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Study on the fluidity of AZ91 + xRE magnesium alloy

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Abstract

Influence of section thickness, pouring temperature, mould temperature and content of rare earth (RE) element on the fluidity of AZ91 magnesium alloy has been studied through fluidity specimens with different section thickness cast in metal mould. The results show that the relation curve of filling length versus section thickness can be divided into two parts: (i) the filling length in the thin section increases slowly with increasing section thickness, after a critical thickness; and (ii) the filling length in the thick section increases rapidly with increasing section thickness. Elevating the pouring temperature has little influence on the fluidity in the thin section, but increases the filling length in the thick section remarkably. As mould temperature increases, the fluidity in the thin section increases a little, but the fluidity in the thick section rapidly increases. As RE content increases, the fluidity in the thin section changes from increasing to decreasing, and the fluidity in the thick section changes from increasing to decreasing, and to increasing again. Moreover, the critical thickness separating region of thin and thickness section behavior moves to higher values.

Keywords: Magnesium alloy; Rare earth; Fluidity

1. Introduction

In order to save materials and energy, the study and development on light and thin wall castings has been an important research field and developing direction [1–3]. As the lightest metal structure material, magnesium alloy has low density, high specific strength and specific stiffness, good damping characteristic, excellent machineability and castability, etc. So more and more magnesium alloy products have been used in automobile, communication and aerospace industries [4–7]. Especially, thin wall magnesium alloy castings such as a shell of portable computer, mobile telephone and camera have showed a promising future [8]. But first of all, the production of thin wall castings requires the molten metal having a good filling ability. At present, little has been known about the fluidity of magnesium alloy [9]. Therefore, it is of great importance to study the influence rule of different casting conditions on the fluidity of magnesium alloy with different section thickness.

AZ91 magnesium alloy is the most extensively used magnesium alloy at present, which has good comprehensive mechanical and casting properties, and rare earth elements are useful in increasing the mechanical properties [10–12] and fluidity [13,14] of magnesium alloy. Therefore, groove fluidity specimens were cast in metal moulds under different conditions of pouring temperature, mould temperature, and rare earth (RE) content, and the fluidity of AZ91 magnesium alloy with different section thickness have been studied.

2. Experimental procedure

AZ91 magnesium alloy was re-melted in an electric furnace with a capacity of 20 kg. After the alloy ingot was melted, cerium-rich RE with a size of about 5 × 5 mm was added into the melt between 600 and 650°C, and the melt was refined with JDMJ refining flux (mainly chlorate) at 720–730°C. Keep the melt killing

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for some 20 min, then adjust it to different pouring temperature. The magnesium alloys used were AZ91, AZ91 + 0.93 wt.% RE, AZ91 + 1.88 wt.% RE, and AZ91 + 2.87 wt.% RE (separately call them as AZ91, AZ91 + 1RE, AZ91 + 2RE, AZ91 + 3RE as follows).

Groove fluidity specimen was cast and the filling length of groove with a different thickness was taken as the index of fluidity, and the data of fluidity are the average of two to three measured values (the experimental conditions are taken as approximately the same when pouring temperature and mould temperature is ± 10°C). The shape of fluidity specimen and the metal mould is shown in Fig. 1. Eight grooves with width of 10 mm, length of 120 mm, and thickness of 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5 and 4.0 mm, are radially and symmetrically around the downsprue. Before pouring, the mould was coated with a thin layer of releasing agent for die casting, preheated and kept under a different temperature in an oven, and the mould temperature was measured by a surface thermometer.

In order to precisely control the temperature, volume and pressure head of the melt, a pouring system with a non-bottom heating furnace was designed. A constant quantity of melt was poured into a crucible, the crucible was put in the non-bottom furnace with a temperature control system; there is a hole ϕ 30 mm in the bottom of the crucible that was plugged up with a stopper. The metal mould was just under the crucible

