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EFFECT OF Ti REINFORCEMENT ON THE WEAR BEHAVIOUR OF AZ91/Ti COMPOSITES FABRICATED BY POWDER METALLURGY

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Abstract. The low corrosion and wear resistance of magnesium limit its industrial applications despite its very high strength to weight ratio and environment-friendly nature. Researchers are working on the development of high wear-resistant magnesium matrix composites. Different types of reinforcements (i.e., B_4C, SiC, carbon nanotubes, graphite, Ti, etc.) are added to the magnesium matrix to enhance wear resistance. Still, metallic reinforcement titanium is most suitable because the addition of Ti increases wear resistance without compromising mechanical strength and ductility. The effect of volume fraction of Ti reinforcement on the wear resistance of AZ91/Ti composites fabricated by powder metallurgy is investigated in the present work. It was observed that the wear rate and coefficient of friction decreased with the addition of Ti in the Mg matrix, and the lowest value of the wear rate and coefficient of friction was observed for Mg/Ti composite reinforced with 6 vol.% Ti.

Keywords: AZ91 mg alloy, powder metallurgy, titanium, composites, wear rate

1. Introduction

Magnesium has attracted the attention of all industries because of its highest strength to weight ratio among the metallic structural materials (i.e., Al, Cu, Fe, etc.) and environment-friendly nature [1,2,3]. Despite its very low density and high biocompatibility, industrial applications of magnesium are still limited because of its low corrosion and wear resistance [4,5]. Hence, to overcome this problem, researchers worldwide are working on the development of high corrosion and wear resistance magnesium matrix composites [6,7]. Mainly, ceramic and carbonaceous reinforcements are added to the magnesium matrix to enhance the wear resistance [8,9]. The addition of ceramic reinforcements to the Mg matrix increases the wear resistance but decreases the toughness [10,11]. On the other hand, the addition of carbonaceous reinforcement to the Mg matrix increases wear resistance but decreases mechanical strength [12,13]. To overcome this problem, now metallic reinforcements such as Al and Ti are being added to the magnesium matrix [14]. These reinforcements increase strength, wear resistance, and ductility.

In the present work, the effect of Ti reinforcement on the wear behaviour of AZ91/Ti composites fabricated by powder metallurgy is investigated. Powder metallurgy over the other composite fabrication technique was selected to fabricate Mg/Ti composites in the present because of its high material utilization, less scrap, and less machining required.

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2. Experimentation

Material Used. Magnesium alloy AZ91 was used as a matrix material, while titanium was used as a reinforcement. Both materials in powder form were purchased from Parshwamani Metals, Mumbai, India. Both magnesium and titanium powders were irregular in shape, and the average particle size was 50µm and 30µm, respectively. Purity of both the powders was around 99% (as quoted by the supplier). Titanium was chosen as a reinforcement because it has very low solid solubility with magnesium and hence does not form tertiary hard phases. So, with the increase in strength, there is no loss of ductility.

Methodology. Mg/Ti composites were fabricated by powder metallurgy techniques, following the procedure shown in Fig. 1 [15,16]. Five types of samples with different volume fractions of matrix and reinforcement materials were prepared, as shown in Table 1. The volume percentage of titanium was selected based on available literature. Calculated amount (based on volume fraction) of the purchased matrix (Mg) and reinforcement (Ti) powders were weighed using electronic weighing balance and mixed. Mixed powders were then mechanically blended in a planetary ball milling machine at 200rpm for 2 hours (ball to powder weight ratio was taken as 10:1). After ball milling, blended powders were compacted to 450MPa in a uniaxial split-die using a universal testing machine to produce green compacts. Green compacts were then sintered in a muffle furnace in a nitrogen environment at 450°C for 90 minutes. After sintering, samples were furnace cooled to room temperature. Then, pin-on-disc wear samples were cut using wire-cut EDM from sintered compacts.

Testing. Wear tests were performed on a pin-on-disc wear tester (DUCOM TR-20), available in the Mechanical Engineering Department, Motilal Nehru National Institute of Technology Allahabad. Wear testing machine is shown in Fig. 2. Wear tests were conducted according to ASTM G99. To perform the wear tests, a pin of 6mm diameter and 25mm were cut from the sintered samples. The surface on which wear tests were to be performed was well finished and polished for all the samples. Sample finishing was done by rubbing the surface of the samples on the emery papers in increasing order of grade (320 grade to 2000 grade). After finishing, cloth polishing with fine alumina powder was done. All the wear tests were performed in an open environment at room temperature. Pin (sample) was rubbed against the EN91 hardened steel disc to wear the surface. Load, rotational speed, and distance of pin wear surface from the disc centre were kept constant at 15N, 220rpm, and 55mm, respectively. All wear tests were conducted continuously for 10 minutes (or a sliding distance of 760m). Two tests were performed for each composite to authenticate the results. The macro image of the pins after the wear tests are given in Fig. 3.

