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# The effect of Cerium addition on microstructure and mechanical properties of high pressure die cast Mg-5Sn alloy

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ABSTRACT

The effect of Cerium addition to Mg-5Sn alloy and its influence on the microstructure and mechanical properties of the alloy were investigated in this work. The microstructural investigations indicate that the alloying addition of Ce leads to effective grain refinement. Also, it was observed that adding Ce to the Mg-5Sn alloy results in the formation of new phases in the alloy such as $Ce_5Sn_4$ and CeMgSn. These intermetallic phases were considered to be effective on the enhancement of the hardness of Mg-5Sn alloy. Furthermore, the tensile test results at room temperature and elevated temperatures revealed that the yield and tensile strength of the Ce added alloy were higher than those of the base alloy. The elongation was also improved up to 5 wt% Ce addition while higher amounts decreased the elongation both at room and elevated temperatures.

## 1. Introduction

There are a lot of metallic structural materials available to the transportation industry most of which are made of ferrous-based alloys due to their attractive mechanical properties. But in the last decades, there has been an increasing demand to the studies on various non-ferrous alloy systems such as aluminium alloys, titanium alloys, zinc alloys, magnesium alloys leading to the replacement of ferrous alloys. The major reasons are to enhance the vehicle fuel efficiency and to provide lower $CO_2$ emission. Among non-ferrous alloys, magnesium alloys are one of the most efficient candidates for significant weight reduction due to their low density. Therefore, several magnesium alloy systems (such as Magnesium-Aluminium (AM), Magnesium-Aluminium-Zinc (AZ)) have been developed [1–6]. But, it is well known that the microstructure of these commercial alloys involve β-$Mg_{17}Al_{12}$ intermetallic along grain boundaries, which forms an incompatible interface with magnesium matrix that detrimentally influences the mechanical properties [7,8]. Hence, new alloying designs without Al are improving nowadays especially Mg-Sn binary alloy system. The literature regarding the Mg-Sn alloy system has shown that the mechanical properties of pure Mg could be improved with Sn addition via precipitation strengthening mechanism. The researchers concluded that the best mechanical properties for the Mg-Sn alloying system was attained through the addition of 5% Sn [9,10]. However, the Mg-Sn alloy still needs improvement in order to compete with commercial Mg-Al alloys because of lower mechanical properties. Thus, several third alloying element candidates such as Calcium, Zinc, and Antimony have been added to enhance the ambient and high temperature mechanical properties. Unfortunately the literature available on the experimental findings regarding the Mg-Sn-Ce alloying system is very limited [11–17]. As a result, this paper focuses on the variations of microstructural and mechanical properties of the Mg-5Sn binary alloy with addition of various amount of Cerium.

## 2. Experimental Details

The alloy composition of Mg-5% Sn was selected as a base material in this study. The specimens were prepared in an induction furnace using a SiC crucible under a gas mixture of carbon dioxide ($CO_2$) and sulphur hexafluoride (2% $SF_6$) from commercially pure magnesium and tin. Cerium was added in Mg-30Ce form as a master alloy. The nominal compositions (wt%) of investigated alloys were Mg-5Sn, Mg5Sn-3Ce, Mg-5Sn-5Ce and Mg-5Sn-7Ce. The alloys were held at 750 °C casting temperature for 5 min, poured into a mould at 200 °C and immediately casted into the die, shown in Fig. 1, using a 100-tonnes clamping and 76 kN injection force cold chamber high-pressure die cast machine.

Samples were prepared for field emission scanning electron microscopy (FE-SEM) investigation using the standard metallographic procedures and chemically etched in nital. X-ray diffraction (XRD) analysis was also carried out to identify the phases present in the experimental alloys using a Rigaku D-Max 1000 X-ray diffractometer. Cu Kα radiation was used at 40 kV and 30 mA, from 20 to 60° with 1°/min and the

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Fig. 1. Macrograph of experimental alloy cast.

phase identification was done by comparison with ICDD database. The grain size measurements were performed by using image analysis software (Clemex).

Brinell hardness tests of the alloys were carried out with a ball diameter of 2.5 mm and an applied load of 31.25 kg, making at least 10 indentations with 10 s of holding time. Uniaxial tensile tests, using rectangular test specimens in accordance with ASTM standard E8/E8M, were performed at room temperature, 125 °C, 175 °C and 225 °C with a universal testing machine with a ram velocity of 0.2 mm/min. Before each high temperature tensile test, the whole samples were kept in the system for 10 min so as to acquire the heat balance. Each test was repeated four times, and the average values were regarded as the experimental data for the ultimate tensile strength (UTS), yield strength (TYS) and elongation (ε).