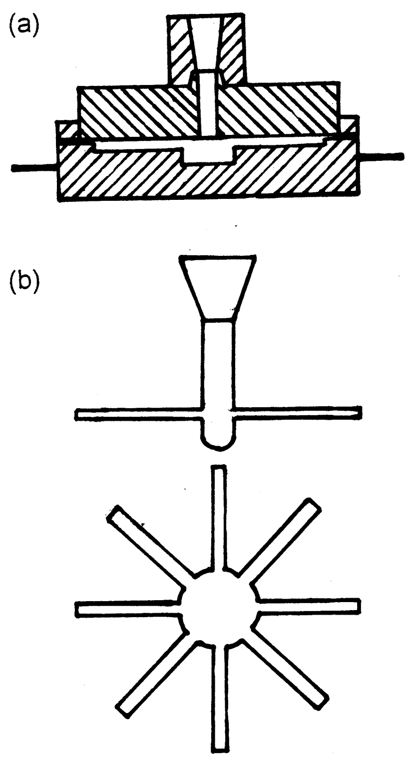

Fig. 1. Fluidity sample and its metal mould: (a) metal mould; and (b) fluidity sample.

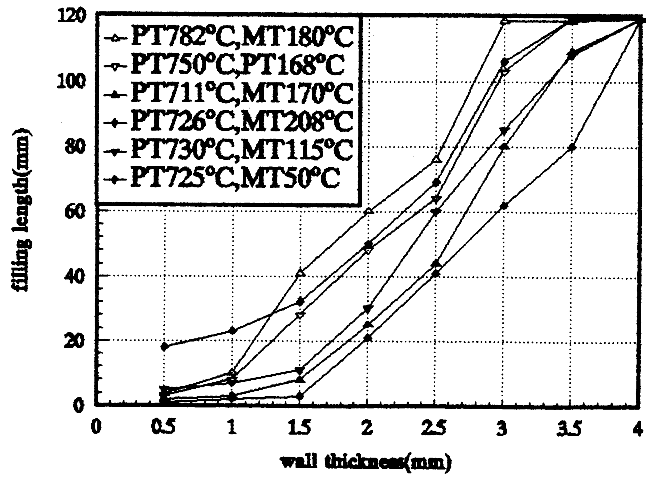

Fig. 2. Fluidity of AZ91 magnesium alloy.

and the center of the pouring cup was aimed at the hole in the bottom of the crucible. The height between the top surface of mould and the bottom of crucible is adjustable, i.e. the pressure head of molten metal can be adjusted. The pressure head was 80 mm in this study. What we need to do is to raise the stopper during pouring process.

Cover flux was used to prevent the melt surface during melting and pouring.

3. Experimental results

3.1. Influence of section thickness on fluidity

The testing results of the fluidity of AZ91, AZ91 + 1RE, AZ91 + 2RE, AZ91 + 3RE magnesium alloys are shown in Figs. 2–5, which indicates the filling length changes with section thickness under different pouring temperatures (PT) and different mould temperatures

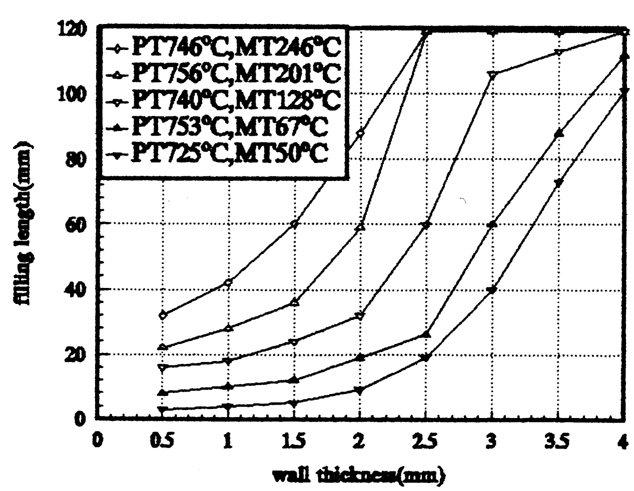

Fig. 3. Fluidity of AZ91 + 1RE magnesium alloy.