Table 1. Sample specifications

Sample ID	Composition
Mg	100 vol.% Mg
Mg + 2% Ti	98 vol.% Mg + 2 vol.% Ti
Mg + 4% Ti	96 vol.% Mg + 4 vol.% Ti
Mg + 6% Ti	94 vol.% Mg + 6 vol.% Ti
Mg + 8% Ti	92 vol.% Mg + 8 vol.% Ti

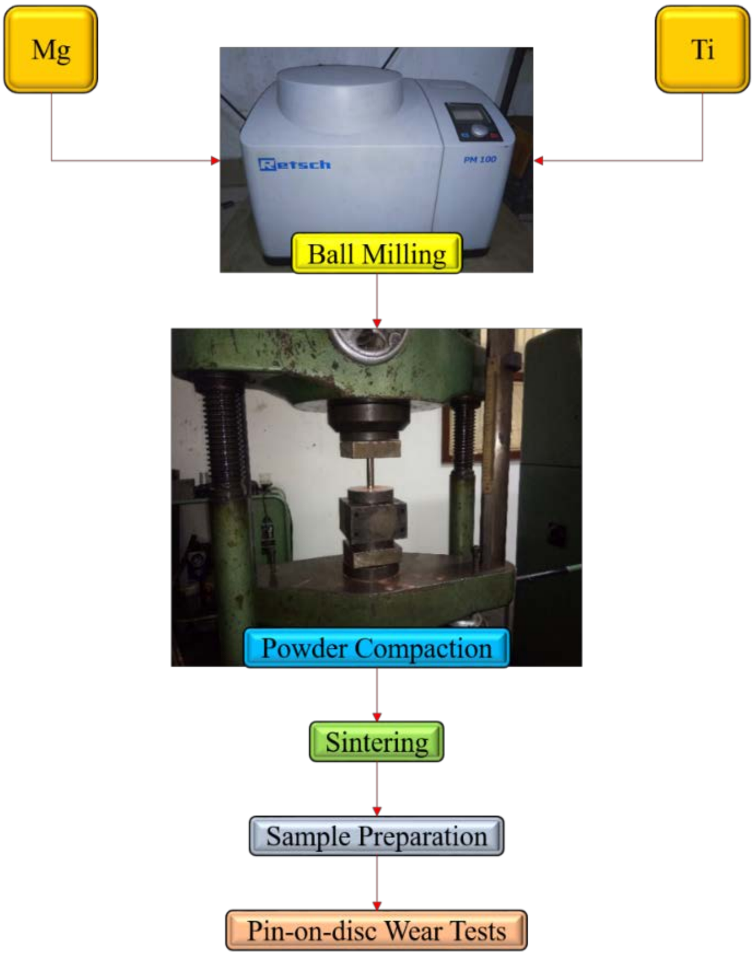

Fig. 1. Flow diagram of powder metallurgy process

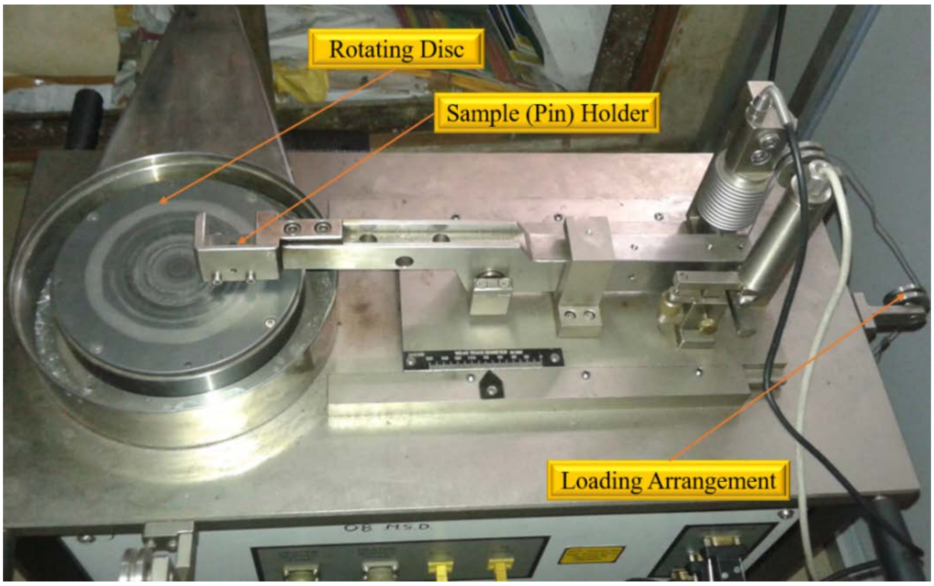

Fig. 2. Pin-on-disc wear testing machine

Fig. 3. The macro images of the pins (Mg, Mg+2%Ti, Mg+4%Ti, Mg+6%Ti, and Mg+8%Ti from left to right) after wear tests

