

Damping Properties of As-Cast Mg-Zn-Y Alloy with *I* Phase

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Abstract: A conventional casting method was adopted to fabricate the alloys of Mg-Zn-Y, in which the dendritic morphology and its relation to the damping properties of as-cast Mg-Zn-Y alloy were studied based on the typical Mg₉₃Zn₆Y₁ alloy containing icosahedral quasicrystal phase. By controlling the pouring temperature, the stirring speed and stirring time, the dendritic morphology with different parameters was obtained. The results show that the microstructure of the as-cast Mg₉₃Zn₆Y₁ mainly consists of α -Mg dendritic crystal and icosahedral quasicrystal phase. After stirring, the primary α -Mg dendritic gradually have fractal characteristics in faith, and its size changes, affecting the damping capacity. The mechanism was discussed.

Key words: Mg-Zn-Y alloy; dendritic morphology; quasicrystal phase; damping properties

Magnesium alloys have become more and more important, which never fail to fascinate scholars, because of their low density, high specific strength and elastic modulus and high recycling efficiency^[1]. When the first remarkable discovery of the icosahedral quasicrystal phase (*I* phase) was in the rapid/solidified Al₈₄Mn₁₆ alloy studied by Shechtman^[2], intensive investigations have been carried out to study the alloy systems with compositions for the formation of icosahedral phases. However, most of the *I* phases are metastable phase, even though the *I* phase is brittle, they exhibit interesting properties such as high strength and hardness, low friction coefficient, and low interfacial energy. Fortunately, thermally stable *I* phase has been reported to form in the Mg-Zn-Y alloy system^[3,4].

Recently, according to the existing works, in which it is determined that isothermal section of Mg-Zn-Y equilibrium phase diagram involved the *I* phase, quasicrystals in Mg-rich Mg-Zn-Y alloys are of technological interest since they can be used as a strengthening phase in the metallic alloys due to their high strength at ambient and elevated temperatures. As the important and significant quasicrystal phase case stands, this work aims to conduct a study on the dendritic

morphology and its relation to the damping properties of as-cast Mg-Zn-Y alloy involving quasicrystal by controlling casting parameters including the pouring temperature, the stirring speed and the stirring time.

1 Experiment

The tested alloy for this study was Mg₉₃Zn₆Y₁ alloy (in atomic percentage). The alloy was fabricated by melting from pure magnesium (99.9%), yttrium for Mg-25wt%Y master alloy and pure Zn (99.90%) as the raw material. The melt was poured into the metallic model for cooling after melting under the protection against CO₂+0.5vol%SF₆ mixed gas. Samples were prepared with different pouring temperatures (680~740 °C), different stirring speeds (900 and 540 r/min) and different stirring time. The microstructure of specimens was observed by optical microscope (OM) and the transmission electron microscope (TEM). Rectangular bending beam specimens with dimensions 50 mm×5 mm×1 mm for damping capacity measurements were machined using an electric spark cutting method. The damping capacity was measured at a measurement frequency of 1 Hz by an inverted torsion pendulum (TPA-8) at room temperature.

Received date: January 08, 2018

Foundation item: National Natural Science Foundation of China (51361010, 51665012); Natural Science Foundation of Jiangxi Province (196 20114BAB216015); Jiangxi Province Science Foundation for Outstanding Scholarship (20171BCB23061); the Foundation of Jiangxi Educational Committee (GJJ12320) and the State Key Laboratory of Solidification Processing in NWPU (SKLSP201321)

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2 Result and Discussion

2.1 Microstructure

Fig.1 shows the microstructures of cast Mg93Zn6Y1 alloy at the pouring temperature from 680 °C to 740 °C. It could be noticed from Fig.1 that the microstructures consist of two parts, i.e. α -Mg matrix and the specific phases; in which, the α -Mg dendritic crystal could be observed obviously and the specific phase located among the interdendritic. In the solidification process, Zn and Y atoms were excreted to the solid-liquid interface, so that the solute enrichment occurred in the front of the solid-liquid interface, resulting in the formation of constitutional supercooling zone. And with the increase of constitutional supercooling, when a part of the interface grew faster and protruded occasionally, it would extend into a liquid with high degree of supercooling, which was more conducive to the growth of the protruding tip toward the liquid. And then the side branches were also developed, so as to form a dendritic skeleton, that is, dendrites. At the late stage of dendritic growth, the quasicrystal phase was formed when the mushy zone between the dendrites satisfied a certain solute condition. A fact that the size of the dendrite became firstly from coarse to fine, then from fine to coarse could be obtained. The size of dendrite at pouring temperature (720 °C) was the finest among the samples. The phenomenon could be attributed to the process of crystallization, which in fact includes the process of nucleation and growth. As for this study, the solidification process would be affected when the pouring temperature changed.

