentage of MWCNT the wear rate & coefficient of friction goes on decreases.SEM investigation confirms that for Mg-0.99 wt% MWCNT & AZ31-0.99 wt% MWCNT composites surfaces are having less cracks & defects.

Keywords— Mg-MWCNT Composites; AZ31-MWCNT Composites; Stir Casting Process; Multi-wall Carbon Nano Tubes; Friction & Wear Characterization.

I. INTRODUCTION

Magnesium alloys have been increasingly used in the automotive industry in recent years due to their lightweight [1]. The density of magnesium is approximately two thirds of that of aluminum, one quarter of zinc, and one fifth of steel. As a result, magnesium alloys offer a very high specific strength among conventional engineering alloys [2]. In addition, magnesium alloys possess good damping capacity, excellent castability, and superior machinability. Accordingly, magnesium casting production has experienced an annual growth of between 10 and 20% over the past decades and is expected to continue at this rate. Magnesium Matrix Composite are the class of Metal Matrix composites composed of magnesium as matrix material that is reinforced with intermetallic or ceramic fiber, whiskers or particulates like SiC, Al_2O_3, and CNTs etc.In the past decade, Al based MMCs have been the main research focus because of their excellent lightweight applications[3]. In more recent years, the superior stiffness-to-weight ratio of Mg based composites has made them attractive in weight saving applications for the aerospace, electronics, automobile and sports equipment industries [4]. The most commonly used particulate reinforcement in Mg is micron-size SiC, due to its low cost and easy availability. Addition of micron-size SiC particles to Mg will generally lead to enhanced yield strength, modulus, hardness, fatigue and wear resistance, better damping properties and thermal stability. Magnesium matrix [5] composites offer a variety of advantages over their monolithic counterpart due to improvements in stiffness, strength, thermal conductivity, and wear resistance. CNTs are having excellent mechanical properties. CNTs have been found as one of next generation materials since their discovery in 1991[6], because of its excellent mechanical properties. Several researches during last decade have shown that carbon nano tubes (CNTs) can considerably enhance the mechanical and conductive properties of polymer and ceramic matrix [7]. In polymer-CNT nanocomposites, the addition of CNT as reinforcement improves the strength of the polymer matrix by several times [8]. However, compared with polymer-CNT and ceramic-CNT nano composites, metal-CNT nano composites have attracted less attention due to their inferior mechanical properties than expected. Even though several researchers have fabricated metal-CNT nano composites by powder metallurgy process including mixing of CNTs with metal powders followed by hot pressing, metal-CNT nanocomposite have failed to show anticipated enhancement of mechanical properties. In previous researches on metal-CNT nanocomposites, inferior mechanical properties are caused mainly by agglomeration of CNTs and low relative density of the nano composites, which ranged between 85% and 95% [9]. In the present study, specimens of Mg and Mg, Mg-MWCNT, Mg alloy AZ31 and AZ31-MWCNT composites are fabricated by stir casting process, and the wear test is carried out using pin-on-disc equipment. The effect of MWCNTs on the wear properties of AZ31-MWCNT [10] & Mg-MWCNT composites and the mechanism behind that are investigated through scanning electron microscope (SEM) and are compared with the monolithic Mg & AZ31 alloy.

II. EXPERIMENTAL PROCEDURE OF WEAR TEST

Dry sliding wear tests on Mg, Mg-MWCNT, AZ31, AZ31-MWCNT specimens are conducted by using a pin-on-disc machine (Model: Wear & Friction Monitor TR-20) supplied by DUCOM, as shown in Fig 2.1.

