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Fabrication of AZ61-1.0%Y antiburning magnesium semisolid slurry

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Abstract: The semi-solid antiburning AZ61-1.0%Y magnesium alloy slurry with fine circular solid phase was fabricated by a novel type continuous mechanical stirring in this work. The microstructure of the semisolid slurry was characterized by a metallography microscope. The results show that the fine circular solid phase distributes uniformly in the slurry when the stirring temperature ranges from 600 to 605 ˚C. With the increase of the stirring velocity, the size of the solid phase becomes smaller and smaller. With the increase of the stirring time, the size of solid phase gets finer, but if the stirring time is longer than the critical time, it will be coarsened abnormally. The mechanical properties of semi-solid AZ61-1.0%Y alloy are superior to those of the normally casting magnesium alloy.

Key words: semi-solid; continuous mechanical stir; microstructure; mechanical properties

1 Introduction

Recently, semi-solid forming has been recognized as a novel technology offering several potential advantages over traditional casting or solid state forming, such as producing high quality components capable of full heat treatment to maximize properties, reducing macrosegregation, solidification shrinkage forming temperature[1−4]. The key factor controlling both the flow of a slurry and the product properties is the equiaxed, non-dendritic microstructure that behaves thixotropically and forms into a net shape[5−6]. As a result, the major effort of all the semi-solid methods is focused on the generation of globular structures[7−10].

Typical non-dendritic microstructure is constituted of solid phase globules suspending in the liquid phase [2,5]. It is now well demonstrated that this thixotropic microstructure, which is very different from that obtained during conventional solidification, can be produced either during solidification or partial remelting of the material after prior solidification[3]. A shear action, such as mechanical stirring[11−12], ultrasonic and electro-magnetic stirring[13−15], during solidification of alloys destroys the forming dendrites, thus leads to globules of the primary solid phase suspended in the liquid. In traditional mechanical stirring methods, the metal melting and stirring technique are carried out in the same furnace, which needs a long cycle period and high cost for the melting and stirring at different temperatures. Accordingly, the continuous mechanical stirring technology is developed and the microstructure and mechanical properties are investigated in this work.

2 Experimental

2.1 Fabrication of antiburning magnesium

AZ61 magnesium alloy which covers a broad range of commercial usage, has high corrosion resistance, and the composition is shown in Table 1. When 1.0% (mass fraction) yttrium was added into AZ61 magnesium alloy, the magnesium alloy with super antiburning characteristic and mechanical properties was fabricated. The magnesium containing 1% yttrium was attained based on AZ61-30%Y intermediate alloy. First, AZ61 magnesium alloy and the intermediate alloy were

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Table 1 Chemical compositions of AZ61 magnesium alloy (mass fraction, %)

Al	Mn	Zn	Si	Cu	Ni	Fe	Others	Mg
5.8−7.2	>0.15	0.40−1.5	0.10	0.05	0.005	0.005	0.30	Bal.

preheated to 300 ˚C after eliminating the oxide and smudginess on the magnesium ingot surface. Then, in order to prevent magnesium alloy from burning, the cover agent was put on the surface of melt magnesium alloy, and argon was poured into the furnace synchronously when the retreated AZ61 magnesium alloy and inter-mediate alloy was heated to 550 ˚C. It was cast into the steel mould after the magnesium was heated to the critical temperature and held for a period of time, then the preparation of antiburning magnesium was accomplished. The wide semi-solid temperature range from 525 to 625 ˚C ensures the semi-solid forming.

The antiburning AZ61-1.0%Y magnesium semisolid slurry was achieved with a novel continuous mechanical stir method. The equipment applied in the experiment is illustrated in Fig.1. It mainly consists of the melting furnace, the stirring chamber and the inert gas supply tube. The antiburning magnesium alloy was heated to 650 ˚C and modified for 30 min, then the furnace was turned off. When the molten magnesium alloy is cooled to 625 ˚C, the piston on the bottom of the furnace is pulled out, and the liquid alloy is poured into the stirring chamber. At the same time, the argon inert gas is introduced into the stirring chamber. At the beginning of the stirring, the temperature decreases slowly to the appointed temperature of the stirring chamber. Finally, the semisolid slurry is poured into the mould through the casting tube.

