

# Mechanical Properties Enhancement of Particle Reinforced Magnesium Matrix Composites Used for Hot Extruded Tubes

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This paper studies new magnesium metal matrix composites (Mg MMCs) reinforced with SiC particles by the stir-casting method for MMCs tubes hot extrusion. AZ61/SiCp MMCs' ingots reinforced with 0, 0.5 and 1 wt.% SiC particles are fabricated by the melt-stirring technique. AZ61/SiCp MMCs' tubes are manufactured by hot extrusion using a specially designed die-set. Obvious grain size refinement both by addition of particles and extrusion process are discovered. However, the grain refinement effect caused by extrusion process is much significant than that effect caused by SiC particle addition. The 0.2% yield strength (YS) of extruded tubes of AZ61 and AZ61/1 wt.% SiCp MMCs (without and with T5 treatment) are increased by 140.9–161.9% and 156.5–156.7%, respectively, compared with those of as-cast billets.

DOI: [10.12693/APhysPolA.127.1271](https://doi.org/10.12693/APhysPolA.127.1271)

PACS: 81.05.Bx, 81.20.Ev, 81.20.Hy

## 1. Introduction

Magnesium alloys metal matrix composites (Mg MMCs) reinforced with ceramic particles (such as AZ61/SiCp MMCs) have being developed to achieve better mechanical properties and can be used as load-bearing components. Lin *et al.* [1] used the modified disintegrated melt deposition (DMD) technique to integrate the nano-scaled particle Al<sub>2</sub>O<sub>3</sub> into AZ91D Mg alloy in order to form the Mg MMCs. Huang and Chen [2] studied the grain refinement of 1, 2 and 5 wt.% of 1 μm AlN particles reinforced AZ91D Mg-based metal-matrix composites, and the β-phase of Mg was almost eliminated through homogenization. Huang *et al.* [3] found that the hardness, ultimate tensile strength and yield strength of Mg alloy (AZ80) can be improved by adding reinforcement particles (becomes AZ80 MMCs). Lim and Gupta [4] investigated the effects of extrusion temperatures on the microstructural and mechanical response of a AZ61/SiCp MMCs. Ugandhar *et al.* [5] investigated the effects of heat treatment on the strength and ductility of AZ61/SiCp MMCs. Chua *et al.* [6] discussed the influence of SiC particles on the mechanical properties of Mg based composite with different sizes of SiC particles. El-Morsy *et al.* [7] tried to obtain grain refinement by hot extrusion and thermomechanical processing of large reduction rolling.

Few papers discussed mechanical properties of seamless extruded tube of Mg alloy based composites rein-

forced with silicon carbide (SiC) particles. In this paper, Mg AZ61 based composites reinforced with 0, 0.5 and 1 wt.% SiC particles are fabricated by the melt-stirring technique. Seamless AZ61/SiCp MMCs tubes are manufactured by forward hot extrusion with a specially designed die-set under forming temperatures, and their mechanical properties are studied.

## 2. Materials

The matrix used in this work is magnesium alloy AZ61 containing approx. 6.0% aluminium. Its chemical composition is shown in Table. SiC particles with weight fraction of 0, 0.5 and 1% within MMCs are used as the reinforcement phase. The commercially- available SiC powder with a particle diameter about 4.5 μm, density of 3.22 g/cm<sup>3</sup> and with purity of approx. 99.6% was added into AZ61 to form the Mg-based metal-matrix composites.

Chemical composition of AZ61.

TABLE

Al	Zn	Mn	Fe	Si	Cu	Ni	Mg
5.95	0.64	0.26	0.005	0.009	0.0008	0.0007	Bal.