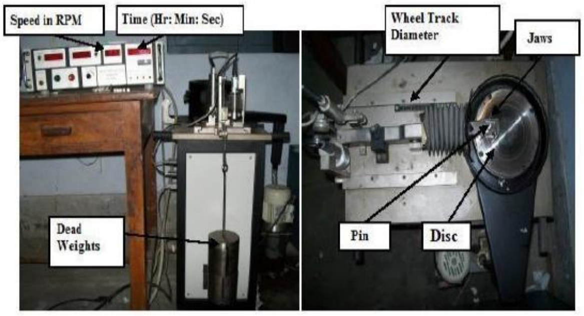
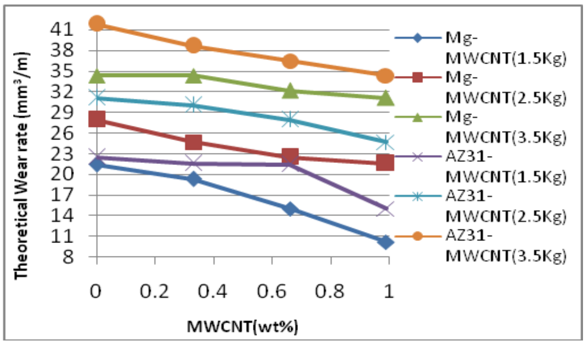


Fig 2.1.-Set up of wear testing machine

The pin is held against the counter face of a rotating disc (EN31 steel disc) with wear track diameter 120mm, 100mm, 80mm [11] and 60mm respectively. The pin is loaded against the disc through a dead weight loading system. The wear test for all specimens is conducted under the normal loads of 1.5kg, 2.5kg and 3.5kg and a fixed sliding velocity of 1.04 m/s. Wear tests are carried out for a total sliding distance of approximately 2900 m[11] under similar conditions as discussed above. The pin samples are 25 mm in length and 10 mm in diameter. The surfaces of the pin samples are cleaned using emery paper (80 grit size) prior to test in order to ensure effective contact of fresh and flat surface with the steel disc. The samples and wear track are cleaned with acetone and weighed (up to an accuracy of 0.0001 gm using microbalance) prior to and after each test. The wear rate is calculated from the height loss technique and expressed in terms of wear volume loss per unit sliding distance.

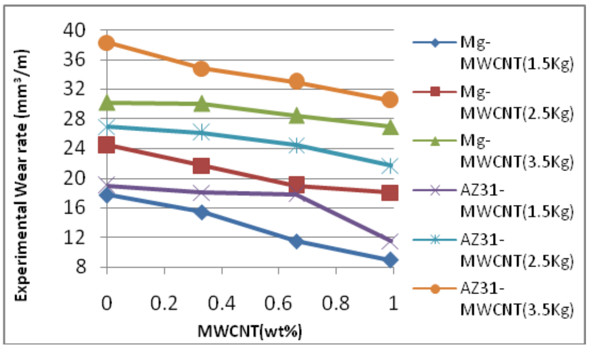
III. RESULTS AND DISCUSSION

3.1. Effect of MWCNT Content on Theoretical Wear Rate



It is found that theoretical wear rate of Mg-MWCNT composites at 1.5Kg load goes on decreases slowly as % of MWCNT increases. However at the same load for AZ31-MWCNT composites constant up to 0.66 wt% MWCNT, then decreases gradually as % of MWCNT increases. The result also shows that at 2.5Kg load for Mg-MWCNT composites goes on decreases continuously as % of MWCNT increases. However for AZ31-MWCNT composites decreases slowly up to 0.33 wt% MWCNT then decreases suddenly as % of MWCNT go on increases. It is observed that at 3.5Kg load for Mg-MWCNT composites constant up to 0.33 wt% MWCNT, then decreases suddenly as % of MWCNT increases. However for AZ31-MWCNT composites goes on decreases continuously as % of MWCNT increases. Under an applied load two different type of wear behavior can be predicted from the graph. Fluctuating, unstable and greater wear at the initial stage corresponds to the run-in wear which avoids initial turbulent period associated with friction. This may be due to adhesive nature of specimen to the sliding disc at the initial stage of wear.