3. Results and Discussion

Micrographs of the worn surface after pin-on-disc wear tests are shown in Fig. 4. It can be observed from Fig. 4(a) that the wear hatching lines of pure magnesium samples are continuous and have uniform spacing. On the other hand, Fig. 4(b-d) shows that the spacing in wear hatching lines of titanium-reinforced samples (2-6 vol.% Ti) are discontinuous and non-uniform. The discontinuous and non-uniform wear hatching lines in Mg/Ti composites are due to the presence of hard titanium particles that obstruct the scratching. At the same time, pores and cavities due to the removal of loosely bonded titanium particles in Mg/Ti composites reinforced with 8 vol.% of Ti are visible in Fig. 4(e).

Wear rate of samples was calculated on the basis of weight loss and the wear time (sliding distance). Variation in wear rate of Mg/Ti composites with the addition of Ti is shown in Fig. 5. The wear rate was highest in the pure magnesium alloy sample. The wear rate decreased almost linearly with the addition of Ti initially (up to 6% by volume) because of the hindrance to the scratching by the hard titanium particles, as discussed above. But, on further increasing the weight fraction of Ti, an increase in wear rate was observed. This happened due to the removal of loosely bonded agglomerated-Ti particles. Hence, the lowest wear rate of 0.0117mm^3/m was obtained for Mg/Ti composites reinforced with 6 vol.% Ti. Wear rate is inversely proportional to the hardness; the higher the hardness, the lower will be wear rate. So, the addition of hard particles (reinforcements) enhances the hardness and reduces the wear rate [17-19]. Kumar et al. investigated the effect of Ti volume fraction on the density and hardness of Mg/Ti composites. Density of the Mg/Ti composite reinforced with 6 vol.% Ti was around 1.717g/cc (higher than the density of the unreinforced sample). The hardness (91.6Hv) was highest for Mg/Ti composites reinforced with 6 vol.% Ti [20]. So, wear rate must be the least for Mg/Ti composites reinforced with 6 vol.% Ti as obtained experimentally. So the wear results obtained in the present work are in good agreement with the available literature on the sliding wear of metal matrix composites.