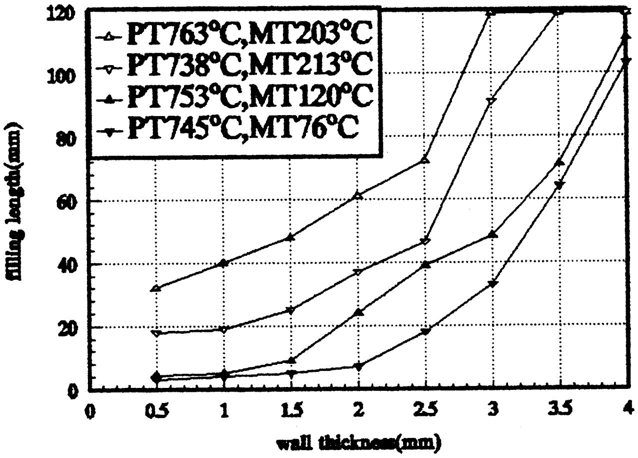

Fig. 4. Fluidity of AZ91 + 2RE magnesium alloy.

(MT). As can be seen, every curve can be approximately divided into two parts, namely the thick section part and the thin section part. The filling length increases slowly with the increasing of section thickness in the thin section part, but increases rapidly with the increasing of section thickness in the thick section part. There is a critical thickness between the two parts, and the position of the critical thickness changes according to the experimental conditions. Under the conditions of this study, the critical thickness changes between 1.0 and 2.5 mm.

3.2. Influence of pouring temperature on fluidity

Figs. 6 and 7 show the influence of pouring temperature on the fluidity of AZ91 and AZ91 + 3RE magnesium alloy. From Figs. 2 and 5–7, it can be seen that the influence of the pouring temperature on filling length is little for the thin section, but the filling length increases rapidly with the increasing of the pouring temperature for the thick section. With the increase of

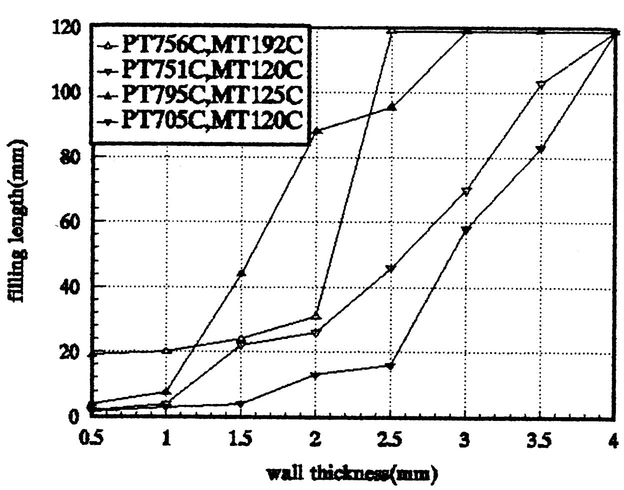

Fig. 5. Fluidity of AZ91 + 3RE magnesium alloy.

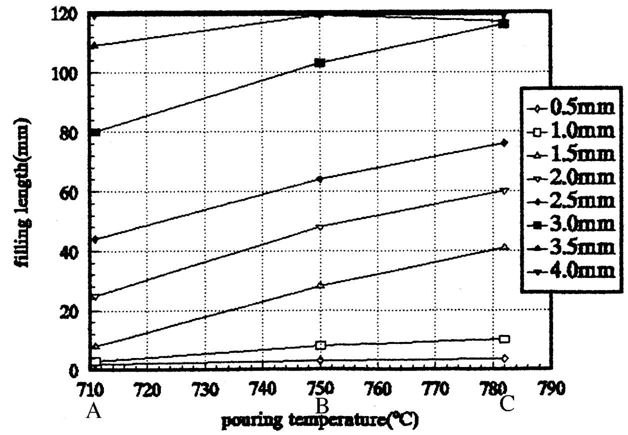

Fig. 6. Effect of pouring temperature on fluidity of AZ91 magnesium alloy. Sample A: PT711°C, MT170°C; sample B: PT750°C, MT168°C; sample C: PT782°C, MT180°C.

pouring temperature, the critical thickness on the curve of filling length versus section thickness moves left. As to AZ91 magnesium alloy, if the section thickness is 0.5 and 1.0 mm, the filling length increases a little with the increasing pouring temperature; if the section thickness is over 1.5 mm, the filling length increases remarkably when pouring temperature increases from 711 to 750°C, and increases slowly or decreases even when the pouring temperature increases from 750 to 782°C. For AZ91 + 3RE magnesium alloy, its filling length increases slowly when the pouring temperature increases from 705 to 751°C, but increases rapidly when the pouring temperature increases from 751 to 795°C.