3.2. . Effect of MWCNT Content on Experimental Wear Rate



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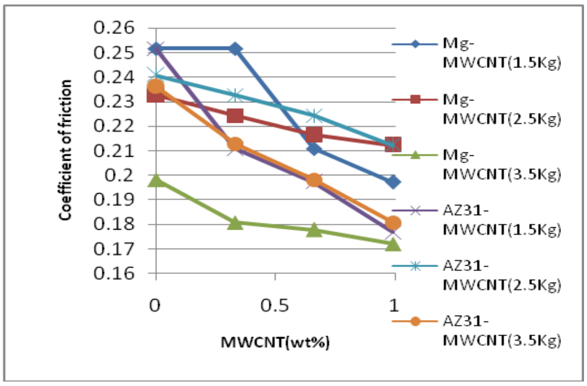
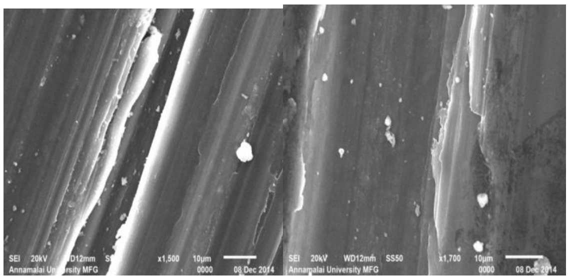
3.3. Effect of MWCNT Content on Coefficient of friction



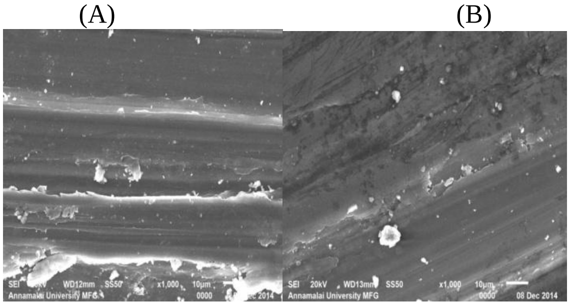
It is found that the coefficient of friction of Mg-MWCNT composites at 1.5kg load constant up to 0.33 wt% MWCNT then goes on decreases suddenly as % of MWCNT increases. However at 2.5 Kg load goes on decreases slowly as % of MWCNT increases. The result also shows that at 3.5 Kg load goes on decreases suddenly up to 0.33 wt% MWCNT, then decreases slowly as % of MWCNT increases. It is observed that the coefficient of friction of AZ31-MWCNT composite at 1.5kg load goes on decreases suddenly up to 0.33 wt% MWCNT, then decreases slowly as % of MWCNT increases. However at 2.5 Kg load goes on decreases continuously as % of MWCNT increases. At 3.5 Kg load goes on decreases suddenly as % of MWCNT increases. The coefficient of friction is higher for Pure AZ31 at 1.5 Kg load & lower for Mg-0.99 wt% MWCNT at 3.5kg load. By comparing the coefficient of friction for Mg-0.99 wt% MWCNT and AZ31-0.99 wt% MWCNT it is clear that by increasing the percentage of MWCNT coefficient of friction goes on decreases. This occurs due to the strong coherence between the carbide phase of Al4C3 developed through inter-metallic reaction during the casting processes and the conglomerated carbon. The composites revealed a low coefficient of friction. Due to the effects of the reinforcement and reduced friction, the wear rate of the composites decreased with increasing volume fraction of MWCNTs at low and intermediate loads. The composites with a high % of wt. fraction MWCNTs exhibited high porosity and their wear resistance decreased under high-load conditions. The experimental results indicated that the friction coefficient of the composite decreased with increasing the % wt fraction of MWCNTs due to the self-lubrication and unique topological structure of MWCNTs. The low coefficient of friction implies that the mechanism of wear is predominantly abrasive in nature due to the harder surface scratching over the softer surface.

