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Effect of side transmission of power ultrasonic on structure of AZ81 magnesium alloy①

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Abstract: In order to promote the application of power ultrasonic in metallurgic industry, ultrasonic vibration is introduced from the side of AZ81 ingot by adopting the automatic-attracting amplitude transformer horn which has independently been designed and produced, and the effect of the side transmission of ultrasonic on the solidification structure of metal is investigated. The results show that under this experimental condition, power ultrasonic can greatly improve the solidification structure of AZ81 magnesium alloy. Compared with the traditional modification methods in which inoculants are added into melt, power ultrasonic has a better performance. The present research gives us a new way for the application of ultrasonic refinement technique.

Key words: power ultrasonic; side transmission; AZ81 alloy; solidification structure
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1 INTRODUCTION

Numerous previous investigations proposed that power ultrasonic is a very effective method to improve the solidification structure of metals[1-3]. Compared with traditional modification methods, this method will not pollute the working surroundings and experimental metals. Therefore, it might become a promising green pollute-free refinement method in foundry in the 21st century.

Up to the present, the major methods of transmitting power ultrasonic into melts involve the top transmission and the bottom transmission[4], as shown in Fig. 1.

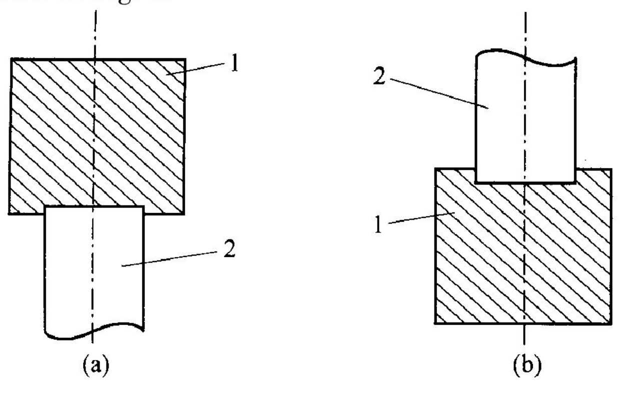

Fig. 1 Two methods of transmitting ultrasonic vibration into melts
(a) —Bottom transmission; (b) —Top transmission
1 —Molten alloy; 2 —Amplitude transformer horn

As far as the bottom transmission method is concerned, part of vibrating energy is inevitably absorbed by the mold because of the adherence of the mold, which would eclipse the treating effect since the vibrating efficiency has been reduced. The effect is unsatisfactory when this method is used to treat high big castings, especially continuous casting billet. The top transmission method, however, brings oxides and impurities on the surface into molten alloy and forms extra inclusions during the violent vibration, which has a negative effect on the mechanical properties of the alloy. Moreover, the amplitude transformer horn will be eroded and worn away as it must be inserted into the high temperature melt, so it can not work for a long time.

In order to promote the application of power ultrasonic in metallurgic industry, ultrasonic vibration is introduced from the side of AZ81 ingot by adopting the automatic-attracting amplitude transformer horn which has independently been designed and produced, and the effect of the side transmission of ultrasonic on the solidification structure of AZ81 ingot is investigated. In this experiment, amplitude transformer horn adheres to the side of crucible tightly, which keeps the amplitude transformer horn from erosion of melt and avoids the formation of extra inclusions.

2 EXPERIMENTAL

AZ81 is used as experimental material. AZ81 alloy is a kind of Mg-Al-Zn foundry alloy which has wildly been used in transportation, civil industry and

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so on. The main compositions are listed in Table 1. Its cast structure includes three parts: α phase (Mg rich) acting as matrix, discontinuous reticulation β phase ($Mg_{17}Al_{12}$) distributing along the crystal boundary of α phase, and some tiny Mn-Al compound particles dispersing in α phase. The crystal size of AZ81 alloy illustrates great disparity and the mechanical properties of the alloy are also undesirable[5].

Table 1 Chemical compositions of AZ81 alloy (mass fraction, %)

Element	Al	Zn	Mn	Fe	Si	Mg
Composition	8.19	0.35	0.41	0.02	0.04	Balance

A schematic view of the experimental apparatus is shown in Fig. 2. The size of the crucible is 60 mm × 40 mm × 140 mm, and the molten alloy occupies four-fifths of the crucible volume. The amplitude transformer horn is made of 45 carbon steel and its diameter is 40 mm. The working procedure is illustrated in Fig. 3. The power of the metallurgic ultrasonic generator can successively be regulated from 0 to 1 kW. The transmitting efficiency of the magnetostrictive transducer is about 8%.

In order to direct power ultrasonic into molten magnesium alloy effectively, the amplitude transformer horn and the crucible must adhere to each other tightly. The automatic-attracting amplitude transformer horn adopted in the paper can satisfy this requirement.

