MICROSTRUCTURE AND MECHANICAL PROPERTIES OF MG/SIC METAL MATRIX COMPOSITES CASTING PRODUCED BY STIR CASTING DOWN POURING PROCESS

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Abstract: In this paper microstructure and mechanical properties of Mg/SiC metal matrix composites produced by stir casting down pouring technique were investigated. Magnesium composites reinforced with 1, 3, 6, 9 and 12 wt. % SiC were produced by stir casting route. The microstructure of as-cast composites was studied by using optical microscope and scanning electron microscope (SEM). The grain size of magnesium metal matrix composite was much smaller as compare to pure magnesium. The mechanical properties of composites were better than monolithic magnesium which were attributed to refined grain size and presence of hard SiC particles. The best results for hardness and tensile strength were obtained with 9% SiC reinforcement. The fracture mechanisms of tensile samples were evaluated by using SEM images.

Keywords: stir casting; metal matrix composite; microstructure; tensile strength

1. INTRODUCTION

Magnesium and magnesium based materials are gaining attention as a light weight material in automotive and structural applications due to rising fuel prices and strict environment norms. The magnesium is the potential candidate to replace the conventional materials due its low density, high specific strength, good castability and machinability (1). Magnesium is the lightest metallic material with a density 35% less than aluminum and 75% less than steel. However the use of magnesium is still limited due to its low strength and hardness. The magnesium metal matrix composite (MMC) have good strength as compare monolithical magnesium, but mostly research work is focused on aluminium based composite and very limited work is done on magnesium based MMCs. The MMC can be produced by powder metallurgy, squeeze casting, spray forming, preform infiltration and stir casting (2-6). The stir casting method technique is a very simple, less expensive, high production rate and produce nearly net shape components (7). To produce magnesium based composite reinforcements like silicon carbide, boron carbide, aluminum oxide, magnesium oxide, yttrium oxide, fly-ash, carbon nano tube some boride and nitride can be used (8-16). Saravanan and surappa (17) fabricated 30% volume fraction SiC based metal matrix composite without any protective gas by stir casting technique. The composite was extruded and tested for microstructure and mechanical properties. The results showed smaller grain size, improved tensile strength and wear resistance as compared to pure magnesium (17). Viswanath et al.(18) fabricated AZ91/SiC composite by using stir casting and reported improvement in the mechanical properties. Aravindan (19) fabricated AZ91/SiC composite by using two step stir casting process and investigated the effect of reinforcement particle size and percentage on mechanical properties. The mechanical results revealed that the yield strength, hardness increase and elongation decrease with increase in the particle content. Poddar et al (20) fabricated AZ91/SiC composite by using stir casting technique and reported significant reduction in the grain size as compared to monolithic magnesium alloy. The hardness and elastic modulus of alloy increase with addition of reinforcement, but elongation decrease. Jiang et al.(21) fabricated TiC reinforced AZ91 based metal matrix composite by using semisolid slurry stirring technique. The TiC-Al master alloy was processed via self-propagating high temperature synthesis reaction. The tensile strength, hardness and wear resistance of composite was better than alloy. So it is clear from the literature that metal matrix composites have the potential to enhance the mechanical properties of monolithic magnesium or magnesium alloy, but very limited work is done on magnesium based materials. Accordingly, the primary aim of this paper is to investigate the effect of silicon carbide particles on microstructure hardness and tensile strength of magnesium matrix.

2. MATERIAL, PROCESSING AND TESTING

2.1. Materials

In the current investigation magnesium was used as a matrix material. It was purchased from swami equipment with 99.9% purity in the form of as-cast billet. The SiC particulate reinforcement with 400 mesh size was purchased from Central Drug House Ltd (CDH), India. The SEM image of SiC particle is shown in fig.1