3.4 Scanning Electron Microscopy (SEM) Analysis

SEM images are used to analyse the characteristics of wear. The specimens are analysed using Jeol, JSM 6510 LV scanning electron microscope at an accelerating voltage of 20 kV. Fig 3.1 & Fig 3.2 shows the SEM micrograph of the different Mg and AZ31 alloy matrix composites at different magnifications. The surface of the pure AZ31 composites without MWCNT is severely deformed and abrasion is caused by the agglomerated MWCNTs into micro debris and large debris due to fatigue. These cracks grow and separate from the surface and become wear debris. The scars of plastic deformation by ploughing are evident in the areas of abrasive wear at the centre area [12]. When the hard surface slides on the soft surface or abrasive grits mounted on the top surface slide on the soft surface, these hard asperities or rigidly held grits pass over the surface like a cutting tool; this phenomenon is called " two-body abrasion"[12][13]. In case the hard surface is a third body, generally, a small particle of abrasive is caught between the two other surfaces and is sufficiently harder, so that it is able to abrade either one or both of the mating surfaces; this is called "three-body abrasion."[12][13] From SEM images of AZ31 & AZ31-MWCNT composites it is clear that wearing of surfaces was higher for pure AZ31 and for AZ31 having 0.99 wt% MWCNT wear rate is minimum, however for AZ31-0.33 wt% MWCNT having more cracks due to higher wear rate.SEM images of Mg & Mg-MWCNT composites shows that more wearing of surfaces are takes place for pure Mg but for Mg-0.99 wt% MWCNT surfaces having less cracks and defects means surfaces are less wear. Homogeneous distribution of particles is desired for achieving better wear behaviour and mechanical properties. Homogeneous distribution of particles in a molten alloy is achieved due to the high shear rate caused by stirring which also minimize the particles settling. However, agglomeration of particles in some regions is clearly visible in all cases; this is due to the presence of porosity associated to it. Presence of entrapped air and moisture in the reinforcement particles results in the voids/ porosity after casting.

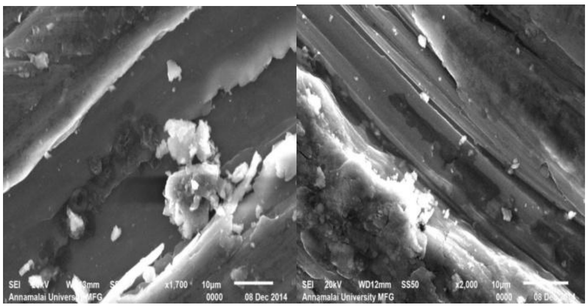


(A) (B)

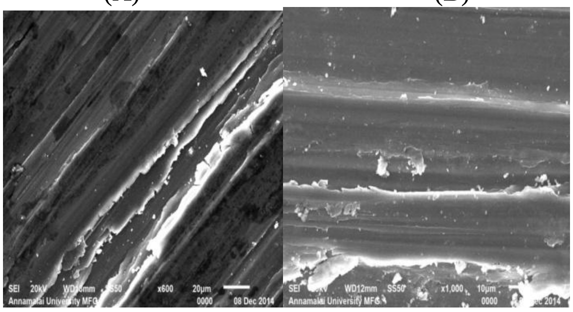


(C) (D)

Fig 3.1- SEM micrographs of the worn surfaces of Mg (A) 0 wt% MWCNT, (B) 0.33 wt% MWCNT, (C) 0.66 wt% MWCNT and (D) 0.99 wt% MWCNT composites.



(A) (B)



(C) (D)

Fig 3.2-SEM micrographs of the worn surfaces of AZ31 alloy (A) 0 wt% MWCNT, (B) 0.33 wt% MWCNT, (C) 0.66 wt% MWCNT, and (D) 0.99 wt% MWCNT composites.

IV. CONCLUSIONS

1. Stir casting technique found to be effective in homogeneous reinforcement of MWCNTs in AZ31 and Mg matrix and fabrication of Mg-MWCNT, AZ31-MWCNT nanocomposites.

2. The wear resistance of fabricated AZ31-MWCNT and Mg-MWCNT nanocomposites is found to be significantly decreases with an increase in the fraction of MWCNTs. The remarkable enhancement of hardness originated from the homogeneously distributed MWCNTs in the AZ31 matrix, and high interfacial strength at the interfaces enhances wear resistance by retarding the peeling of AZ31 grains during the sliding wear process.

3. Addition of 0.33 wt% MWCNTs to the Mg matrix results in high agglomeration of MWCNTs and increases the wear rate due to poor interfacial strength and weak bonding between the matrix and conglomerated MWCNTs.

4. It is concluded that the homogeneous distribution of MWCNTs with sound interface in the AZ31 and Mg matrix is an important technological issue to enhance the mechanical behaviour and wear resistance of AZ31-MWCNT and Mg-MWCNT nanocomposite.

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