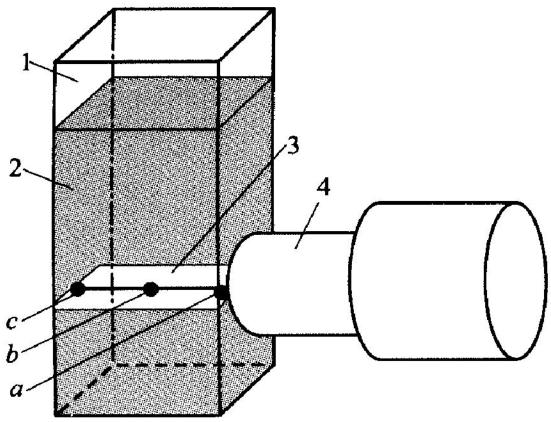

Fig. 2 Schematic view of experimental apparatus
1 —Crucible; 2 —AZ81 alloy; 3 —Cross section of sample; 4 —Automatic-attracting amplitude transformer horn
a —Point close to amplitude transformer horn;
b —Central point of cross section;
c —Point distant from amplitude transformer horn

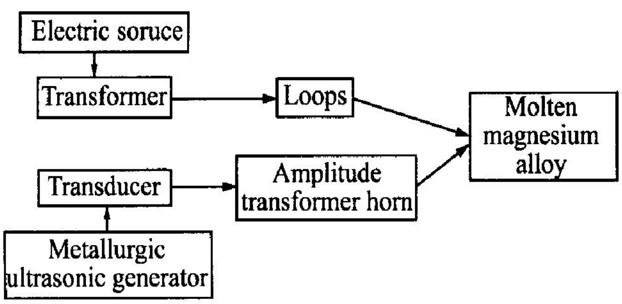

Fig. 3 Schematic of working procedure

In the experiment, magnesium alloy was loaded into a crucible which was then put into a resistance furnace. The experiment included three groups: the first one was untreated and the pouring temperature of it was 650 ℃. The second one was modified with $CaCO_3$ at 780 ℃, in which $CaCO_3$ powders, amounted to 0.5% of the magnesium alloy mass, was wrapped with aluminum foil and pushed into the molten alloy by a bell-shape cover, and the treating time was about 5 min. In the third group, the crucible was taken out of the resistance furnace at 680 ℃, putting it on a flat support, conducting 600W power ultrasonic into the molten alloy at 650 ℃ from the side of the crucible until the alloy has been completely solidified. The cooling condition was identical in the three groups.

The samples from the area close to the amplitude transformer horn (see Fig. 2, points *a*, *b* and *c*) were taken to analyze metallographic structure. The sample was etched by 2% oxalic acid. Three typical points: *a* is close to the amplitude transformer horn, *b* is the central point of the cross section, and *c* is distant from the amplitude transformer horn, were selected to observe microstructure. The same parts were chosen in other two samples.

The distribution of aluminum at central points of the samples from the first and the third groups and the micro-hardness of matrix were measured respectively.

3 RESULTS AND DISCUSSION

3.1 Comparison of microstructure

Fig. 4 shows the metallographic photos of the cross sections from the three different experimental groups. According to the comparisons in Fig. 4, it is evident that the grain size of magnesium alloy modified by $CaCO_3$ is reduced. However, when the power ultrasonic is conducted into the molten alloy from the side of the crucible, in the area near the amplitude transformer horn, the size of α phase crystals is greatly refined and the net-shape structure of β phase tends to be uniform and finer.

The principle of the modification that $CaCO_3$ acts as inoculant is as follows[6]: the carbon compound decomposes at the melting-point,

$$CaCO_3 = CaO + CO_2 \uparrow \quad (1)$$

$$CO_2 + Mg = 2MgO + C \quad (2)$$

and then new carbon atoms will combine with aluminum atoms to produce a lot of diffuse Al_4C_3 particles which can act as favorable heterogeneous nucleus because the Al_4C_3 particles are stable at high temperature and have the same crystal structure and similar