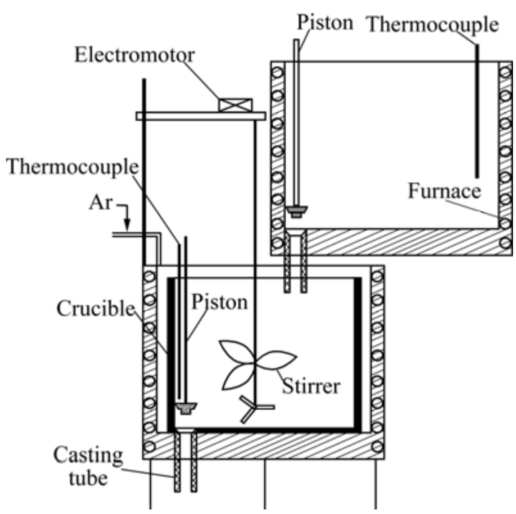

Fig.1 Novel continuous semi-solid mechanical stirring equipment

The specimen was observed on an optical microscope. The tensile properties was obtained on an electronic test machine.

3 Result and discussion

3.1 Microstructure

The effect of the stirring temperature on the semisolid microstructure of AZ61-1.0%Y magnesium alloy is shown in Fig.2. The semi-solid microstructure contains the approximate circular white solid phase α-Mg and the gray liquid phase with dendrite shape which is the eutectic microstructure made up of α-Mg and β-$Mg_{17}Al_{12}$. The stirring temperature plays an important role in the morphology of the semisolid microstructure of antiburning magnesium alloy. When the temperature reaches 595 ˚C, the circular solid phase distributes as conglomerations in the alloy, and the solid phase is coarse and anomalous (as shown in Fig.2(a)). When the stirring temperature is lower, the high content of the solid phase blocks severely the movement of the stirrer. So, the stirrer cannot easily break the dendrites of the α-Mg, the perfect circular shape of solid phase cannot be formed. With the increase of the stirring temperature, the morphology of solid phase becomes fine at 600−605 ˚C. The perfect solid phase with small size distributes uniformly in the alloy when the stirring temperature increases to 600 ˚C and 605 ˚C (Figs.2(b) and (c)). But the solid phase at 610 ˚C is not better than that of 600 ˚C, since with the decrease of the volume fraction of solid phase, the probability of the collision between the solid phase and the stirrer decreases. In addition, with the increase of temperature, the dendrite is easily shaped because the instability and the low viscidity of liquid alloy reduce the friction of the liquid phase on the solid phase. Therefore, arms of the dendrite exist easily in the alloy. Consequently, the stirring temperature between 600 and 605 ˚C is the most favorite.

With the increase of the stirring velocity, the size of the solid phase α-Mg becomes smaller; the shape is rounder and the solid phase distributes more uniformly, as shown in Fig.3. The collision chance between the solid phase and stirrer increases when the velocity is enhanced, so the high velocity stir is favored to form small solid phase. But high velocity needs more power, which increases the cost consequently. Furthermore, the high velocity of the stirrer makes the gas wrap in the liquid magnesium alloy, which decreases the properties of magnesium. When the velocity is 100 r/min, the primary α-Mg has the rosebush shape for the growing velocity of the dendrite is higher than that of the

