



Effect of Ti reinforcement on the physical and mechanical properties of AZ91/Ti composites

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Magnesium-metal matrix composites reinforced with ceramic materials (TiO₂, SiC, B₄C, Al₂O₃) have better mechanical strength as compared to pure magnesium but their ductility is very low. On the other hand, the Mg-based composites reinforced with carbonaceous (carbon nanotubes, graphite, graphene, etc.) reinforcements have better wear resistance; however, there are chances of agglomeration of reinforcement. To overcome the limitations mentioned above; the Mg based composites reinforced with metallic reinforcements (Ti) have prepared in the present work. The physical and mechanical properties of prepared Mg/Ti composites have diagnosed experimentally. The density (green and sintered), hardness, compressive stress, and ductility have increased with the addition of Ti to the Mg matrix. Reason for increase in the density and other mechanical properties after the addition of Ti to the Mg matrix is the increased compressibility, reduced porosity and proper mechanical bonding of Mg-Ti. The maximum hardness (47.5 BHN) and ultimate compressive strength (187 MPa) has obtained for Mg + 6% Ti composite.

Keywords: AZ91 magnesium alloy, Compressive stress, Hardness, Powder metallurgy, Titanium reinforcement.

1 Introduction

The magnesium (94 kN.m/kg) has the highest specific strength among all the metallic structural materials such as aluminium (88 kN.m/kg), cast iron (55 kN.m/kg), copper (24.7 kN.m/kg), etc.^[1-3]. Despite of high strength-weight ratio, applications of magnesium and its alloys are limited because of its high corrosion tendency, low creep strength, low thermal stability, and autoignition at high temperatures (400-450 °C)^[4-5]. To enhance mechanical strength, wear and corrosion resistance of magnesium-based materials; various reinforcements such as ceramic reinforcements (TiO₂, SiC, B₄C, Al₂O₃, etc.) and carbonaceous reinforcements (graphite, carbon nanotubes, graphene, etc.) are added to the magnesium matrix to prepare the magnesium-metal matrix composites (MMMCs)^[6-11]. The MMCs reinforced with ceramic materials have high strength, but their ductility is very low^[12, 13]. The MMCs reinforced with carbonaceous reinforcements exhibit very high agglomeration^[8, 14, 15]. In order to overcome the limitations mentioned above; the MMCs

reinforced with metallic reinforcements can be prepared. The researchers have found that the MMCs reinforced with metallic materials have high strength as well as high ductility^[16, 17].

In the present work, the MMCs reinforced with titanium particles have produced using powder metallurgy technique. There are different MMCs fabrication techniques available in the literature such as stir-casting, powder metallurgy, friction-stir-processing, etc. Among these techniques, the powder metallurgy was selected to produce MMCs because of its scrap material utilization, low energy consumption and nearly net-shape (required shape) production^[18]. The physical and mechanical properties of prepared MMCs have inspected to study the influence of titanium particles reinforcement.

2 Materials and Methods

2.1 Materials Required

The magnesium alloy (graded as AZ91) powder as a matrix material and titanium particle as a reinforcement were used to prepare MMCs in the present work. The metallic powders of magnesium alloy and titanium were purchased from M/s

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Parshwamani Metals, Mumbai, India. Both the magnesium alloy AZ91 and titanium powders were irregular in shape. The average particle size of magnesium powder was 150 μm while the particle size of titanium powders was 20–40 μm .

2.2 Methodology

As already stated, the MMCs were produced by powder metallurgy method. The schematic diagram for the preparation of MMCs is shown in Fig. 1. First of all, both the powders (matrix and reinforcement) were ball milled at 200 RPM for 2 hours to mix the powders properly. After mixing, powders were consolidated as a compact having 20 mm diameter in cylindrical shape (green compacts) using split uni-axial powder compaction dies^[19, 20]. The heat treatment also called sintering process of produced compacts was done in a muffle furnace at a temperature 450 °C for 1.5 hours. Before start of the sintering process, the air present in the muffle furnace was removed and nitrogen gas was purged to prevent magnesium's auto-ignition. After holding samples at 450 °C for 1.5 hours, all the samples were brought to room temperature cooling in the furnace.