3.3. Influence of mould temperature on fluidity

It can be seen from Figs. 2, 3, 8 and 9 that the influence of mould temperature on the fluidity of the magnesium alloy is remarkable. With the increasing of

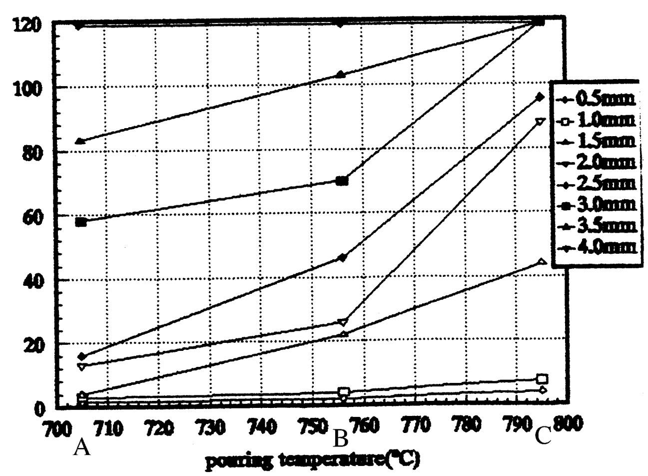

Fig. 7. Effect of pouring temperature on fluidity of AZ91 + 3RE magnesium alloy. Sample A: PT705°C, MT120°C; sample B: PT756°C, 120°C; sample C: PT795°C, MT125°C.

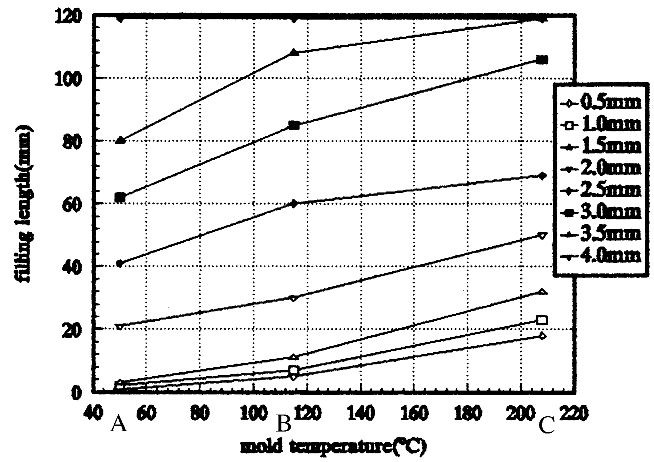

Fig. 8. Effect of mould temperature on fluidity of AZ91 magnesium alloy. Sample A: PT725°C, MT50°C; sample B: PT730°C, MT115°C; sample C: PT726°C, MT208°C.

mould temperature, the filling length increases and the critical thickness on the curve of filling length versus section thickness moves left. With the increasing of mould temperature, the filling length increases a little for the thin section, but the filling length increases a lot for the thick section.

3.4. Influence of RE content on fluidity

Figs. 10 and 11 show the effect of RE content on the fluidity of AZ91 magnesium alloy. After 1 wt.% RE is added, the fluidity of AZ91 magnesium alloy is improved. With the addition of more RE, two different results can be got. If the section thickness is under 2.0 mm, the filling length reduces with the increasing of RE content. If the section thickness is over 2.0 mm, the filling length decreases when RE content increases from