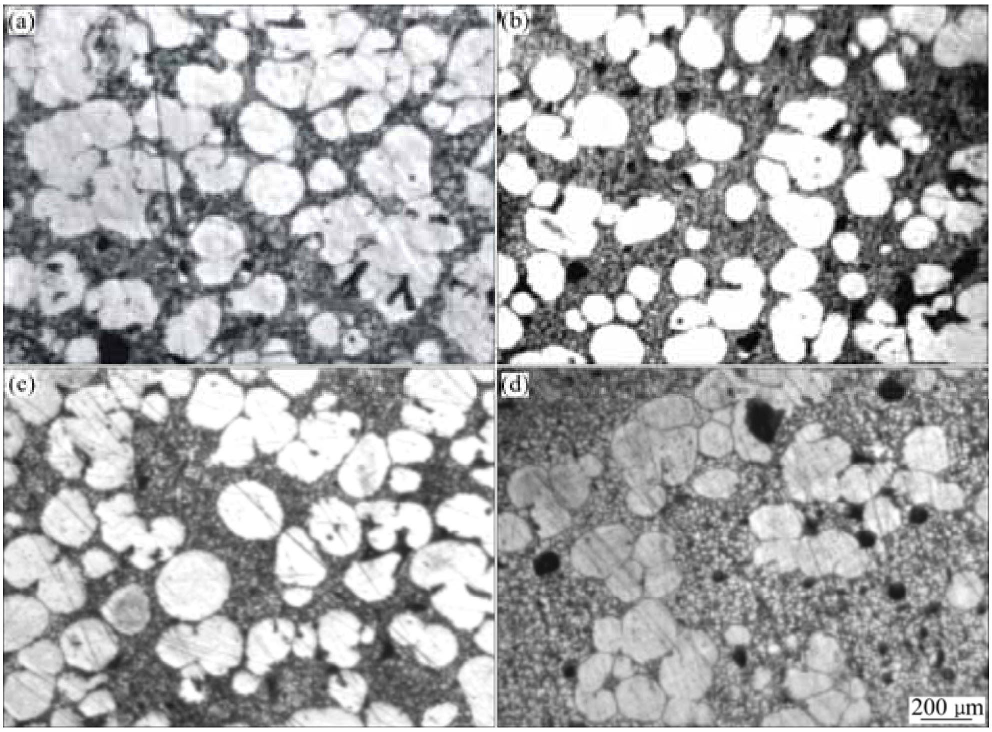

Fig.2 Semi-solid microstructures of AZ61-1.0%Y magnesium alloy with different stirring temperatures: (a) 595 ˚C; (b) 600 ˚C; (c) 605 ˚C; (d) 610 ˚C

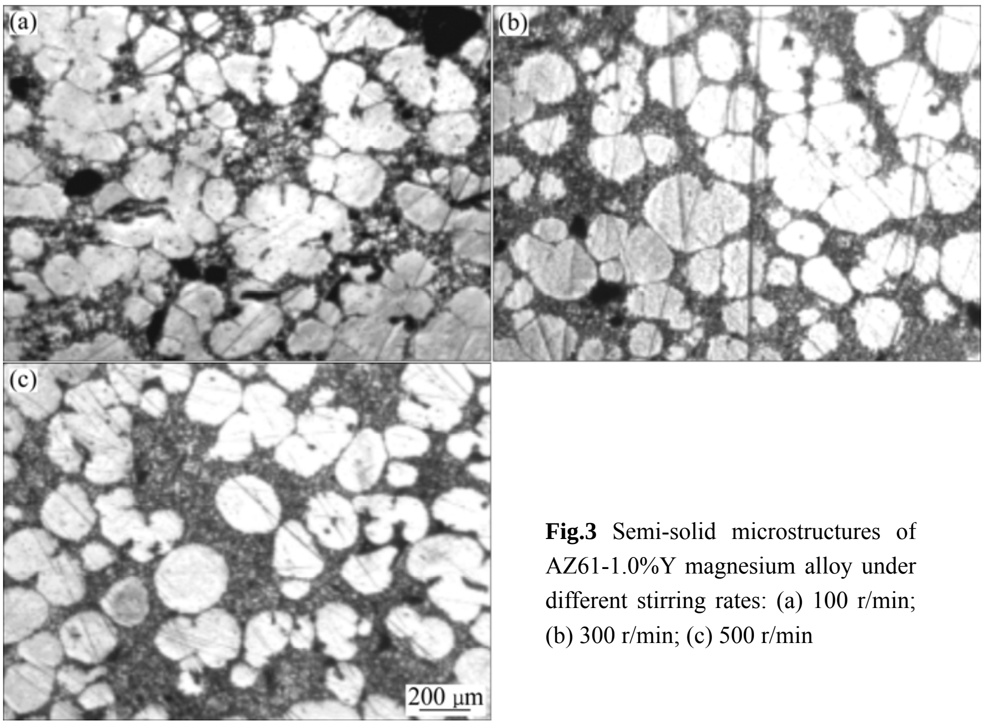

Fig.3 Semi-solid microstructures of AZ61-1.0%Y magnesium alloy under different stirring rates: (a) 100 r/min; (b) 300 r/min; (c) 500 r/min

break of the dendrite arms, so the low velocity cannot meet the need of the favorite semisolid slurry.

When the liquid magnesium alloy is not stirred, the microstructure is in the typical dendrite casting state, as shown in Fig.4(a). But when the magnesium is treated by continuous mechanical stirring, the dendrite arms are broken and the residual dendrites become circle-shaped in order to reduce the surface energy of a single grain, so the root of dendrite is wrapped into the inside of the grain. Since one minute is not enough to form a whole grain by the diffusion of the atom, the grain shape is like a rosebush. With the increase of the stirring time, the