As we know, the liquid alloy is the most subtle at 720 °C (Mg93Zn6Y1 liquidus temperature range). When the pouring temperature is below the liquidus, the higher the temperature is, the more intensely the atom diffuses, the higher the crystallization nucleation rate is. At the same time, the higher the temperature, the lower the viscosity and the surface tension of the alloy melt; the flow rate and the filling time of the alloy are increased, thereby improving the fluidity of the alloy. On the contrary, when the pouring temperature is above the liquidus, although the cooling rate is large enough and the overheat degree of metal is also relatively large, the nucleation rate is lower, the growth of crystal nucleus is inhibited, resulting in coarse dendritic. When the pouring temperature is too high, the oxidation tendency of the alloy is significantly increased, and the viscosity of the alloy increases, resulting in a decrease in the flow rate. The size of the secondary arm spacing directly affects the mechanical properties of castings. For the dendrites, the secondary dendrite arm spacing can reflect the degree of refinement of alloys. The secondary dendrite arm spacing sizes at different temperatures are shown in Fig.2.

Fig.3 is a transmission electron micrograph of the as-cast alloy and its corresponding SAED patterns. The specific phase is proved to be quasicrystal phase by analyzing the specific phase morphology of the as-cast alloy and its corresponding diffraction spots. The fivefold rotational symmetry is the most significant characteristic of the icosahedral quasicrystal, which is different from the conventional crystal. Fig.3b, 3c and 3d of the constitutive

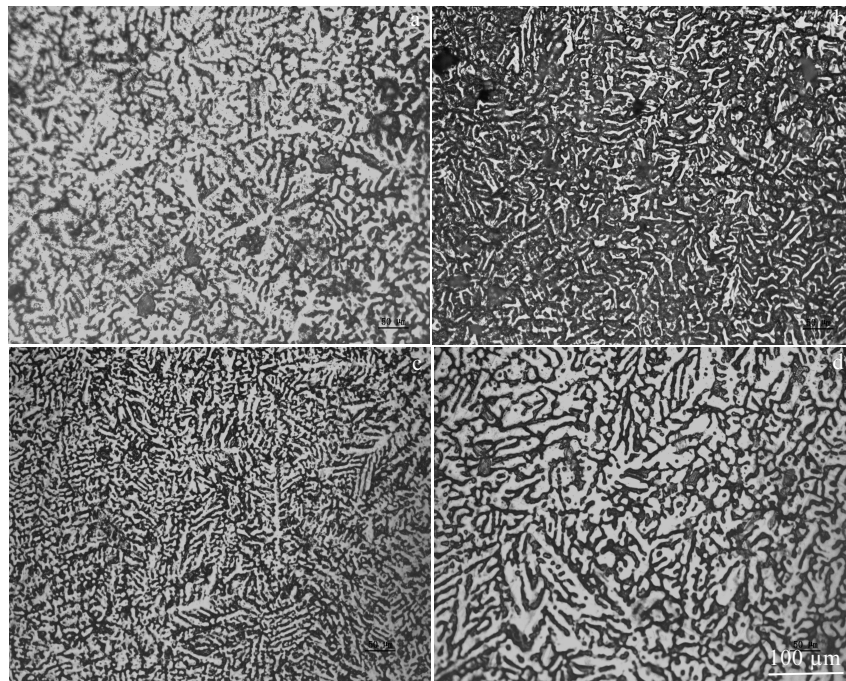


Fig.1 Microstructures of alloys at different temperatures: (a) 680 °C, (b) 700 °C, (c) 720 °C, and (d) 740 °C

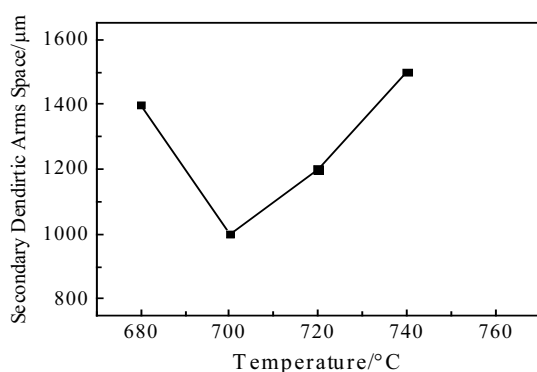


Fig.2 Size of secondary dendrite arm spacing at different temperatures

electron diffraction spots corresponding to Fig.3a have two-, three- and fivefold rotational symmetry, respectively. It shows that the quasicrystal phase is an icosahedral quasicrystal phase.