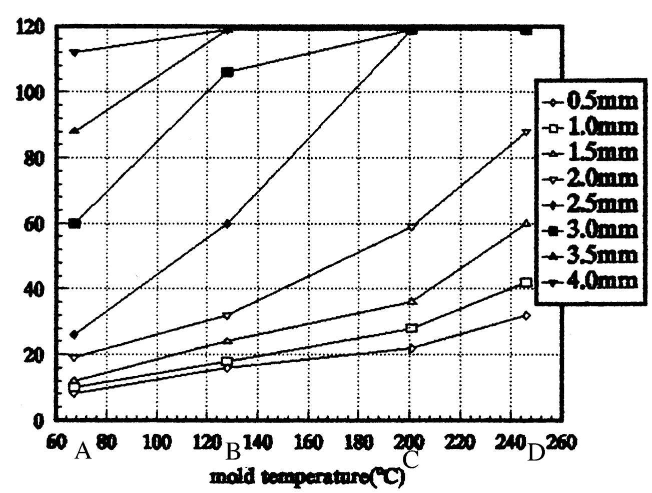

Fig. 9. Effect of mould temperature on fluidity of AZ91 + 1RE magnesium alloy. Sample A: PT753°C, MT67°C; sample B: PT740°C, MT128°C; sample C: PT756°C, MT201°C; sample D: PT746°C, 246°C.

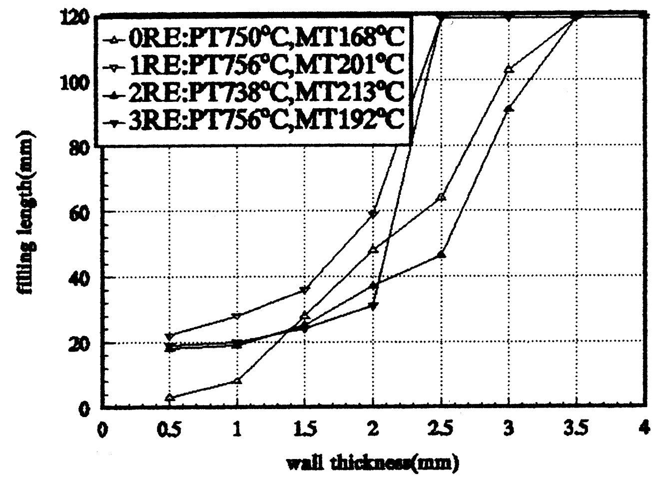

Fig. 10. Effect of RE content on fluidity of AZ91 magnesium alloy.

1 to 2 wt.% and increases when RE content increases from 2 to 3 wt.%.

4. Discussions

Fluidity (L) can be expressed by the distance that molten metal has flew during filling and solidification. It is the product of filling speed (V) and filling time (t) before molten metal stop filling, that is $L = Vt$. So factors changing filling speed and filling time will affect fluidity. The influence of section thickness, pouring temperature, mould temperature and RE content on the fluidity of AZ91 magnesium alloy will be discussed as follows.

4.1. Section thickness

It is easy to understand that with the increasing of

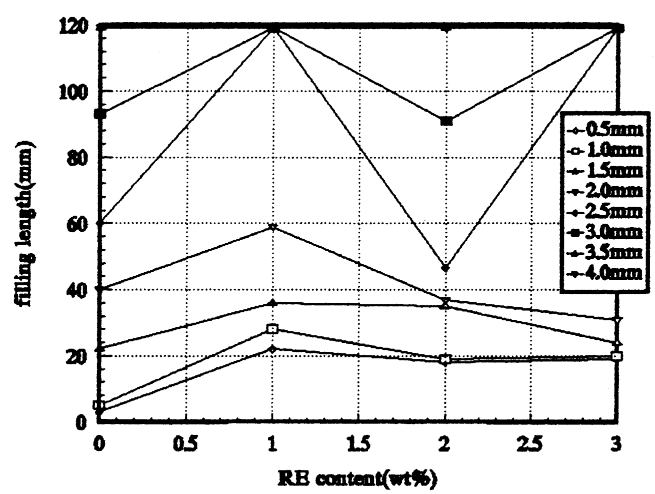

Fig. 11. Effect of RE content on fluidity of AZ91 magnesium alloy. 0RE: PT750°C, MT168°C; 1RE: PT750°C, MT168°C; 2RE: PT738°C, MT213°C; 3RE: PT756°C, MT192°C.

section thickness, the filling time of molten metal that was ended by the jam caused by solidification will increase. That will lead to the increasing of filling length. However, the curve of filling length versus section thickness can be divided into two parts: (i) the filling length in the thin section increases slowly with the increasing of section thickness; and (ii) the filling length in the thick section increases rapidly with the increasing of section thickness. That means that the fluidity in the thick and thin section changes according to different rules. So more analysis are needed about these results.