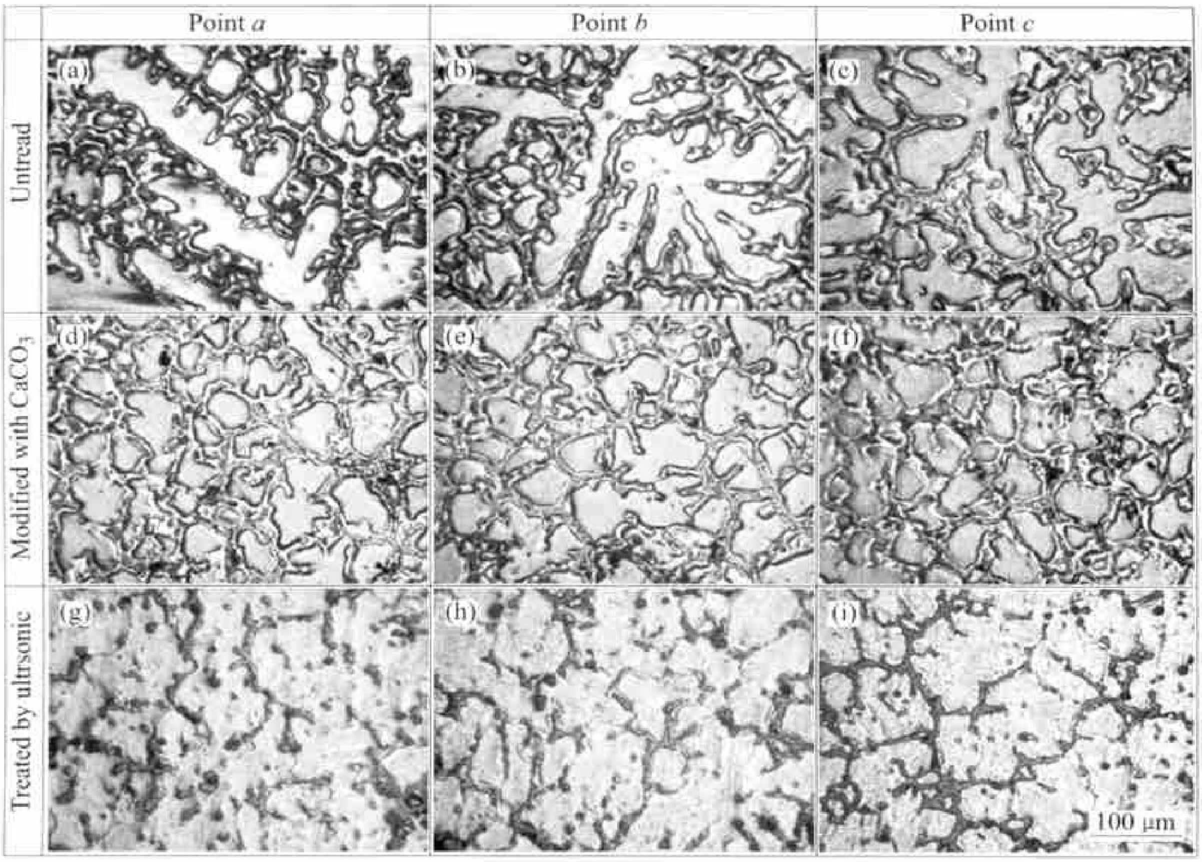

Fig. 4 Comparison of cross-section structures of AZ81 magnesium alloy

crystal lattice constant as α phase. Thus the addition of $CaCO_3$ can promote nucleation of α phase, refine the structure of the alloy and improve the mechanical properties. But the melt would be polluted when $CaCO_3$ is added.

When power ultrasonic is introduced into the molten magnesium alloy, cavitation and acoustic streaming play the main roles[7, 8]. In the cavitation area, the tiny bubbles and violent shock wave caused by cavitation break the initial crystal nucleus, at the same time, near the bubbles the greater supper-cooling degree will facilitate the formation of nucleus[9]. As a result, many tiny nuclei are formed and the grain size is refined during the solidification process of magnesium alloy under power ultrasonic.

Previous studies indicated that near the amplitude transformer horn the temperature of molten alloy tended to be much more uniform for the stirring of acoustic streaming. Part of power ultrasonic energy could make the molten alloy form convection. Some crystals formed under ultrasonic would follow circumfluence when the vibrating intensity reached a certain value, the circumfluence would become unsteady with increasing ultrasonic intensity, and the nucleus moving along the circumfluence would follow vortices. All of these factors could accelerate the nucleus to disperse uniformly in the whole molten alloy.

$CaCO_3$ modification merely increases the amount of extra heterogeneous nucleus while ultrasonic breaks initial nucleus into tinier and much more heterogeneous nucleus. The distribution of temperature and nucleus tends to be much more uniform under acoustic steaming. Furthermore, there are no special requirements on chemical compositions, no contamination and better treating effect.

According to the metallographic photos from the third group, the closer the area to the amplitude transformer horn, the smaller the α phase and β phase become. The reasons for this phenomenon include both the different cooling conditions at different points and the attenuation of ultrasonic vibration in the molten alloy, and the farther the vibration leaves from the amplitude transformer horn, the weaker the effect is.

3.2 Distribution of aluminum in AZ81 alloy

As for the side transmission method, its efficiency is lower than the top transmission method because the vibration must travel through the crucible or the solidified shell of the ingot firstly. Despite this negative aspect, the side transmission method can satisfy the continuity requirement in continuous casting and shorten transmission distance. In order to find out the acting mechanism of power ultrasonic on the solidification structure of magnesium alloy, the distribution of aluminum in AZ81 alloy is determined with SEM. The results are shown in Fig. 5.