Compared with other casting methods, the stirred casting method is the most popular traditional method to prepare high volume fractional particles reinforced metallic matrix composites, which could be used to modify the dendritic morphology. Mechanical stirring casting is often used to produce the semi-solid metals and it is an optimizing method to produce the high performance metals. It can be seen from Fig. 2 that the secondary dendrite arm spacing of the alloy is the smallest when the pouring temperature is 700 °C. Therefore, in the subsequent experiments, the casting temperature was chosen to be 700 °C. At the same time, the stirring time was focused on 30, 60 and 90 s.

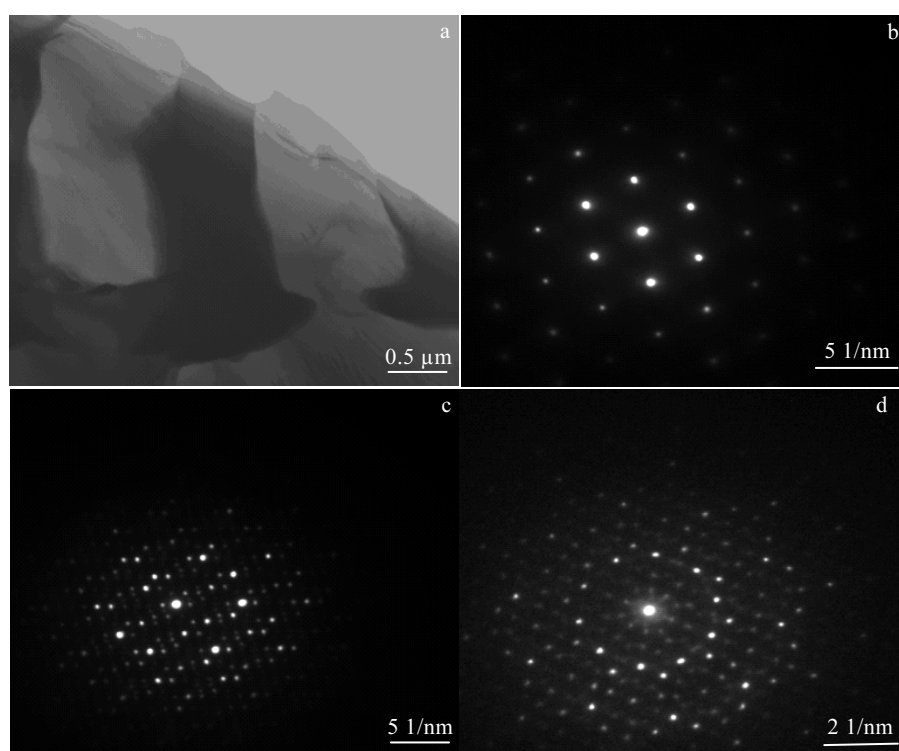


Fig.3 Transmission electron micrograph of the as-cast alloy (a) and its corresponding SAED patterns (b-d)

Fig.4 is the microstructures of as-cast Mg-Zn-Y alloy obtained with different stirring parameters and pouring temperature of 700 °C. The microstructures of alloys were occupied by the dendritic. It can be seen that primary phase morphology in the Mg-Zn-Y alloy obtained by stirring is greater than that before being agitated. Meanwhile, in terms of the high-speed stirring, the longer the stirring time, the finer the dendrite size; at the same stirring speed, the greater the stirring time, the finer the dendrite size, which was also confirmed in other reports^[5-8]. Furthermore, it is indicated that primary phase morphology in Mg-Zn-Y alloy prepared for mechanical stirring casting has fractal

characteristics in faith^[9]. Generally, at the initial stage of solidification, weak interaction is between grains, and the drive force of the dendrite growth is supercooling degree. Influenced by anisotropy of crystal, the grain size is regular hexagons because magnesium alloy has a hexagonal close-packed crystal structure. Then, the dendrite arm gradually developed on the preferentially growing direction of small protuberance. Provided that growth front is unimpeded, the dendrite arm will continue to stretch from the supercooled liquid phase. Therefore, the original symmetric dendrite morphology is partly destroyed, and the irregular dendrite morphology is gradually formed.