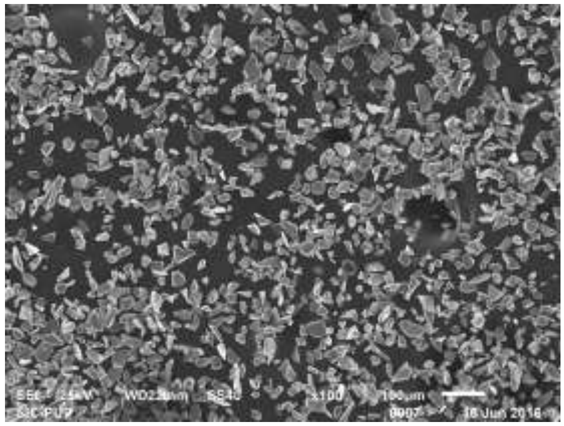

Fig 1. SEM image of SiC powder

2.2. Fabrication of the composites

The SiC reinforcement with 1%, 3%, 6%, 9% and 12% weight percentage was selected to produce magnesium matrix composites. The stir casting down pouring setup supplied by swami equipment was used to fabricate the composites. The fabrication process was conducted under protective atmosphere of CO_2 and SF_6 to avoid magnesium burning. Stainless steel crucible with a capacity of 2 kg used for fabricating the Mg/SiC composites. The magnesium was melted to 700°C temperature and hold at this temperature for 30 minutes and then SiC particles preheated to 400°C temperature were added through opening provided at top. The mixer was stirrer for 30 minutes by using two blade stirrer and then poured though bottom opening by using automatic pouring system into a preheated square steel mold (400°C). Then 80*80*100 mm size casting as shown in Fig. 2 were removed from the mould and allowed to cool in air. Unreinforced magnesium is also cast in similar condition.

Fig. 2 As-cast Mg/SiC block

2.3. Microstructures

The microstructure of pure magnesium and as-cast Mg/SiC composites were investigated by using optical microscope (Make: Leica; Model: DFC295) and Scanning Electron Microscopy (SEM). The samples for optical observations were prepared by using emery papers from 100 grit size to 3000 grit size and finally polished by using alumina powder. The samples for optical observation were etched with picric solution with following composition; 50ml picric acid, 20 ml glacial acetic acid, 10 ml ethanol and 10 ml distilled water (11). The mean linear intercept method was used to measure the grain size of magnesium and composite casting samples (22).

2.4. Macrohardness

The macrohardness measurements were performed under a Rockwell hardness tester (Model: MRS 250). The 10*10*5 mm samples polished with 2000 mesh size paper were used for the measurements. The hardness testing of magnesium was done by using the E scale. The average value of hardness taken at three different points on the same sample was reported in the study.

2.5 Tensile testing

The tensile strength of as-cast magnesium and composites is tested by using tensile testing machine (Make: Tenius Olsen). The tensile samples with cross sectional area 6 x 5 mm^2 and gauge length of 32 mm were cut from casting by using wire EDM.

3. RESULTS AND DISCUSSION

3.1 Microstructure results

Optical microscope images of as-cast magnesium and composites are shown in Fig. 3 and grain size in Table 1. The grain size of as-cast magnesium varies from hundred microns to few millimeters and the average value is around 800µm.

