Application of silicocalcium in Mg-6Al-0.5Mn alloy

WANG Li-guo1, ZHANG Bao-feng2, ZHU Shi-jie1, ZHANG Chun-xiang1, *GUAN Shao-kang1
(1. School of Materials Science and Engineering, Zhengzhou University, Zhengzhou 450002, China; 2. Huanghe Science and Technology College, Zhengzhou 450062, China)

Abstract: The mechanical properties of magnesium alloys at both ambient and elevated temperatures can be improved with the existence of Mg2Si phase in the matrix. However, these properties can be deteriorated if the Mg2Si phase is of coarse Chinese script type. Effects of the silicocalcium addition on the microstructure and properties of an Mg-6Al-0.5Mn alloy (AM60) were studied. The microstructure of the alloy with the addition of silicocalcium is featured with dispersedly distributed small polygonal type Mg2Si phases. The microhardness, tensile strength, percentage elongation and toughness of as-cast AM60+1.0Si-Ca alloy are 20%, 13.3%, 28.5% and 50% higher than these of AM60 alloy respectively. Further corrosion measurements showed that the silicocalcium-modified AM60 alloy increases the corrosion potential by 0.04V and decreases the lost weight corrosion rate by 45%.

Key words: silicocalcium; magnesium alloy; microstructure; mechanical properties; corrosion


Magnesium alloys have the advantages of light-weight, high strength/weight ratio, high stiffness/weight ratio, high damping property and electromagnetic shielding property and so on. They can be potentially applied in aviation, aerospace, automobile, and electro-communication industries [1]. Mg2Si can be formed in Mg alloys by adding Si. The compound phases usually strengthens Mg alloys because of its high melting point, high hardness, low density, high elastic modulus and low thermal expansion coefficient [2]. But the existence of the coarse Chinese script type Mg2Si phase deteriorates the mechanical properties of the alloys [2, 3]. It has been reported recently that the proper addition of Ca can lead to a morphological change of Mg2Si particles from coarse Chinese script shape to small polygonal type [4, 5]. To import Si and Ca, experiments have been performed by adding Al-Si, Al-Ca or Mg-Ca master alloys into Mg alloys by adding Si. The compound phases usually strengthens Mg alloys because of its high melting point, high hardness, low density, high elastic modulus and low thermal expansion coefficient [2]. But the existence of the coarse Chinese script type Mg2Si phase deteriorates the mechanical properties of the alloys [2, 3]. It has been reported recently that the proper addition of Ca can lead to a morphological change of Mg2Si particles from coarse Chinese script shape to small polygonal type [4, 5]. To import Si and Ca, experiments have been performed by adding Al-Si, Al-Ca or Mg-Ca master alloys into Mg alloys during smelting [4, 5]. However, less work has been carried out on importing Si and Ca by silicocalcium, which has been applied widely in steel-making. The present work is to investigate the influence of small addition of silicocalcium on the microstructure and properties of an Mg-6Al-0.5Mn (AM60) alloy.

1 Experimental procedures

The AM60 alloy and AM60+1.0Si-Ca were prepared in a steel crucible placed in an electric resistance furnace protected by CO2-0.5%SF6. Commercially pure magnesium, aluminum, zinc, and silicocalcium were used. Manganese was added as Al-10Mn master alloy. The melt was held at 720℃, and silicocalcium was added at 780℃. Then, the melt was poured into a 30 mm-diameter steel mould at 720℃. The composition of silicocalcium alloy is listed in Table 1.

Homogenization (T4) for as-cast specimens was performed at 410℃ for 12 hours followed by water quench. The microstructural analysis was carried out by using of optical microscopy (Olympus), and scanning electron microscopy (Quanta-200) equipped with an energy dispersive X-ray spectrometer (EDAX). The phase identification was performed by an X-ray diffraction apparatus (XRD, Philips-PW1700) using monochromatic CuKα radiation working at an acceleration voltage of 40 kV and a current of 40 mA. The microhardness was tested using HV1000 type microhardness instrument with 0.98N load. Tensile testing of the as-cast samples with a gauge length of 25 mm and a gauge diameter of 5 mm were performed on an Instron 5585 testing machine. Impact toughness test was carried out using a 2BC-30B testing machine, and the specimen has a standard dimension of 10 mm × 10 mm × 55 mm without notch. The electrochemical corrosion were measured using a Princeton Applied Research EG & G potentiostat (model 352) in 3.5wt-% NaCl solution at 25℃. Samples for measuring weight loss were dipped in 3.5wt-% NaCl solution at 25℃ for 72 h. After testing, the corrosion products were removed with CrO3+AgNO3+Ba(NO3)2+H2O solution.