## 3. Results and Discussion

### 3.1. Microstructure and Characterization

The XRD patterns displayed in Fig. 2 indicated that the α-Mg and $Mg_2Sn$ intermetallic phases were present in all of the specimens. However, the intensity of the diffraction peaks for the $Mg_2Sn$ was decreased in the alloys containing Ce. The addition of Ce to the Mg-5Sn alloy led to the formation of new intermetallic phases of CeMgSn and $Ce_5Sn_4$. The Table 1 shows the effect of Ce alloying element addition into Mg-5Sn alloy on the grain size. It can be said from Table 1 that the grain size of Mg-5Sn alloy gradually declined with increasing Ce addition. The best grain size decrement was achieved in the Mg-5Sn-7Ce alloy (from 11.1 μm to 3.59 μm).

The SEM images of the microstructures of Mg-5Sn alloy with different Ce containing are shown in Fig. 3. As observed, the

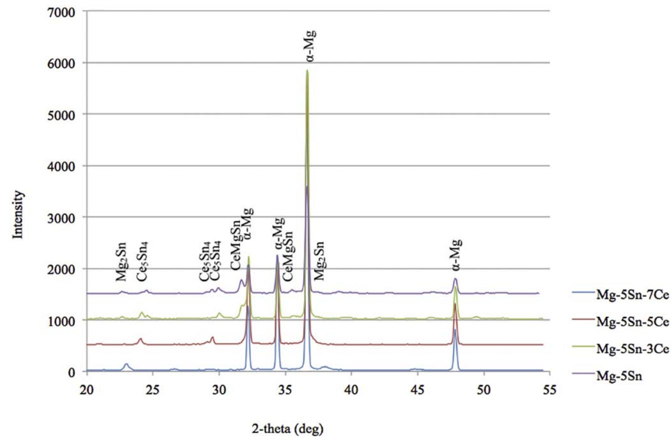


Fig. 2. The X-ray diffraction analysis patterns of the alloys.

**Table 1**
The effect of alloying element on grain size of Mg-5Sn alloy.

| Alloy | Grain size (μm) |
|---|---|
| Mg-5Sn | 11,1 ( ± 5,08) |
| Mg-5Sn-3Ce | 6,01 ( ± 2,67) |
| Mg-5Sn-5Ce | 5,03 ( ± 1,98) |
| Mg-5Sn-7Ce | 3,59 ( ± 1,72) |

microstructures of all Ce containing alloys consist of finer α-Mg grains surrounded by intermetallic phases compared to that of the Mg-5Sn. In addition to this, when the Ce content is higher than 3 wt%, the new coarse intermetallic phases were found to be located along and within the grain boundaries.

Previous studies have reported that Mg-Ce binary alloy systems can contain $Mg_{12}Ce$, $Mg_{39}Ce_5$ or $Mg_3Ce$ intermetallic phases whereas, in the Mg-Ce-Sn ternary alloying systems, it can be observed that other phases such as $Ce_5Sn_4$, $Ce_5Sn_3$ or CeMgSn, may exist as well [18–20]. Fig. 4 exhibits EDS analysis (point measurement and line profiling) of the Mg-5Sn-7Ce alloy to determine the new found phases from XRD results. The Spot 1 from Fig. 4(a) indicated that some Ce was solved in α-Mg grain. The spot 2 identified as the rod-like CeMgSn intermetallic according to atomic ratio of Ce to Sn. Also, the spot 3 was the coarse $Mg_3Ce$ intermetallic phase and the spot 4 and 5 were the rod-like CeMgSn intermetallic phase (Fig. 4(b)). The EDS line result (Fig. 4(c)) supported that the $Ce_5Sn_4$ intermetallic phase distributed in the grain boundaries.

### 3.2. Tensile Properties

Fig. 5 shows the yield stress, tensile stress, elongation and hardness as a function of Ce concentration at room temperature. The room and elevated temperature tensile properties of Mg-5Sn with different Cerium concentrations are listed Table 2. As was revealed from Fig. 5 the yield and tensile strengths as well as the hardness values were considerably improved with increasing Cerium concentration. The elongation found to be slightly increased up to 5wt%Ce addition, and then gradually decreased with addition of 7 wt%Ce at the room temperature. The yield and tensile strengths and the hardness of Mg-5Sn alloy were improved 62.5% (from 80 MPa to 130 MPa), 50% (from 108 MPa to 162 MPa) and 39.5% (from 43 HRB to 60 HRB), respectively due to the addition of 7 wt% Ce. Whereas an ~19% decrease in the elongation to failure was observed in the alloy with 7 wt% Ce addition. The tests at elevated temperatures showed similar trend for tensile properties (Table 2). It can be said that both yield and tensile strengths declined with the increasing temperature but still the Ce containing alloys exhibit higher strength values than the base alloy.

According to Hall–Petch relationship, the mechanical properties