2.3 Sample Preparation

As per the experimental plan, for the reference purpose, a category of samples without reinforcement of Ti (containing pure AZ91 powder) were compacted and sintered. To see the effect of reinforcement of Ti particle to AZ91 powder matrix, four other different types of samples of MMCs having reinforcement of Ti particles as 2%, 4%, 6%, and 8% by volume were prepared. For each category, five samples were compacted and sintered. In order to identify, the sample IDs and other specifications are given in Table 1.

2.4 Testing

As per the objectives of the present research work, the samples were divided in to two groups to observe the impact of the effect of reinforcement of titanium particles to the matrix of magnesium alloy AZ91 on the physical and mechanical properties. The samples were prepared as per the standard procedure given in the literature and subjected to physical characterization and mechanical characterization. The detail of each characterization individually is given as follows.

2.4.1 Physical Properties

The physical properties such as green density, green porosity, sintered density, and sintered porosity were calculated by measuring the weight and volume

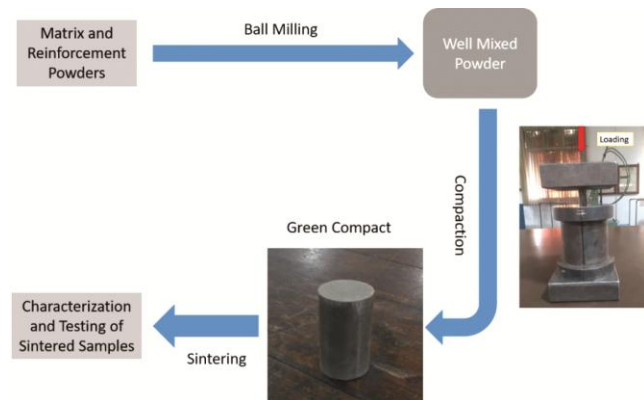


Fig. 1 — The schematic diagram for the preparation of MMCs.

Table 1 — Sample Specifications

Sample ID	The volume fraction of AZ91 Mg alloy (%)	The volume fraction of Ti (%)
Mg	100	0
Mg + 2% Ti	98	2
Mg + 4% Ti	96	4
Mg + 6% Ti	94	6
Mg + 8% Ti	92	8

of prepared cylindrical samples. The porosity was calculated with respect to the as-cast density of respective powders. The green density of all the samples at different compaction pressures was also calculated to investigate the effect of Ti's reinforcement on the densification of ball-milled powders. Optical microscopy of the prepared samples was also done to see the distribution of matrix and reinforcement particles and voids.

2.4.2 Mechanical Properties

As mostly required for the powder metallurgy product, the mechanical properties such as hardness and compressive strength of all the samples were determined. The hardness and compression tests were conducted as per the ASTM E10 and ASTM E9, respectively. The length-diameter ratio of 0.8 for compression test samples was taken as per ASTM standard. The samples before the compression test and fractured samples are shown in Fig. 2.

3 Results and Discussion

3.1 Optical Microscopy

Optical micrographs of all the samples are shown in the Fig. 3. It can be observed from that there is high porosity in pure Mg sample. Sample reinforced with Ti have relatively less porosity. It can also be observed that the Mg/Ti composite reinforced with 8% Ti have high agglomeration and burn phases.

