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ARTICLE

Microstructure and Mechanical Properties of Extruded Mg-Sm-Ca Alloys

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Abstract: Microstructure, age hardening response and mechanical properties of Mg-4.0Sm-*x*Ca (*x*=0.5, 1.0, 1.5, wt%) alloys extruded followed by isothermal aging at 200 °C were investigated. The results indicate that with the addition of Ca, the bulk and particle-like $Mg_{41}Sm_5$ phase containing Ca and the needle/rod-like Mg_2Ca phase are formed in the Mg matrix, grains of the alloy are refined and tensile mechanical properties are improved remarkably. Under T5 (peak-aging) condition, the Mg-4.0Sm-1.0Ca alloy shows the smallest grain size of 5.1 μm. With the increase of Ca content the amount of Mg_2Ca phase increases gradually, but that of the bulk Ca-containing $Mg_{41}Sm_5$ phase, which is mainly distributed at the grain boundaries, decreases obviously when Ca content reaches 1.5 wt%. The peak-aged Mg-4.0Sm-1.0Ca alloy exhibits the highest hardness HV (820 MPa) and the optimal ultimate tensile strength, yield tensile strength and elongation of 267 MPa, 189 MPa and 24%, respectively. The improved mechanical properties of the alloy are attributed to the grain refinement, the solution strengthening and the precipitation strengthening of Mg_2Ca phase and $Mg_{41}Sm_5$ phase.

Key words: Mg-Sm-Ca alloy; extruding-aging; microstructure; mechanical property

Magnesium alloys, as the lightest structural materials, have great potential applications in aircraft, automotive industry and transportable equipment due to their excellent properties [1]. However, the use of magnesium alloys was restricted in the past owing to their poor mechanical properties and low formability[2-4]. Extruded magnesium alloys exhibit superior mechanical properties to as-cast one, due to the refinement of the grains, the elimination of casting defects and the homogenization of microstructure during the plastic deformation processes[5].

It is reported that the addition of rare earth elements (RE) can remarkably improve the mechanical properties of magnesium alloys by a solid solution strengthening and a precipitation strengthening[6,7]. It has been found that the Mg-Nd alloys exhibit promising mechanical properties[8]. Samarium (Sm) belongs to the same subgroup as Nd, and the maximum solid solubility of Sm in Mg is 5.7 wt% at 803 K, which is higher than that of Nd (3.6 wt%) in Mg. Therefore, it is reasonable to assume that the Mg-Sm alloys also exhibit good mechanical properties.

The alkaline earth element Ca is often added to magnesium alloys to improve the mechanical properties by the grain refinement and precipitation strengthening of the Mg_2Ca phase[9,10]. In addition, Jun et al.[11] investigated that Ca addition can not only refine the primary α-Mg grains but also increase the thermal stability of the Mg-RE phases in the Mg-Nd-RE-Ca alloys. Accordingly, it can be concluded that Ca may play a beneficial role in the improvement of mechanical properties of Mg-Sm based alloys.

Although some Sm containing magnesium alloys have been developed, the investigation on the effect of Ca addition on the microstructure and the mechanical properties of Mg-Sm alloys has not been reported yet until now. In the present work, the microstructure and the mechanical properties of Mg-4.0Sm-*x*Ca (*x*=0.5, 1.0, 1.5, wt%) alloys extruded followed by isothermal aging at 200

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^{o}C were investigated, and the corresponding strengthening mechanism was discussed.

1 Experiment

The alloy ingots with nominal compositions shown in Table 1 were prepared from high purity Mg (>99.95%) and master alloys of Mg-25% Ca (wt%) and Mg-25% Sm (wt%) by melting in an electric resistance furnace at about 730 ^{o}C under the mixed gas of CO_2 and SF_6 with the ratio of 99:1. As-cast ingots with 80 mm in diameter and 110 mm in length were homogenized at 500 ^{o}C for 24 h followed by quenching in water of 70~80 ^{o}C, and then were hot extruded at 460 ^{o}C into rods of 16 mm in diameter with an extrusion ratio of 25:1. The aging treatment was carried out at 200 ^{o}C for 170 h in an electric furnace. In the present experiment, the aging treatment was immediately carried out after extrusion, and the T5 condition means the peak-aged state. Vickers hardness (HV) was measured at the loading force of 100 g and the holding time of 20 s.