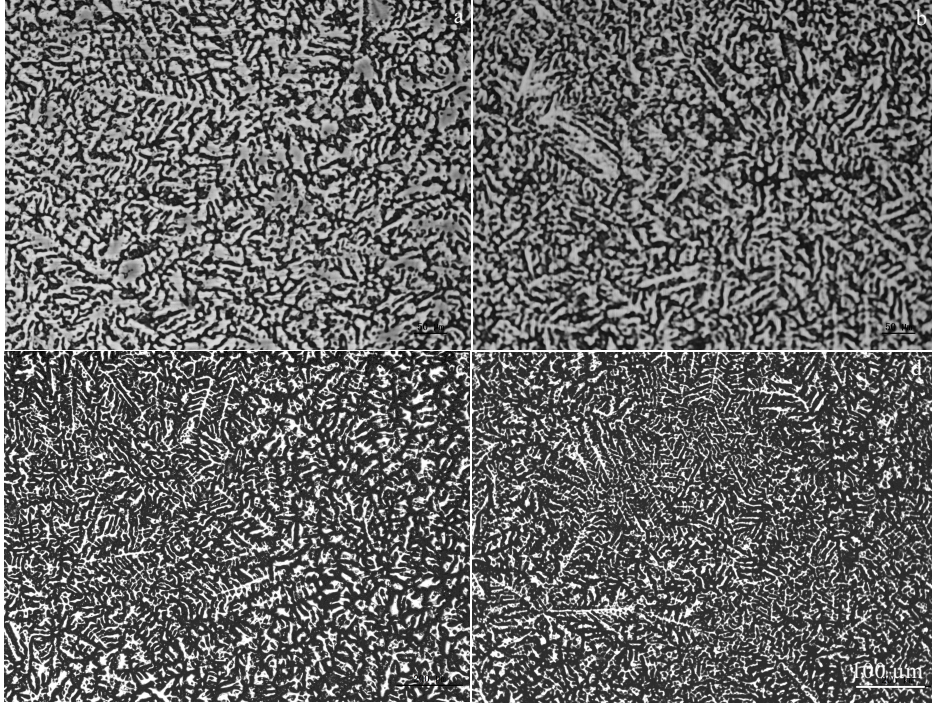


Fig.4 Microstructures of as-cast Mg-Zn-Y alloy obtained under different speeds and time: (a) low speed stirring for 30 s, (b) low speed stirring for 60 s, (c) high speed stirring for 60 s, and (d) high speed stirring for 90 s

2.2 Damping properties

The damping properties at different pouring temperatures are shown in Fig.5. It can be seen that the damping capacity is greatly influenced by the pouring temperature, and there is a significant difference for the dependent part of the strain amplitude. The damping property of the as-cast alloy is the highest at 700°C, but it is very poor at 740°C. The curves contain two parts, strain amplitude independent part and strain dependent part. When the applied stress is low, the dislocation is pinned by the weak pinning points. When the stress increases, dislocation could gradually breakaway from the weak pinners, which is a thermal activation process. The bonding force between solute atoms and dislocation is declined, hence the dislocation departure from the equilibrium position.

According to G-L dislocation pinning model^[10,11], damping capacity of magnesium alloys Q^{-1} can be divided into the strain-amplitude that is weakly dependent on damping Q_1^{-1} and the strain-amplitude that is strongly dependent damping Q_H^{-1} , where dislocation segments bow out between weak pinning points.

$$Q^{-1} = Q_1^{-1} + Q_H^{-1} \quad (1)$$

which contribute to the strain-amplitude that is weakly dependent on damping Q_1^{-1} . Its value can be calculated as:

$$Q_1^{-1} = \frac{B\Delta L_c^4 \omega}{36Gb^2} \quad (2)$$

When the strain amplitude is big enough, the dislocation loops would breakaway from the weak pinning points but still being pinned by strong pinning points, which produce strain-amplitude strongly dependent damping Q_H^{-1} and it can be expressed as:

$$Q_H^{-1} = \frac{C_1}{\varepsilon} \exp\left(-\frac{C_2}{\varepsilon}\right) \quad (3)$$

In which,

$$C_1 = \frac{\rho F_B L_N^3}{6bEL_c^2} \quad (4)$$

$$C_2 = \frac{F_B}{bEL_c} \quad (5)$$

where B is a damping constant for dislocation movement; ω is the angular frequency; G is the shear modulus; b is the Burgers vector of dislocations; F_B is the binding force between a dislocation and a solute atom; E is the Young's modulus; ρ is the density of dislocations participated in the breakaway process; L_c is the average dislocation distance between weak pinning points; L_N is the average dislocation distance between strong pinning points.