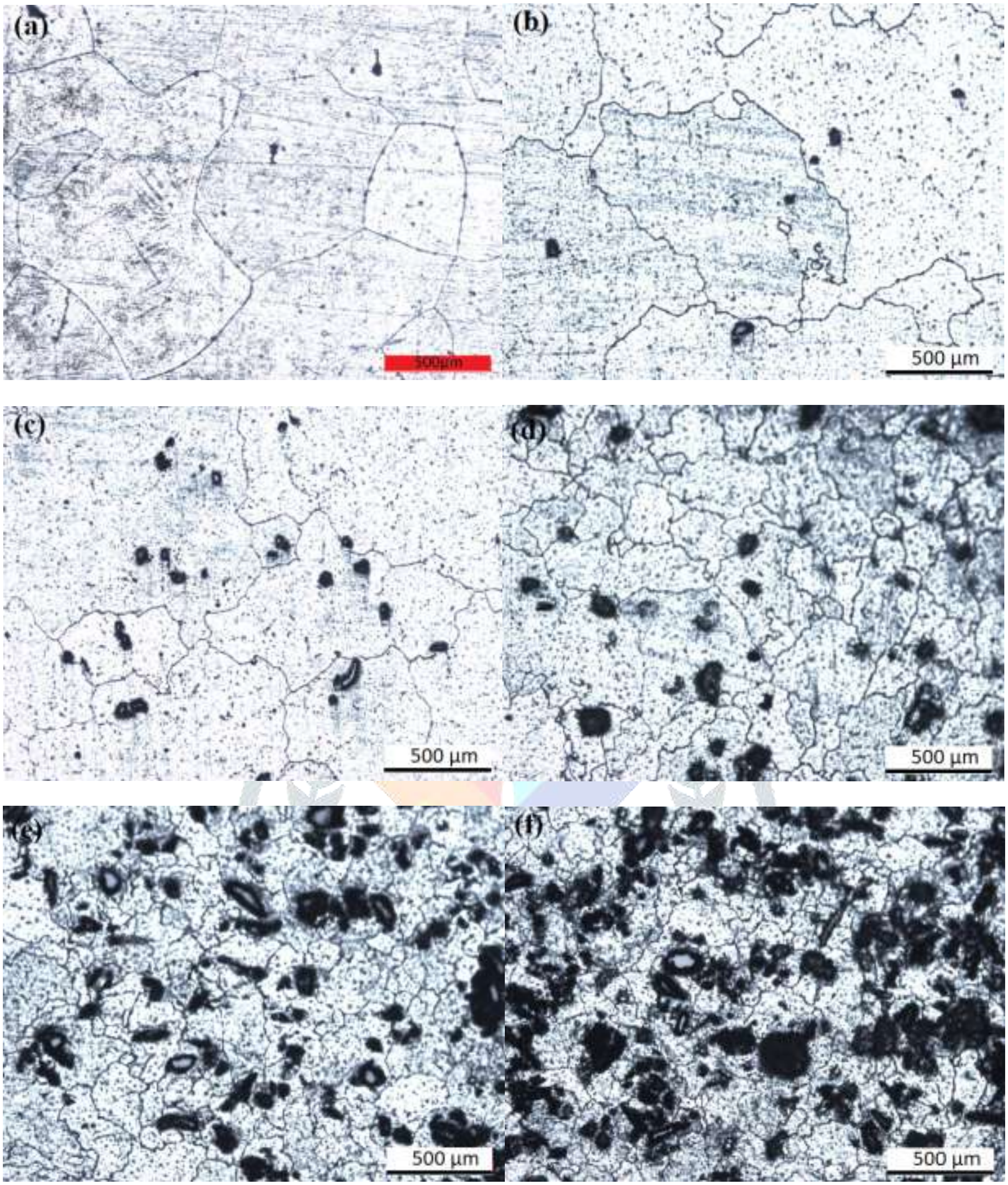

Fig.3. Optical images of (a) Mg (b) Mg/1%SiC (C) Mg/3%SiC (d) Mg/6%SiC (e),Mg/9%SiC (f) Mg/12%SiC

The grain size of Mg/SiC composite with 1% SiC addition is also close to as-cast magnesium as shown in Fig .3 (b). That means adding very small percentage of SiC does not have any positive effect on grain size. The grain size of composite with 3% SiC reduced to 400µm, which means grain size reduced by 50%. As depicted in Fig.3 (c) Further when the reinforcement increase to 9%, the grain size reduced to 170 µm. Finally at 12% reinforcement addition no significant refinement in the grain size was observed, the grain size was limited to 160µm. SiC particles distribution was nearly uniform upto 9% SiC contents, but agglomerations were observed at many locations in composite with 12% SiC reinforcement as shown in Fig. 3 (f). Saravanan and Surappa (17) also observed occurrence of cluster at some location in Mg/30%SiC composite. So it is clear from the Fig. 3, that the reinforcement play a significant role in refining the grain of magnesium matrix. The SiC particles acts as a nucleation site for grain growth, so as number of particle in liquid metal increase, nucleation rate increase (23, 24). Zang and Hu (23) observed similar results for AM50A reinforced with 5% SiC reinforcement.