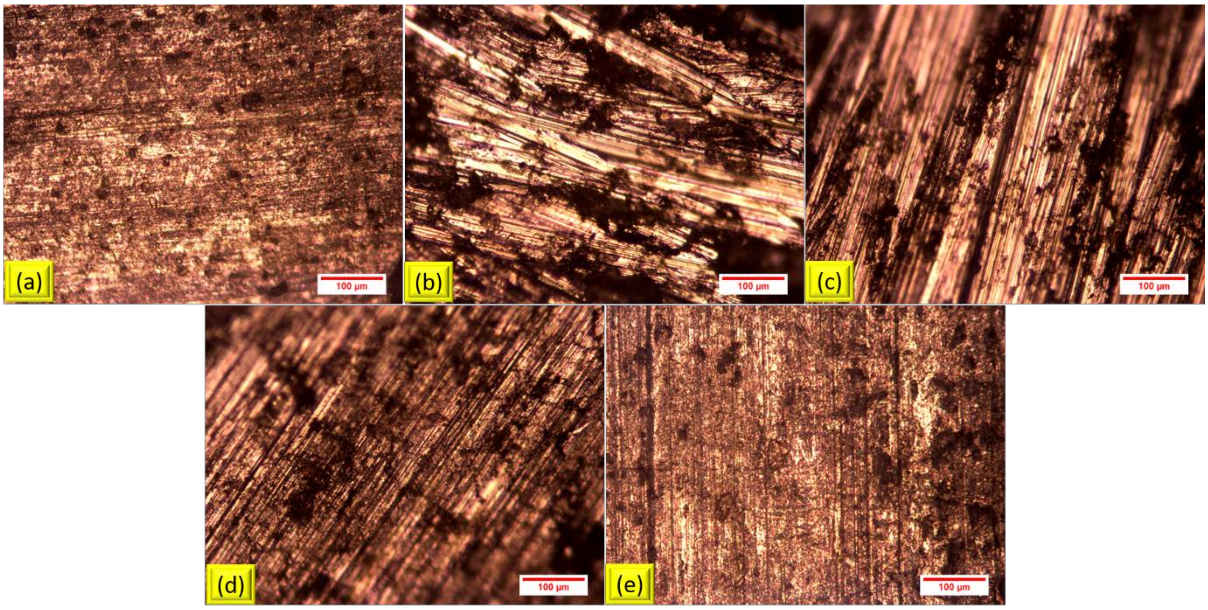

Fig. 4. Micrographs of the worn surface after pin-on-disc wear tests (a) Mg, (b) Mg+2%Ti, (c) Mg+4%Ti, (d) Mg+6%Ti, and (e) Mg+8%Ti

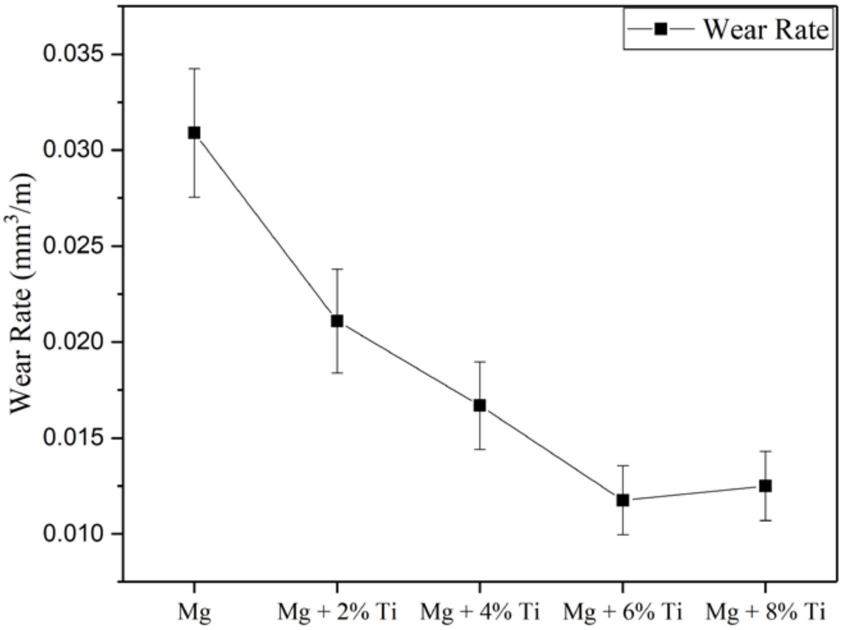

Fig. 5. The variation in wear rate of Mg/Ti composites with varying volume fractions of Ti