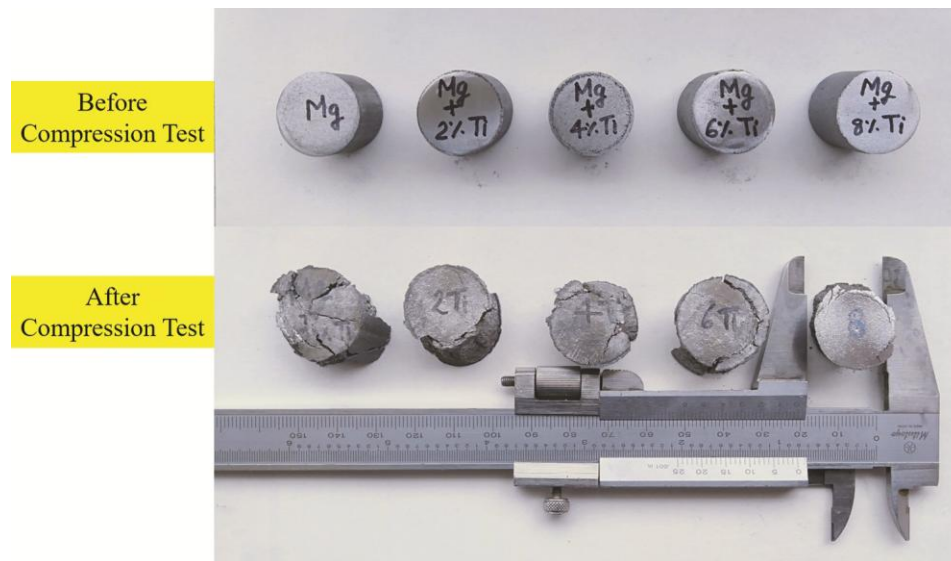


Fig. 2 — A photograph of real samples before and after compression test.

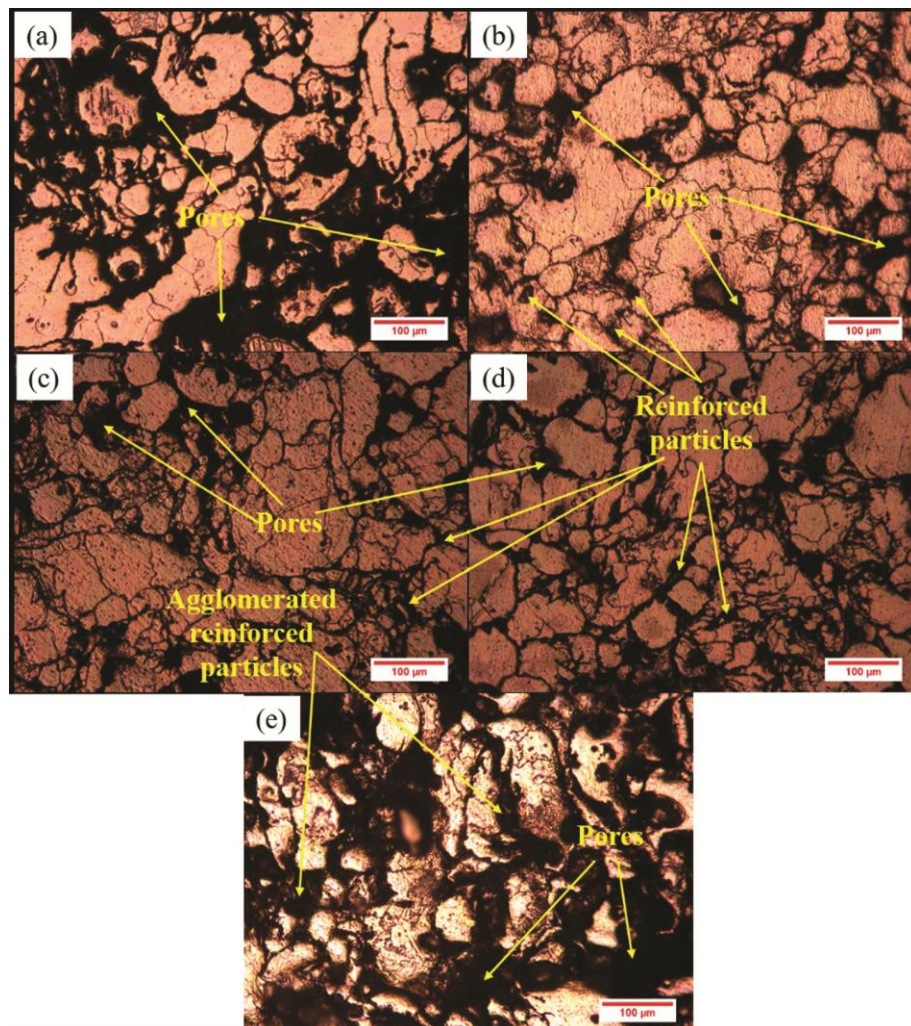


Fig. 3 — Optical micrograph of (a) Mg, (b) Mg+2%Ti, (c) Mg+4%Ti, (d) Mg+6%Ti, and (e) Mg+8%Ti.