The morphology of the α -Mg dendrites appears to have a significant impact on the damping capacity of magnesium

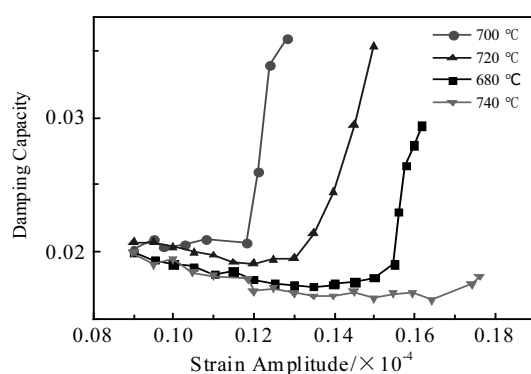


Fig.5 Damping properties of the casting alloys obtained at different pouring temperatures

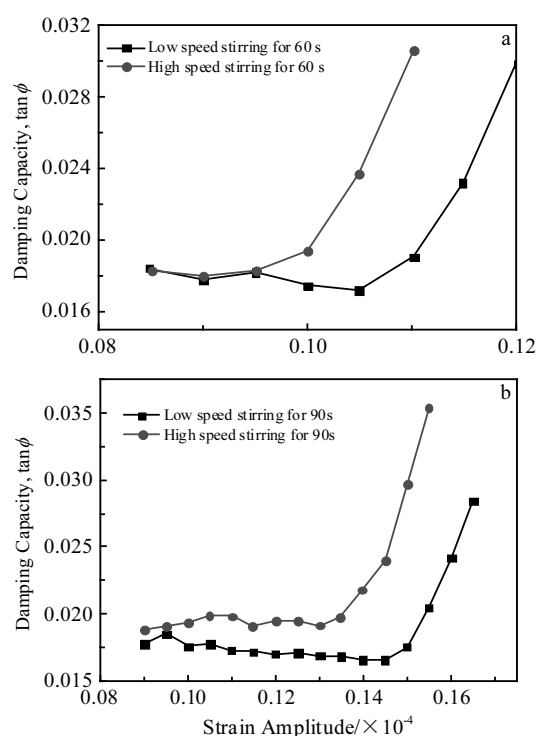


Fig. 6 Damping properties at different stirring rates for different time: (a) 60 s and (b) 90 s

alloys. The primary α -Mg phase with finer size improves the damping properties. This suggests that the amplitude-dependent damping caused by the movement towards the basal dislocations is extremely sensitive to the crystallographic orientation^[12,13]. It has been reported that the primary dendrites of magnesium alloy are responsible for the well-defined amplitude-dependent damping. The mean size of the globular grains must be greater than that about some microns for keeping high damping capacity. If the size is smaller than this value, the dislocation in the magnesium

alloy can not move and breakaway even at high stress levels. However, further additional experiments are still required to determine the details of this physical process. The damping properties at different stirring rates are shown in Fig.6. It could be clearly noticed that the damping property has good performance at high stirring speed; as previously referred, after high speed stirring, the primary dendritic α -Mg gradually became non-dendritic and its size decreased leading to the better damping property. Generally, the interface damping between the matrix and the secondary phase, as well as the occurrence of grain boundary sliding, can effectively ensure the damping capacity^[14-17].

3 Conclusions

- 1) The microstructure of the as-cast Mg93Zn6Y1 mainly consists of α -Mg dendrite and icosahedral phase.
- 2) With respect to the effect of casting temperature on the microstructure, the size of the dendrite of the alloy becomes firstly from coarse to fine, and then from fine to coarse; the size of dendrite of the alloys at casting 720°C is the finest among the several samples.
- 3) With respect to the effect of stirring rate on the microstructure, after high speed stirring, the primary dendritic α -Mg gradually is refined, so the damping property is improved.
- 4) At a certain situation, the finer the grain size is, the more the grain boundary, and thus the damping property of the alloys performs much better.

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含二十面体准晶相的铸态 Mg-Zn-Y 合金阻尼性能的研究

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摘要: 采用传统铸造方法制备Mg-Zn-Y合金, 基于典型的含二十面体准晶相的Mg₉₃Zn₆Y₁合金, 研究了铸态Mg-Zn-Y合金的枝晶形貌与其阻尼性能的关系。通过控制浇注温度、搅拌速度和搅拌时间, 获得不同参数下的合金的枝晶形貌。结果表明, 铸态Mg₉₃Zn₆Y₁的显微组织主要由 α -Mg树枝状晶体和二十面体准晶相组成。搅拌后, 初始 α -Mg树枝状晶体逐渐具有分形特征, 且其尺寸变化, 从而影响合金的阻尼能力。

关键词: Mg-Zn-Y合金; 枝晶形貌; 准晶相; 阻尼性能

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