Effect of Alloy Contents on Shrinkage Porosity Defects in Mg-*x*Y Cast Alloys

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Abstract: As a common defect in cast magnesium alloys, shrinkage porosities can greatly deteriorate material properties. In this study, Mg-xY binary alloys with x ranging from 0.5 wt.% to 19.0 wt.% are investigated. Results show that the porosity distribution is uneven and the morphologies are diverse. As the Y content increases, the porosity tendency of Mg-xY alloys initially rises then declines. The increased Y content refines the grain size and increases the eutectic content, which bolsters resistance to solidification shrinkage and promotes liquid feeding. The shrinkage porosity tendency is lowered after reaching the extreme. Besides, raising Y content reduces the liquidus temperature, while the solidus temperature remains constant, resulting in decreasing solidification temperature range.

Keywords: Mg-Y alloy; Shrinkage porosity; Solidification behavior; Microstructure

1 Introduction

Most magnesium alloy products are shaped through casting processes [1]. Because of wide solidification range and significant volume shrinkage, magnesium alloys are highly prone to shrinkage porosities [2]. Forming at late solidification, shrinkage porosities result from insufficient liquid feeding, which greatly deteriorates material properties [3].

Formation tendency of shrinkage porosities varies with alloy compositions. This paper focuses on the influence of alloy contents on shrinkage porosities by exploring microstructure evolution and solidification behavior in Mg-*x*Y alloys.

2 Experimental procedure

Pure Mg (99.99 wt.%) and Mg-30Y (wt.%) master alloy were used to prepare Mg-*x*Y binary alloys. The actual chemical compositions were listed in Table 1.

Table 1. Compositions of Mg-xY cast alloys (wt.%)

x =	0.5	2	5	7
Mg	Bal.	Bal.	Bal.	Bal.
Y	0.51	2.03	4.80	6.92
x =	10	13	16	19
Mg	Bal.	Bal.	Bal.	Bal.
Y	10.23	13.11	16.07	19.13

Phase analysis was conducted using a Rigaku D/MAX-2500PC X-ray diffractometer (XRD). Micro-Computed Tomography (Micro-CT) analysis was performed using a Phoenix Nanotom m device. Phase diagrams and solidification curves of Mg-*x*Y alloys were calculated using Pandat thermodynamic software. The solidification behavior was investigated using a Differential Scanning Calorimeter (DSC) with a STA 449F3 synchronous thermal analyzer produced by NETZSCH. Computer-aided cooling curve analysis (CA-CCA) was performed using a dual thermocouple thermal analysis device.

3 Result and discussion

Fig. 1 shows the number of shrinkage porosities in Mg-*x*Y alloys. As the Y content increases, the shrinkage tendency of Mg-*x*Y alloys initially rises and then declines.

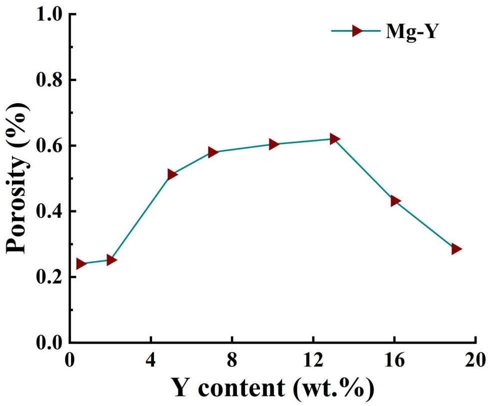

Fig. 1. The number of shrinkage porosities vs Y content.

Fig. 2 shows the micro-CT slice images of Mg-13.0Y alloy. Fig. 3 presents the 3D characteristics of shrinkage porosities. Larger porosities have complex and irregular shapes, while smaller ones tend to be spherical. Fig. 3(b) illustrates the size distribution of porosities. Accordingly, shrinkage porosities exhibit large size and complex morphology characteristics.