The microstructures of the alloys were examined by an optical microscope (OM, Nikon) and a scanning electron microscope (SEM, S4800) equipped with an energy dispersive X-ray spectrometer (EDS). The metallographic specimens were mechanically polished and etched by immersing for 3~5 s in a solution of 10 mL acetic acid, 5 g picric acid, 10 mL distilled water, and 85 mL ethanol. The grain sizes were measured using a linear intercept method in the OM micrographs. The overall phase constitution analyses were identified by X-ray diffractometer (XRD, Y-2000) with Cu-Kα radiation. The flat dog-boned specimens for tensile tests had 14 mm in gauge length and 3 mm×2 mm in a cross section. The tensile axis was aligned parallel to the extrusion direction. The tests were conducted on a universal testing machine (Instron1121) at ambient temperature with an initial strain rate of 1.0×10^{-3} s^{-1}. The ultimate tensile strength (UTS), 0.2% yield strength (YS) and elongation to fracture were obtained based on the average value of three tests.

2 Results and Discussion

2.1 Effects of Ca on microstructure

Fig.1 shows the optical micrographs of alloys as the extruded state and the peak-aged state. The alloys are mainly composed of equiaxial grains. Compared with the extruded alloy, the average grain size of the peak-aged one increases slightly. The average grain sizes of the alloys as the two states are listed in Table 2.

Fig.2 shows the XRD patterns of the peak-aged alloys. As shown in Fig.2, the alloys are mainly composed of α-Mg, $Mg_{41}Sm_5$ and Mg_2Ca phases. Furthermore, it is found that the diffraction peaks of the Mg_2Ca phase are not observed in S1 alloy. The absence of the Mg_2Ca phase is ascribed to the relatively small amount of Ca in S1 alloy.

As shown in Fig.1, the Ca content has a great effect on grain size of alloys. Under T5 condition, the average grain sizes of the S1, S2 and S3 alloys are about 10.2, 5.1 and 11.0 μm, respectively. When the content of Ca increases to

Table 1 Nominal chemical composition of alloys (wt%)

Alloy	Sm	Ca	Mg
S1	4.0	0.5	Bal.
S2	4.0	1.0	Bal.
S3	4.0	1.5	Bal.

Table 2 Average grain sizes of the alloys for different states (μm)

Alloy	Extruded state	Peak ageing state
S1	8.6	10.2
S2	4.2	5.1
S3	9.1	11.0

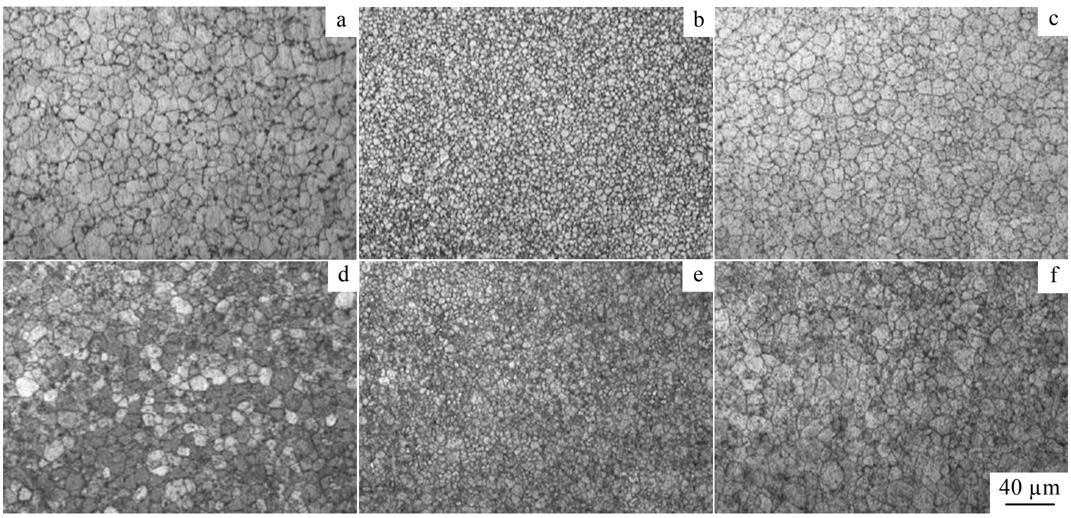

Fig.1 Optical micrographs of Mg-Sm-Ca alloys: (a) S1 alloy as extruded state, (b) S2 alloy as extruded state, (c) S3 alloy as extruded state, (d) S1 alloy as peak aged state, (e) S2 alloy as peak aged state, and (f) S3 alloy as peak aged state