3.2 Physical Properties

The variation in the green density after compaction but before sintering for all samples is shown in Fig. 4. The green density increased continuously with increasing compaction pressure for all the samples and became almost constant at a compaction pressure of 450 MPa. Initially, material flow at a faster rate due to the presence of a large number of voids, and green density increased rapidly. At pressure around 450 MPa number of voids of large size (around the size of powder particles) reduced significantly; as a result the flow of material goes very slow and consequently, green density nearly exhibited constant.

Similarly, the relative green density and porosity (green compact) of all the samples are shown in Fig. 5. The relative green density (around 88%) of the unreinforced Mg alloy AZ91 sample was the lowest,

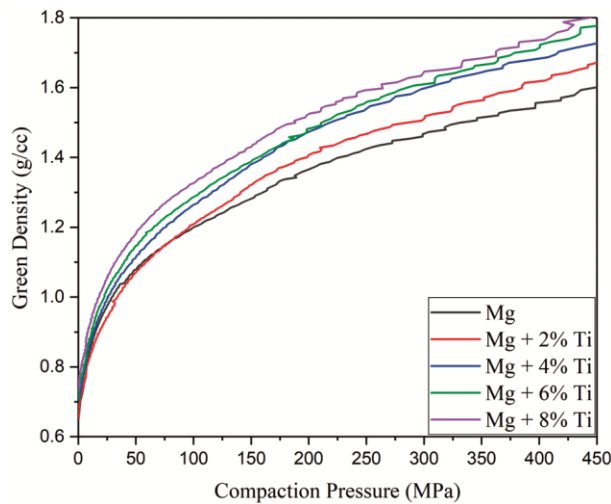


Fig. 4 — The variation of green density with compaction pressure.

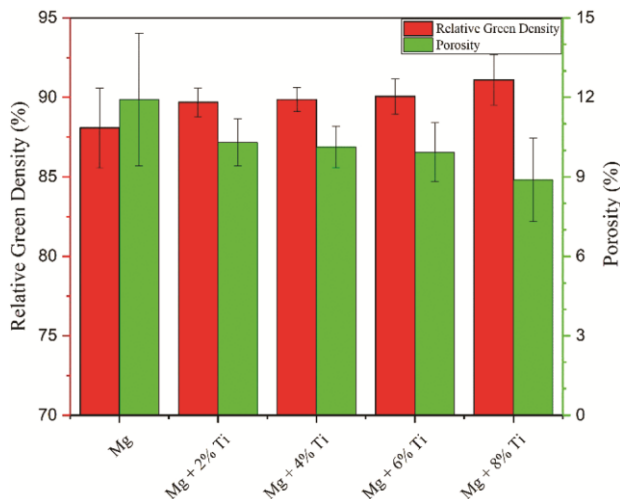


Fig. 5 — The relative green density and porosity with the variation of reinforcement of Ti.

and porosity (approximately 12%) was highest. Relative green density increased, and porosity decreased continuously with the addition of Ti because the metallic reinforcement (Ti) enhanced the compressibility of powder. Also, the average particle size of Ti (20-40 μm) was less compared to the average particle size of matrix material AZ91 Mg alloy (around 150 μm). On account of that the flow of material increased and as a result, high densification in the material was achieved. The highest relative green density (around 91%) and lowest porosity (about 9%) were obtained for sample 5 (Mg + 8% Ti).

The green density and sintered density of prepared samples are shown in Fig. 6. The sintered density of all the samples was less than the green density of the respective samples. A decrease in the density of samples after sintering was evident from the observed expansion in sintered samples. All the sintered samples' length and diameter were slightly larger than the respective green sample's length and diameter. The highest green and sintered density were obtained for sample Mg + 8% Ti because of the relatively high volume fraction of high-density Ti (4.54 g/cc). The relatively high relative green density of the Mg + 8% Ti sample due to improved compressibility was also responsible for high green and sintered density.