Table.1 Grain size and hardness (HR) of Mg and Mg/SiC composites

S.no	Material	Grain size(μm)	Hardness(HR)
1	Mg	800	40
2	Mg/1%SiC composite	800	40
3	Mg/3%SiC composite	600	45
4	Mg/6%SiC composite	250	53
5	Mg/9%SiC composite	170	60
6	Mg/12%SiC composite	160	58

3.2 Macrohardness

Microhardness results of as-cast magnesium and Mg/SiC composite are shown in Table.1. The hardness of as-cast magnesium was 40HR, whereas hardness of Mg/9%SiC composite was 60HR, which means hardness increased by 50% with addition of SiC reinforcement. The hardness of composite increase with increase in the weight percentage of SiC particles upto 9%. This improvement in the hardness may be attributed to the presence of hard reinforcement in the soft matrix, which take the load and restrict the dislocation movement (22). The refinement in the grain size also contributed to increase the hardness, according the hall patch principal hardness of material inversely proportional to its grain size (25). At 12%SiC hardness slightly decrease, owing to presence of air pockets or porosity near the SiC clusters.

3.3 Tensile test results

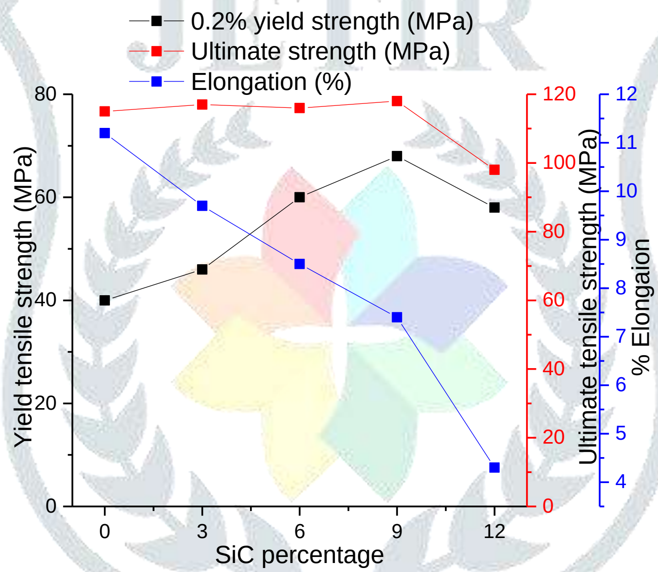

Fig. 4 Yield strength, ultimate strength and elongation results of as-cast composites

The room temperature tensile results of monolithic Mg and Mg/SiC composites with different SiC percentages are shown in Fig 4. It is clear from the Fig. 6 that the yield strength of the Mg/SiC is higher than monolithic magnesium and it increases with increase in the percentage of the reinforcement. The yield tensile strength of magnesium is 40MPa, whereas tensile yield strength 68 MPa. So yield strength is improved by 50%. The improvement in the tensile strength may be attributed to the grain refinement, load transfer from matrix to reinforcement and High dislocation density due to difference in coefficient of thermal expansion of SiC and magnesium (26, 27). However, there is not any noticeable improvement in the ultimate strength is observed. The tensile yield strength and ultimate strength decrease sharply when SiC percentage increased from 9 to 12 percentage. The elongation of composite samples decrease with increase in the SiC percentage(20). Jayamathy et al (28) also reported increase in the yield tensile strength and decrease in elongation for AM60/SiC composites produced by squeeze casting technique.