## 3. Fabrication of AZ61/SiCp MMCS' ingot and its T4 treatment

The fabrication of the AZ61/SiCp MMCs containing 0, 0.5 and 1 wt.% of 4.5 μm SiC particles was carried out using the melt-stirring technique. Firstly, magnesium AZ61 alloy chips accompanied with SiC particles were put inside the stainless crucible. SF<sub>6</sub>+CO<sub>2</sub> gas started to blow

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into the stainless crucible after the heating temperature reaching 400 °C in order to avoid oxidation and burning of the magnesium alloy. The synthesis procedure involved continuously heating the magnesium AZ61 chips with SiC particles to 750 °C followed by stirring of the melt in the range of 450–470 rpm for about 5 min. The stirring was carried out using a twin blade stirrer close to the bottom of the crucible to facilitate the incorporation and uniform distribution of the SiC particles in the AZ61 matrix. Following stirring, the disintegrated melt slurry was deposited on a cylindrical metallic mold by removing a plug that initially blocks a hole at the bottom of the stainless crucible. The pouring process was carried out in an argon atmosphere in order to minimize oxidation of the magnesium alloy composite. AZ61/SiCp ingots with 80 mm in diameter and 140 mm height obtained by the melt-stirring process were machined to be billets with 25 mm inner and 64 mm outer diameters, respectively, and 50 mm height. After machining ingot, prior to extrusion process, T4 treatment (homogenization) was carried out on the billets for 10 hours at 400 °C in order to obtain best quality of extrusion.

#### 4. Hot extrusion and T5 treatment of AZ61 and AZ61/SiCp MMCS' Tubes

Right after the T4 treatment, extrusion experiments of AZ61 and AZ61/SiCp MMCs' tubes were conducted using a 350 tons' extruder with single pushing cylinder. In the experiments, an initial billet temperatures, 300 °C, was adopted for investigating the influence of the forming temperatures on the mechanical properties of the extruded tubes of AZ61 and AZ61/SiCp MMCs. The extrusion ratio was designed to be 14.7, which is the ratio of the cross-sectional area of the billet to that of the tube. The ram speed was set as 1 mm/s. After extrusion, T5 treatment was carried out on tubes for 16 hours at 177 °C.

### 5. Results and discussion

#### 5.1 Grain size refinement

Figure 1 shows the grain size of billet and extruded tubes with 300 °C extrusion temperature. The averaged grain sizes are measured by the linear intercept method. The tendency of the relative grain sizes of AZ61/SiCp MMCs before and after extrusion is the same as that for AZ61. It can be observed that grain size decreased tremendously by extrusion process for any AZ61 MMCs of a fixed percentage of SiC addition. Besides, by virtue of SiC particle addition, the grain size decreases with increasing percentage of SiC for specific AZ61 MMCs billet and tube. It can be concluded that the grain size refinement effect caused by extrusion process is much obvious than that effect caused by SiC particle addition.

#### 5.2 Tensile test

Specimens for tensile tests were taken from the billets and extruded tubes. The ultimate tensile strength

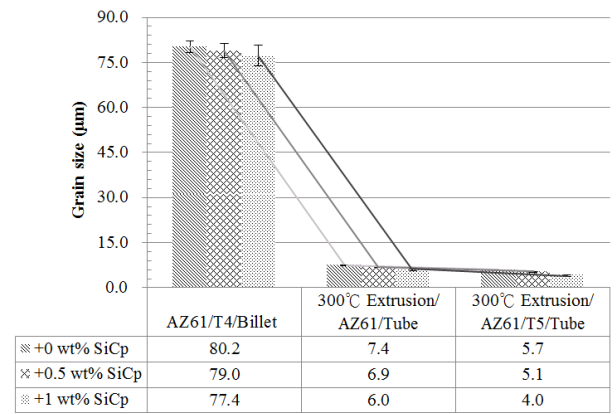


Fig. 1. Grain size of billet and extruded tube.

(UTS) of billets after T5 treatment increases with increasing percentage of SiC addition. The 0.2% yield strength and ultimate tensile strength of the billets and extruded tubes under different temperatures are shown in Fig. 2 and 3, respectively. From the Fig. 2–3, it is found that the ultimate tensile strength and 0.2% yield strength of AZ61/SiCp MMCs' tubes are all larger than those of AZ61 tubes. For extruded tubes with and without T5 treatment, the ultimate tensile strength and 0.2% yield strength increase with increasing percentage of SiC addition. Besides, that the ultimate tensile strength and 0.2% yield strength increased tremendously by extrusion process for any AZ61 MMCs of a fixed percentage of SiC addition. The maximum UTS 274.6 MPa and YS 156.1 MPa of AZ61/1 wt.%SiCp MMCs tubes were found at the conditions of extrusion temperature 300 °C and T5 treatment.