3.3 Mechanical Properties

3.3.1 Hardness

The Brinell hardness tests of all the samples were done at a load of 31.25 Kg. The load was put on for 30 seconds so that the plastic deformation could take place. The diameter of the spherical indenter was 2.5 mm. Fig. 7 shows hardness of different prepared

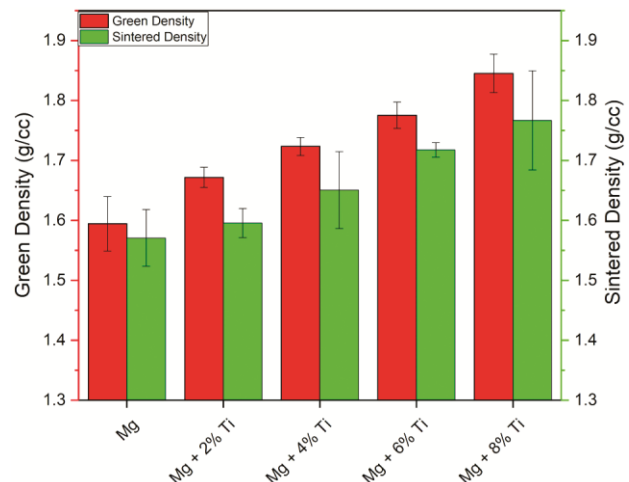


Fig. 6 — The green density and sintered density with the variation of reinforcement of Ti.

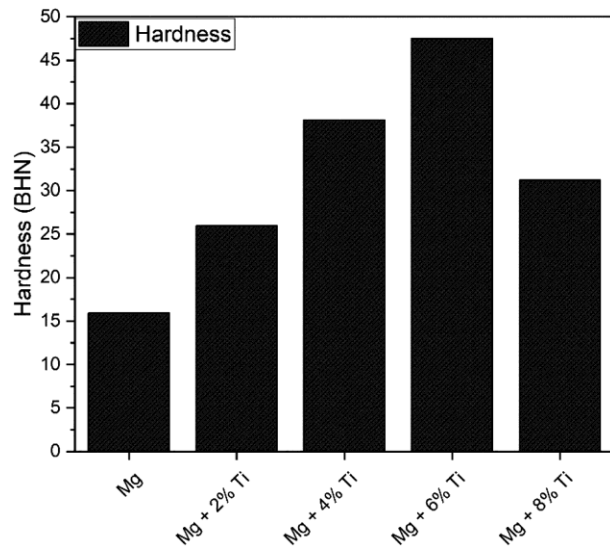


Fig. 7 — The Brinell Hardness with the variation of reinforcement of Ti.

samples. The hardness of Mg/Ti composites initially increased with the increasing volume fraction of Ti, and then it started to decrease on further increasing the volume fraction of Ti beyond 6%. The highest hardness of 47.5 BHN was obtained for Mg/Ti composite reinforced with 6 % by volume of Ti. The High strength and hardness of reinforcement (Ti) compared to the matrix (Mg alloy AZ91) was the reason behind the increase in hardness of Mg/Ti composites with the increasing Ti volume fraction.

The hardness of the Mg + 8% Ti sample (31.22 BHN) was less than the hardness of the Mg + 6% Ti sample (47.5 BHN); this can be due to the aggregation of Ti particles. A similar effect of Ti volume fraction on the hardness of Mg-composites was noticed by other researchers also^[12, 16].