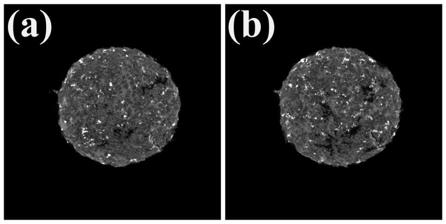

Fig. 2. Selected CT sections of shrinkage porosities in Mg-13.0Y alloy. (a)-(b) Different sections.

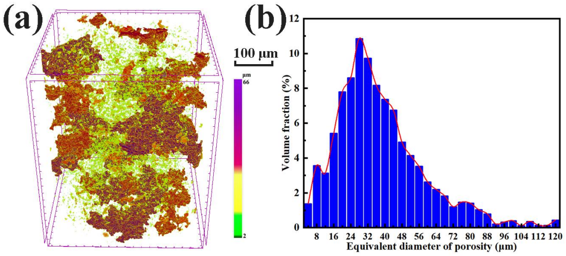

Fig. 3. Shrinkage porosity morphologies in Mg-13.0Y alloy. (a) 3D reconfiguration; (b) Quantitative statistics.

Table 2 lists the volume fraction of the secondary phase in Mg-*x*Y alloys, showing a positive correlation between eutectic content and Y content.

The Y addition promotes formation of the secondary phase, reduces dendrite spacing, and effectively refines the grain. With the increase of Y content, T_l, T_s, and ΔT show similar trends. As ΔT decreases, the coexistence time of solid and liquid phases is shortened, resulting in reduced solidification shrinkage and decreased formation tendency of shrinkage porosities.

Table 2. Volume fraction of the secondary phase in Mg-xY alloys (%)

x =	0.5	2	5	7
f (%)	0.048	0.234	0.334	1.174
x =	10	13	16	19
f (%)	5.224	10.050	16.384	31.096

The XRD patterns of Mg-*x*Y alloys are shown in Fig. 4. Table 3 summarizes the liquidus temperature (T_l), the solidus temperature (T_s), and the solidification temperature range (ΔT) of Mg-*x*Y alloys based on the thermodynamic calculation, DSC, and CA-CCA.

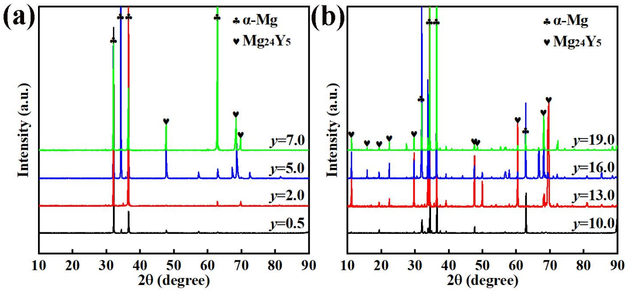

Fig. 4. XRD patterns of Mg-*x*Y alloys: (a) *x*=0.5-7.0; (b) *x*=10.0-19.0.

Table 3. Liquidus temperature, solidus temperature, and solidification range of Mg-xY alloys calculated by Scheil model, DSC, and CA-CCA (℃)

Alloy	T_l	T_s	ΔT
Mg-0.5Y	648	574	74
Mg-2.0Y	645	574	71
Mg-5.0Y	639	574	64
Mg-7.0Y	634	574	59
Mg-10.0Y	626	574	51
Mg-13.0Y	617	574	42
Mg-16.0Y	607	574	32
Mg-19.0Y	596	574	21

Conclusion

(1) Shrinkage tendency in Mg-*x*Y alloys follows a "Λ" pattern with increasing Y content, initially rising and then declining. Increasing Y content results in grain refinement and increased eutectic phase. This enhances resistance against solidification shrinkage.

(2) Increasing Y content decreases T_l while T_s remains constant, reducing ΔT and shrinkage tendency. The Y addition promotes formation of secondary phase, promotes liquid feeding and reducing porosity defects.

Acknowledgments

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