Aluminum plays solid solution strengthening role

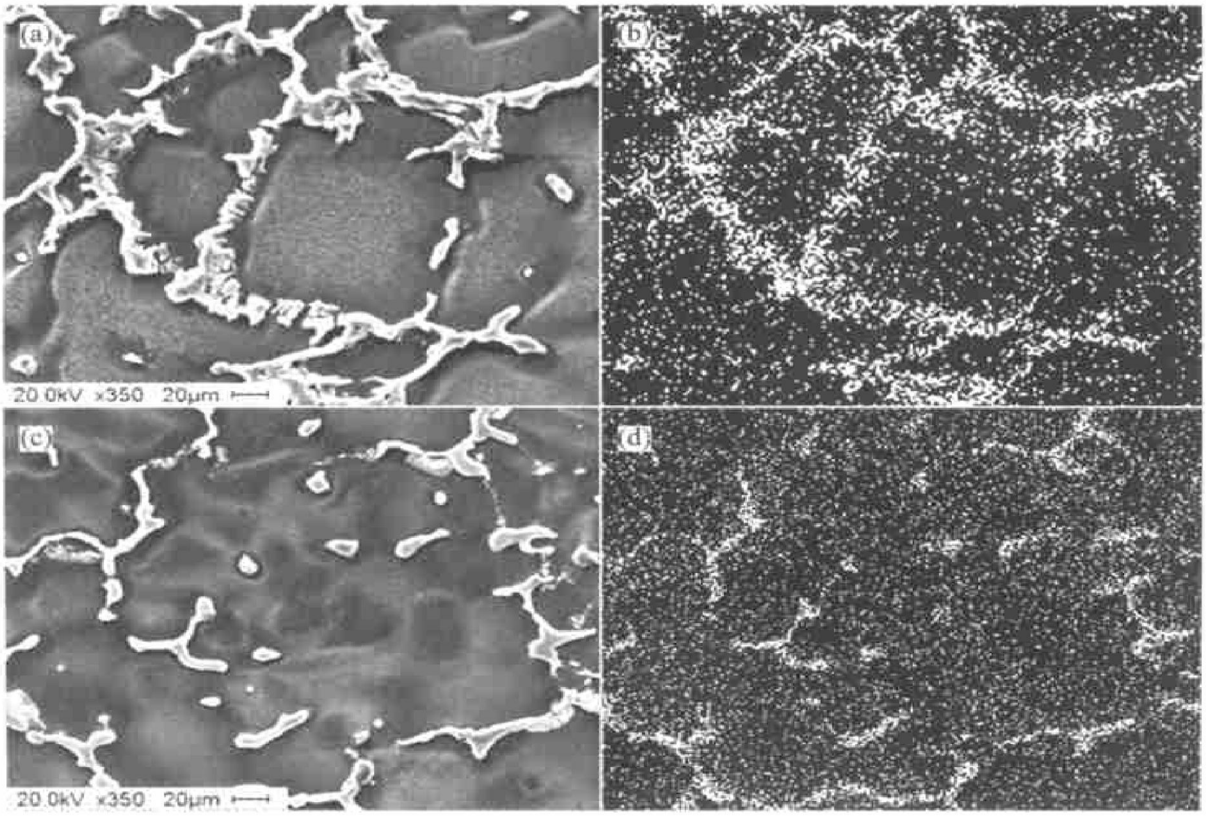

Fig. 5 Distributions of aluminum in AZ81 magnesium alloy
(a) —Untreated structure; (b) —Distribution of Al atoms;
(c) —Structure treated by 600 W power ultrasonic; (d) —Distribution of Al atoms

in magnesium alloy. When the aluminum content is low, the solution content of aluminum in α phase and its strengthening effect on magnesium alloy will increase with the content of aluminum rising[10]. Fig. 5 shows that the amount of aluminum atom along crystal boundaries decreases and more aluminum atoms dissolve in α phase after the melt is treated by power ultrasonic. In other words, more aluminum atoms play solid solution strengthening role in this case. The determination of micro-hardness shows that the micro-hardness of the matrix phase of untreated sample is HV 86.3 while that of the treated one increases to HV 112, which means the amount of aluminum atom dissolved in α phase has increased greatly. After treated by power ultrasonic, the coarse arborization β phase is broken into tinier particles and some of them dissolve in the matrix phase again. At the same time, the grain size is refined and the size of β phase becomes tiny and uniform, which is favorable for increasing the toughness and plasticity of magnesium alloy. Compared with the traditional solid solution strengthening and aging heat treatment technique, power ultrasonic not only refines grain size but also cuts the treating time markedly.

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