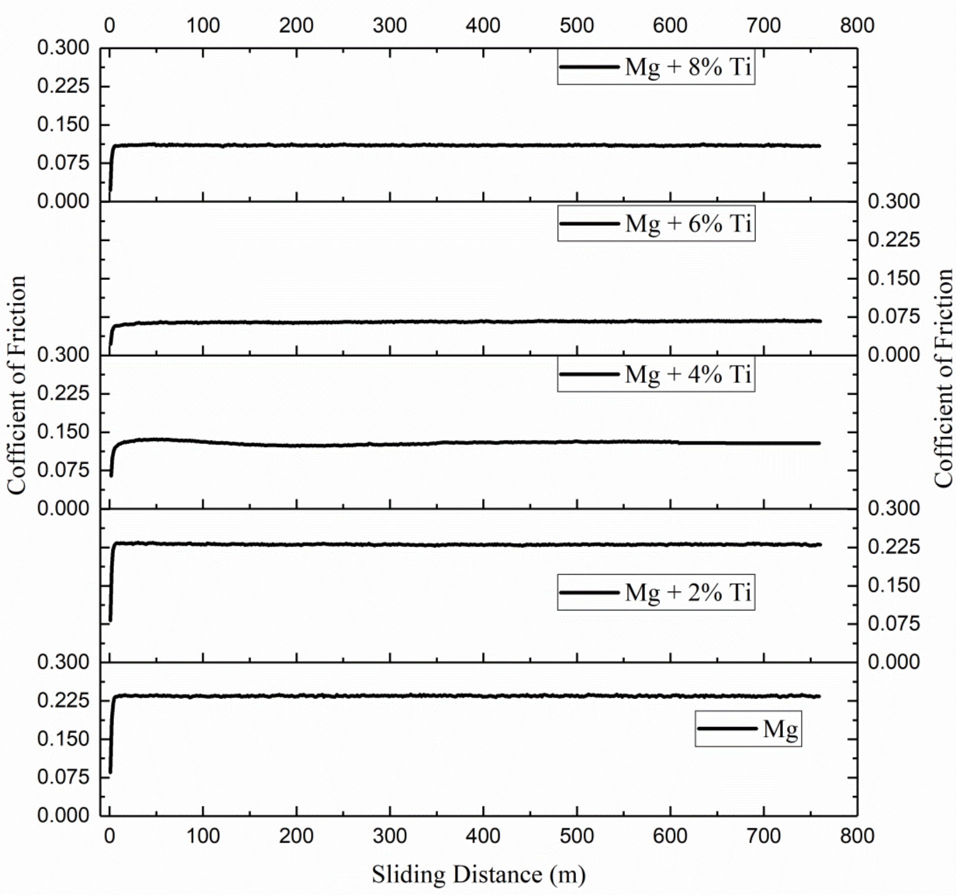

Fig. 6. The variation in the coefficient of friction of Mg/Ti composites with sliding distance

There were inbuilt sensors (load cell, electronic friction sensor, and LVDT sensor) in the testing apparatus that measure the load, displacement, and friction force continuously to calculate the coefficient of friction (COF). Variation in COF with sliding distance for Mg/Ti composites reinforced with different volume fractions of Ti is shown in Fig. 6. The variation in the average coefficient of friction of Mg/Ti composites with volume fraction of Ti is shown in Fig. 7. Like wear rate, coefficient of friction also decreased initially with the addition of Ti, and on further increasing volume fraction of Ti beyond 6% by volume, coefficient of friction increased slightly. Slightly high coefficient of friction of Mg/Ti composite reinforced with 8 vol.% of Ti compared to coefficient of friction of Mg/Ti composite reinforced with 6 vol.% of Ti cab due to interlocking of peaks of disc material in the increased cavities (as seen in the worn surface micrographs) of pin material. Hence the lowest coefficient of friction (0.065) was offered by Mg/Ti composites reinforced with 6 vol.% Ti. It can also be observed from Fig. 6 that the coefficient of friction remained almost constant with the variation in the sliding distance for all the samples. The constant value of the coefficient of friction indicates that the sample heating during pin-on-disc wear tests had no significant effect on the wear rate because the temperature rise was low (around 2-3 degrees).

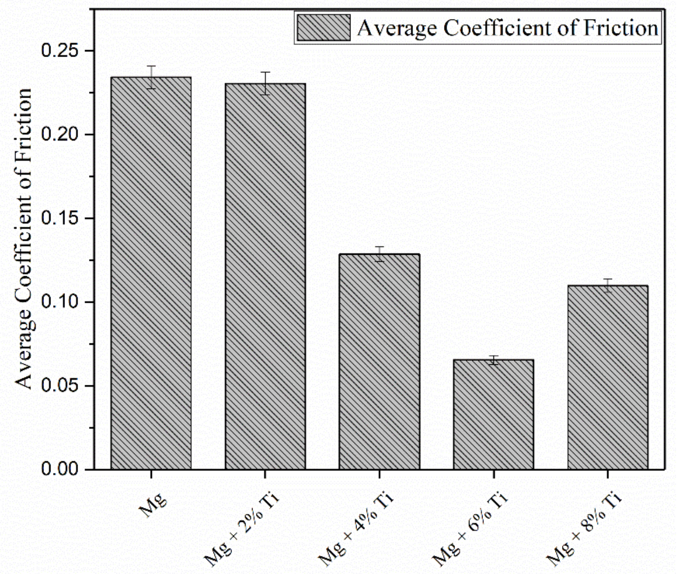

Fig. 7. The variation in the average coefficient of friction of Mg/Ti composites with volume fraction of Ti

4. Conclusions

Mg/Ti composites were fabricated, and the effect of Ti reinforcement on wear behaviour was investigated successfully. Wear resistance increased with the addition of Ti, and the highest wear resistance was offered by the Mg/Ti composite reinforced with 6 vol.% Ti. An increase in the wear resistance of Mg/Ti composites with the addition of Ti was due to the high resistance to scratch and wear of reinforcement Ti. For Mg/Ti composite reinforced with 8 vol.% Ti, wear resistance decreased slightly due to the easy removal of agglomerated Ti particles and the formation of cavities. Similarly, the coefficient of friction (0.065) was also minimum for Mg/Ti composite reinforced with 6 vol.% Ti.

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