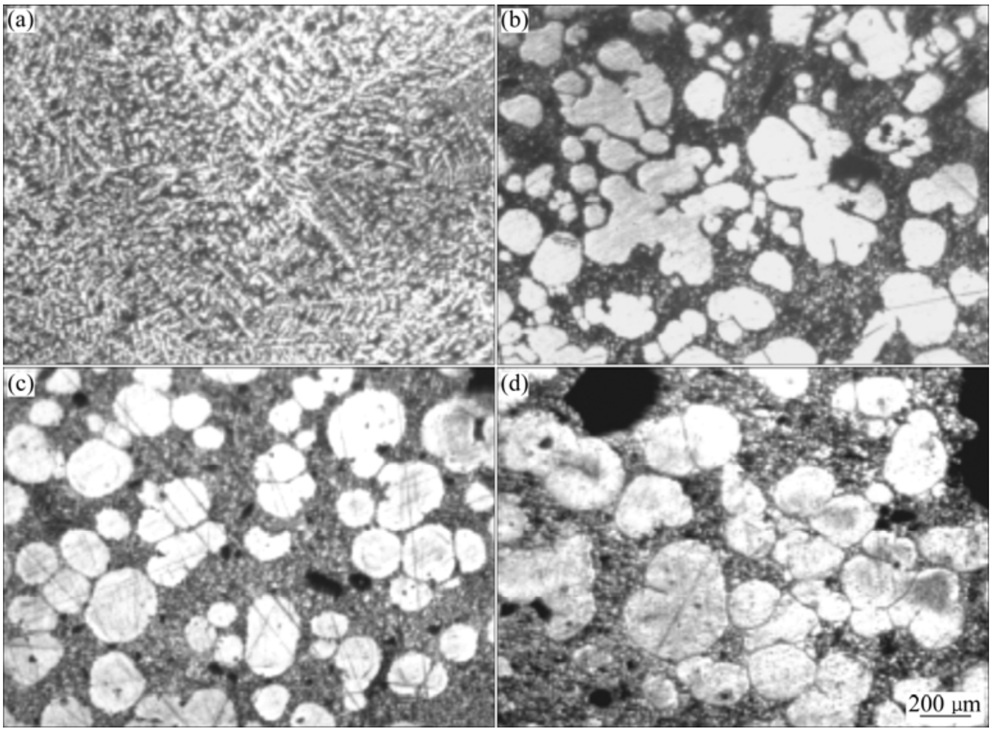

Fig.4 Semi-solid microstructures of AZ61-1.0%Y magnesium alloy with different stirring time: (a) 0 min; (b) 1 min; (c) 10 min; (d) 20 min

grains are broken into fragments, so the size of the grain is small. When the stirring time is about 10 min, the solid phase of fine grains in circle shape distributes in the slurry uniformly, which is necessary for the advance materials. The solid phase grain becomes larger and larger while the stirring time is longer than 10 min. The reason is that the stirrer cannot break the fine circle grains for the grain has stable structure and high strength. At the same time, the grain is impossible to break itself because it has little inner flaw and disadvantage contour. Otherwise, the stable grain may catch many small solid phase to form a bulky grain and the bulky grain is likely to congregate because of its weight. So, with the increase of the stirring time, the size of solid phase grain reaches a minimum value.

3.2 Mechanical properties

The tensile strength at room temperature of AZ61-1.0%Y is shown in Table 2. The ultimate strength and the ductility of the magnesium alloy with semi-solid microstructure is higher than those of casting alloy. The alloy with semi-solid microstructure contains the circle solid phase α-Mg and fine dendrite with the composition of the liquid phase. According to the fundamental of metal forming, the deformation includes the major forming cross the grain and the minor one among the grains. Slide in metal which is the main way of the metal plastic deformation occurs in the low strength region. Accordingly, in the semi-solid alloy, the deformation takes place at the liquid phase since the strength of solid phase is higher than that of the liquid phase region. The strength increases with the decrease of the size of the grain. Thus, the strength and ductility of the magnesium alloy with semi-solid microstructure is higher than those of the casting alloy because the size of dendrite grains of the former are smaller than that of the latter. Further more, the circle solid phase grain eliminates the stress concentration and the casting defect, which increases the strength of the metal materials.

Table 2 Tensile properties of alloys at room temperature

Specimen	σ_b/MPa	δ/%
Casting state	179.32	5.02
Semi-solid state	196.45	5.85

4 Conclusions

1) The semi-solid antiburning AZ61-1.0%Y magnesium alloy slurry with fine circular solid phase was fabricated by a novel continuous mechanical stirring.

2) The fine circular solid phase distributes uniformly in the slurry when the stirring temperature ranges from 600 ˚C to 605 ˚C. With the increase of the

stirring velocity, the size of solid phase gets smaller and smaller. With the increase of the stirring time, the size of solid phase gets small, but if the stirring time is longer than the critical time, solid phase coarsens abnormally.

3) The mechanical properties of the semi-solid AZ61-1.0%Y alloy is superior to those of the normally casting magnesium alloy.

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