For AZ91 magnesium alloy, Kanji indicated [8] that the relation between solidification time t (s) and section thickness e (mm) is $t = 0.005\ e^2$. It is obvious that solidification time increases more rapidly in the thick section than in the thin section with the increasing of section thickness. On the other hand, the resistance along the path that the molten metal flows are larger, and the resistant effect of surface tension on fluidity is stronger in the thin section [15]. So the filling speed of magnesium alloy in the thin section is lower than that in the thick section. These two kinds of factors indicate that the increasing speed of the fluidity is larger in the thick section than that in the thin section, as the section thickness increases.

The directive meaning of the rule that the fluidity of magnesium alloy changes with the change of section thickness to casting production is that the effort of getting sound castings by increasing section thickness is little and other technologies must be adopted if the section thickness is in the thin section. Only when the section thickness is in the thick section, it is effective to get sound castings by increasing the section thickness.

4.2. Pouring temperature

Generally speaking, the viscosity and surface tension of molten metal decrease with the increasing of pouring temperature, which leads to the increasing of filling speed. At the same time, the heat capacity of molten magnesium alloy increases with the increasing of the pouring temperature, which leads to the increasing of filling time. On the other hand, the oxidation liability of magnesium alloy increases with the increasing of pouring temperature, which will increase the viscosity and decrease the filling speed. For AZ91 magnesium alloy, the two contrary factors lead to two results. One is that the filling length increases with the increasing of pouring temperature from 711 to 750°C. The other is the filling length increases slowly or even decreases with the increasing of pouring temperature from 750 to 782°C, because of the obvious oxidation liability increase (Figs. 2 and 6). Therefore, in practice production, we can increase the pouring temperature for better filling ability of AZ91 magnesium alloy between 710 and 750°C, but it is not advisable above 750°C. For AZ91 + 3RE magnesium alloy, filling ability can be improved by increasing the pouring temperature under 795°C.

4.3. Mould temperature

The filling length of an alloy is inversely proportional to the difference of pouring temperature and mould temperature [16], so the fluidity increases with the increasing of mould temperature. For the thin section, the filling length does not increase remarkably with the increasing of mould temperature due to very short solidification time. On the contrary, the filling length of magnesium alloy in the thick section increases remarkably because of the much longer solidification time.

In foundry production of magnesium alloy, it is very effective to increase filling ability of thick section castings by increasing mould temperature. But when the section is thin, other technologies have to be adopted to improve the filling ability to get sound castings of magnesium alloy.

4.4. RE elements

It has been indicated that RE could reduce the range of crystalization temperature of magnesium alloy, and the Mg-RE eutectic has good fluidity [12] and RE elements have the functions of degassing and deslaging [5]. Besides, it was found that RE can refine grain, reduce the quantity of coarse $Mg_{17}Al_{12}$ phase between grain interface (Fig. 12). Those factors lead that RE elements can increase the fluidity of magnesium alloy. However, the results of this study indicate that the influence of RE elements on fluidity of AZ91 magnesium alloy is complex. The reason might be the affinity between oxygen and RE is larger than the affinity between oxygen and magnesium [14]. So the melt surface of RE-bearing magnesium alloy is easier to form oxide film containing RE elements, which can decrease the fluidity of magnesium alloy. Especially for the thin section, the decreasing effect of RE elements on the fluidity of magnesium alloy plays a leading role. While the section is thick, the increasing effect of RE elements on the fluidity plays a leading role. With the increasing of RE content, the oxidization liability of molten magnesium alloy increases and the decreasing effect of RE on the fluidity in the thin section is more important. As a result, the fluidity of magnesium alloy in the thin section changes from increasing to decreasing, and the fluidity in the thick section changes from increasing to decreasing, and to increasing again with the RE content increasing. Moreover, the critical thickness on the curve of filling length versus section thickness moves right with RE content increasing.