<p>| Table 1 Composition of Si-Ca alloy, wt-%* |</p>
<table>
<thead>
<tr>
<th>Ca</th>
<th>Si</th>
<th>C</th>
<th>Al</th>
<th>P</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;30</td>
<td>55-65</td>
<td>&lt;0.8</td>
<td>&lt;2.4</td>
<td>&lt;0.04</td>
<td>&lt;0.06</td>
</tr>
</tbody>
</table>

*Note: National standard YB/T5051-1997

Male, born in 1962, Ph.D, prof., the research field: Al, Mg and their alloys.
E-mail: skguan@zzu.edu.cn
Received: 2006-10-24; Accepted: 2007-06-30
2 Results and discussion

2.1 Microstructures

Figure 1(a) and 1(b) are XRD spectrums of as-cast AM60 alloy and AM60+1.0Si-Ca alloy. It shows that the main phases in AM60 alloy are $\alpha$-Mg phase and $\beta$-$\text{Mg}_17\text{Al}_{12}$ phase (Fig. 1a). Mg$_2$Si phase is only found in the alloy with silicocalcium addition (Fig. 1b). Calcium in silicocalcium doesn’t result in the formation of any new phase. Figure 2 shows the microstructures of both alloys in different state, and Fig. 3 shows the SEM micrograph of AM60+1.0Si-Ca alloy. It can be seen from Fig. 2 that the as-cast microstructure of AM60 alloy consists of $\alpha$-Mg matrix, discontinuous $\beta$-$\text{Mg}_17\text{Al}_{12}$ phase along the grain boundaries, and a small amount of Al-Mn particles inside the grains. With a small addition of silicocalcium, many small polygonal type particles show up and they randomly distributed inside the gains or at the grain boundaries. According to XRD patterns (Fig. 1b) and EDS analysis (Fig. 3b), these particles are mainly Mg$_2$Si and only small amount are Al-Mn phase. The coarse Chinese script type Mg$_2$Si phase, as reported by [3], are no longer found in the alloy modified with silicocalcium. SEM micrograph (Fig. 3a) also reveals that Mg$_2$Si particles has core-shell structure with small particle inside, this core-structured particles can presumably act as nucleation sites for Mg$_2$Si phase during solidification. Based on the quantitative EDS analysis and Al/Mn molar ratio, this phase can be Al$_5$Mn$_2$ [7]. It can also be seen from Fig. 2 that the grains are effectively refined and the Mg$_17$Al$_{12}$ phases became finer and more dispersed with silicocalcium addition. It is proposed that grain refinement in this alloy is due to the formation of a large number of fine Mg$_2$Si particles with high melting point, those particles precipitate firstly and pin the grain growth in process of solidification and subsequent heat treatments [7].
2.2 Mechanical properties

Mechanical properties of the two as-cast Mg alloys are summarized in Fig.4. It can be seen that the microhardness, tensile strength, elongation and impacts toughness of the alloy with silicocalcium addition are generally better than those of the as-cast AM60 alloy. The microhardness, tensile strength, elongation and the impact toughness of as-cast AM60+1.0Si-Ca alloy were 20%, 13.3%, 28.5% and 50% higher than that of AM60 alloy respectively.

The addition of silicocalcium enhances the combination of mechanical properties of Mg alloys. This is mainly attributed to fine-grain strengthening and matrix strengthening by the dispersed Mg$_2$Si particles.

2.3 Corrosion properties

The macrostructures of two as-cast alloys immersed in 3.5% NaCl solution for 72 h are shown in Fig.5. It can be seen that the corrosion took place on whole sample surface of AM60 alloy, while corrosion took place on sectional sample surface of the alloy with silicocalcium addition. It also appear that the corrosion surface is rougher for the AM60 alloy without silicocalcium addition. The corrosion rate is decreased by 9.7% with silicocalcium addition (Fig.6).

The polarization behaviors of both alloys in 3.5wt-% NaCl solution are shown in Fig.7. It can be seen that the $E_{\text{corr}}$ (corrosion potential) of subject alloy with silicocalcium addition increased, while the $I_{\text{corr}}$ (corrosion current density) decreased with reference to the as-cast AM60 alloy without modification. The improvement of corrosion resistance of the modified alloys with silicocalcium is due to the following microstructural features: refined grain structure, refined $\beta$-Mg$_{17}$Al$_{12}$ phases and uniformly distributed small polygonal Mg$_2$Si particles. The corrosion barrier effect of $\beta$ phase on $\alpha$-phase is enhanced in this optimized microstructure configuration.

3 Conclusions

(1) Small polygonal type Mg$_2$Si phases can be gained directly with the addition of silicocalcium and the microstructure can be
refined efficiently. The Mg$_{17}$Al$_{12}$ phases become finer and more dispersed.

(2) The microhardness, tensile strength, elongation and impacts toughness of the AM60 alloys are favorably improved with silicocalcium addition.

(3) The corrosion resistance of AM60 alloy is improved with the addition of silicocalcium.

References