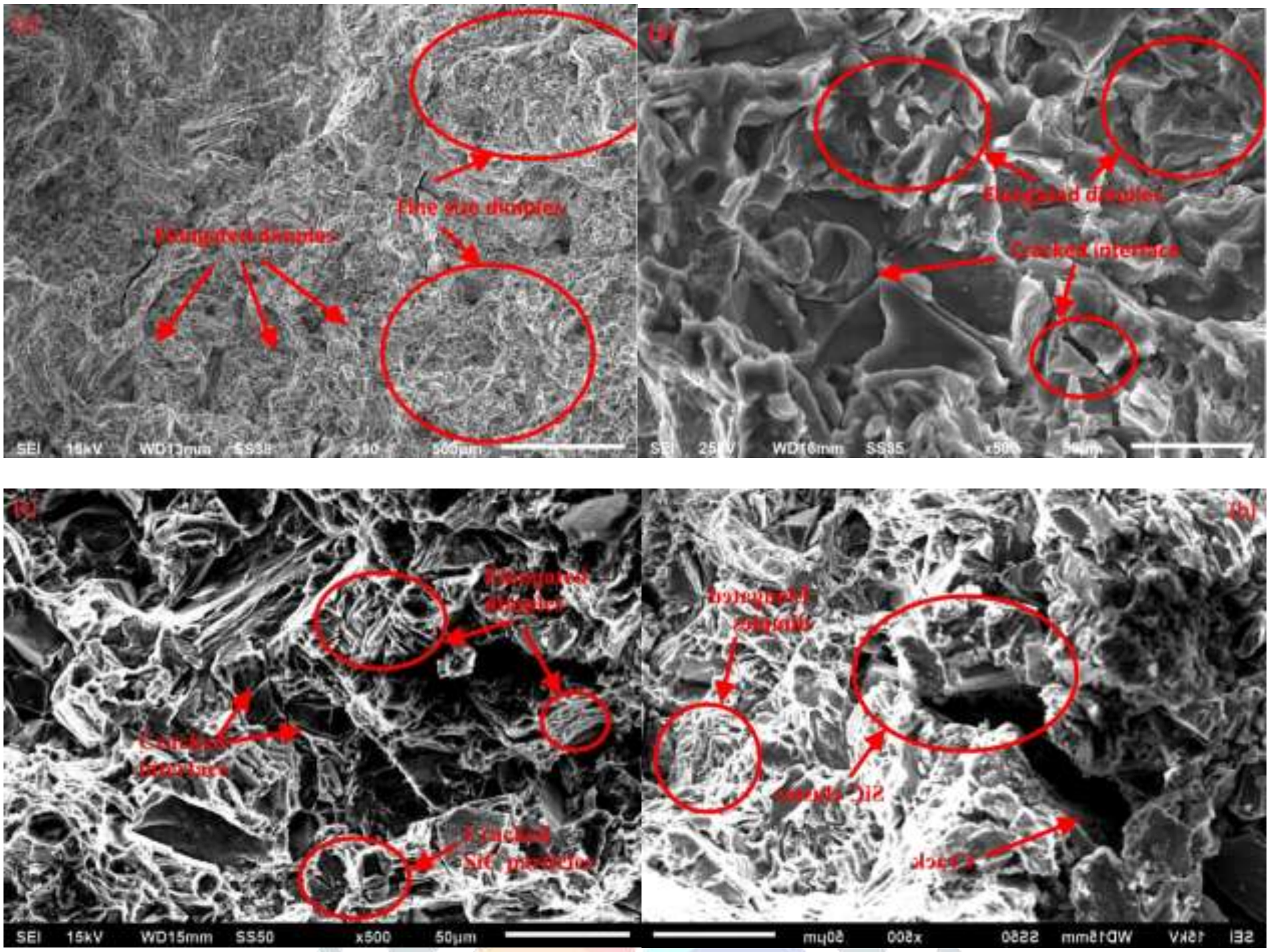

Fig. 5. SEM images of fracture surface after tensile tests (a) Mg (b) Mg/6% SiC (c) Mg/9%SiC (d) Mg/12%SiC

The SEM images of fractured surfaces of monolithic Mg and Mg/SiC composites are shown in Fig. 5. The fracture surface of Mg in Fig. 5(a), show that the failure is ductile in nature. The small size and elongated dimples were observed in fracture surface of Mg, which signify the ductile failure. The fracture surface of Mg/SiC (Fig (b-d) show the elongated dimple in the Mg rich areas, and cracked Mg/SiC interface and pullout SiC particles, which resulted into brittle failure. Presence SiC clusters or agglomeration on fractured surface of Mg/12% SiC composite was evident as depicted in Fig. 5(d). Agglomeration of SiC particles reduced the yield tensile strength, ultimate tensile strength and elongation sharply.

4. CONCLUSIONS

1. The Mg/SiC based composite were successfully fabricated by using stir casting down pouring setup and significant grain refinement observed with addition of SiC reinforcement.
2. The hardness of composite is significantly higher as compared to monolithic magnesium.
3. The yield strength of composite is much higher as compared to monolithic magnesium, but there is no remarkable improvement in the ultimate tensile strength and elongation decreased with increase in SiC contents.

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