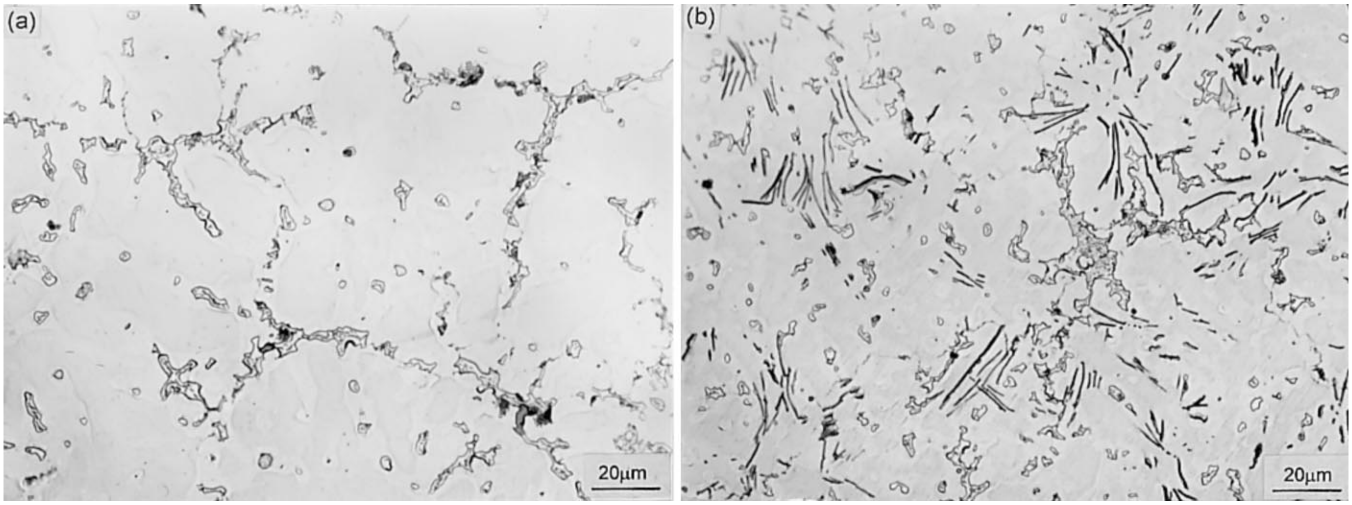

Fig. 12. Effect of RE on microstructure of AZ91 magnesium alloy from fluidity sample with 4 mm thickness: (a) AZ91; (b) AZ91 + 3RE.

As to the conclusion that RE elements can increase the fluidity of magnesium alloy [3], it does not conflict with the conclusion of this study. Because when the content of RE elements is low or cooling speed is high, the conclusion of this study is also that RE elements increase the fluidity of magnesium alloy. So we can improve the filling ability of castings by the addition of RE elements when the section is thick in practical production; while the section is thin, we have to decrease the content of RE elements or adopt other technologies to improve the fluidity of magnesium alloy.

5. Conclusions

By casting fluidity specimen in metal mould, the influence of section thickness, pouring temperature, mould temperature and content of RE elements on the fluidity of AZ91 magnesium alloy have been studied in this paper. The conclusions are as follows.

(1) The filling length of AZ91 magnesium alloy increases with the increasing of section thickness. The filling length in the thin section increases slowly with the increasing of section thickness, but the filling length in the thick section increases rapidly with the increasing of section thickness. There is a critical thickness on the curve of filling length versus section thickness between the thick section part and the thin section part, which lies in the zone of between 1.0 and 2.5 mm under the conditions of this study.

(2) The influence of pouring temperature on the filling length is little in the thin section, but with the increasing of pouring temperature, the filling length in the thick section can increase rapidly and the critical thickness on the curve of filling length versus section thickness moves right. It is beneficial to increase the fluidity of AZ91 magnesium alloy by increasing the pouring temperature between 710 and 750°C, but it is beneficial under 795°C for AZ91 + 3RE magnesium alloy.

(3) With the increasing of mould temperature, the filling length increases and the critical thickness on the curve of filling length versus section thickness moves left. The filling length increases slowly with the increasing of mould temperature for the thin section, but the filling length increases rapidly with the increasing of mould temperature for the thick section.

(4) As RE content increases, the fluidity of magnesium alloy in the thin section changes from increasing to decreasing, and the fluidity in the thick section changes from increasing to decreasing, and to increasing again; moreover, the critical thickness on the curve of filling length versus section thickness moves right.

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