It is observed that the strength of AZ61 and AZ61/SiCp MMCs extruded tubes are exceptionally bigger than those of their billets.

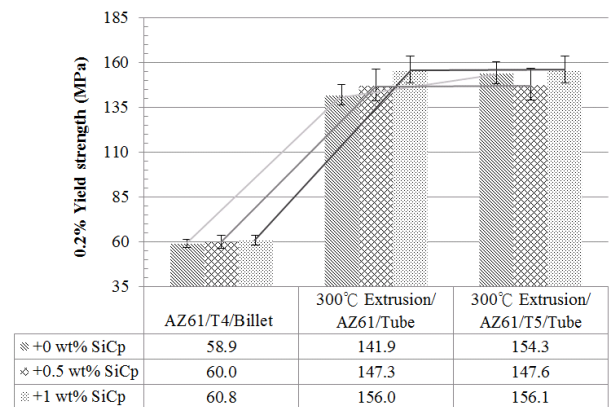


Fig. 2. Yield strength of billet and extruded tube.

The 0.2% yield strength (YS) of extruded tubes of AZ61 and AZ61/1 wt.% SiCp MMCs (without and with T5 treatment) are increased by 140.9–161.9% and 156.5–156.7%, respectively, compared with those of as-cast billets. The ultimate tensile strength (UTS) of extruded

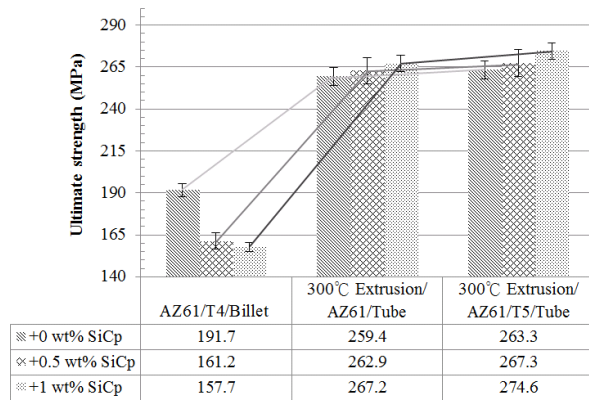


Fig. 3. Ultimate strength of billet and extruded tube.

tubes of AZ61 and AZ61/1 wt.% SiCp MMCs (without and with T5 treatment) are increased by 35.3–37.3% and 69.4–74.1%, respectively, compared with those of as-cast billets. Therefore, particle addition can strengthen the extruded AZ61 within certain amount of strength. But the strength reinforcement caused by extrusion (dynamic recrystallization) has stronger than that caused by particle addition.

### 6. Conclusions

In this paper, AZ61/SiCp MMCs reinforced with 0, 0.5 and 1 wt.% SiCp were fabricated by the melt-stirring technique. Then, AZ61 and AZ61/SiCp MMCs' tubes were firstly manufactured by hot extrusion processes. Based on the experimental results, the following conclusions and some important novelties could be drawn:

The grain size refinement effect caused by extrusion process is much obvious than that effect caused by SiCp particle addition.

A grain size less than 10  $\mu\text{m}$  for the extruded tube with extrusion temperature of 300 °C was obtained, which is much smaller than 84  $\mu\text{m}$  for the grain size of the billets.

The 0.2% yield strength and ultimate tensile strength of extruded tubes of AZ61 and AZ61/SiCp MMCs are larger than those of as-cast billets by 140.9–161.9% and 35.3–74.1% increase, respectively.

The maximum UTS 274.6 MPa and YS 156.1 MPa of AZ61/1 wt.% SiCp MMCs tubes were obtained at the conditions of extrusion temperature 300 °C and T5 treatment.

### Acknowledgments

The authors would like to extend their thanks to the National Science Council of the Republic of China under Grant no. NSC 97-2221-E-110-027-MY3 and NSC 96-2923-E-194-001-MY3. The advice and financial support of NSC are greatly acknowledged.

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