3.3.2 Compressive Strength

The compressive stress-strain curves of prepared samples is shown in Fig. 8. The ultimate compressive stress and compressive strain (up to fracture point) values of all the samples is shown in Fig. 9. On increasing the volume fraction Ti in Mg-matrix, both the compressive stress and strain increased initially due to effective load transfer from matrix Mg to Ti. During sintering, metallic reinforcement Ti formed a strong mechanical bonding with matrix material AZ91 due to material diffusion. However, on increasing the volume fraction of Ti beyond 6%, both the ultimate compressive stress and compressive strain (up to fracture) decreased. It can be attributed

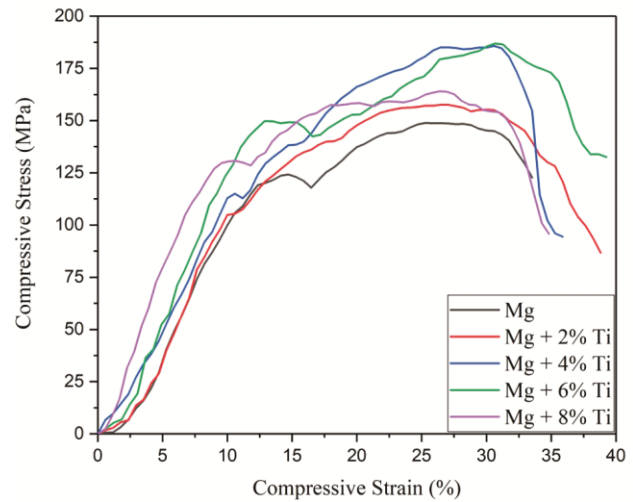


Fig. 8 — The Compressive stress and compressive strain with the variation of Ti.

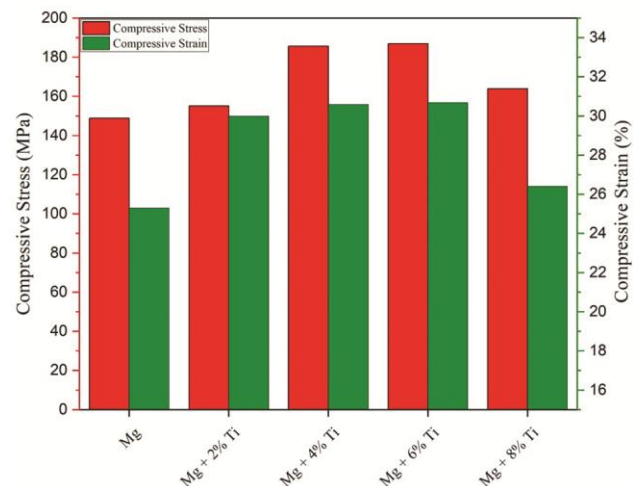


Fig. 9 — The ultimate compressive stress and compressive strain (up to fracture point) with the variation of Ti.

due to agglomeration of Ti particles. The agglomerated Ti particles could not diffuse properly in the magnesium matrix and resulted in poor bonding between Mg-matrix and Ti-reinforcement.

The proper load transfer from matrix to reinforcement could not take place due to the poor mechanical adhesion between the matrix and reinforcement particle and resulted in low strength of Mg + 8% Ti composite in comparison to the strength of Mg + 6% Ti composite. Other researchers also noticed the same impact of Ti volume fraction on Mg/Ti composites' compressive strength^[12, 16]. Hence, it was observed that 6% volume fraction of Ti to AZ91matrix is optimum for both the hardness and compressive strength of Mg/Ti composites.

4 Conclusion

After investigating the physical and mechanical properties of MMCs reinforced with Ti, the following conclusions were drawn:

- Both the green density and sintered density have increased with the addition of Ti because of high density of Ti in comparison to density of AZ91 Mg alloy.
- The highest relative green density of 91% and lowest porosity of 9% have obtained for Mg/Ti composite reinforced with 8% (by volume) Ti because of the increased compressibility and flow of material (during powder compaction) after the addition of Ti.
- The density has decreased after sintering of all the samples due to expansion in the material during sintering.
- The highest hardness (47.5 BHN) and ultimate compressive strength have obtained for the Mg/Ti composite reinforced with 6% Ti because of good mechanical bonding between Mg and Ti and proper load transfer from matrix to reinforcement.
- Ductility has also increased with Ti's addition in the Mg matrix because no tertiary hard phase forms between Mg and Ti due to very low solid-solubility of Ti in Mg upto 450°C.

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