Research Progress on Semi-Continuous Casting of Magnesium Alloys under External Field

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Abstract: High-performance magnesium alloy shows a trend of large-scale and integrate and the key foundation for its preparation is high-quality casting ingots. Magnesium alloy ingots prepared by traditional semi-continuous casting process inevitably have casting defects, making it difficult to produce high-quality ingots. The external field assisted controlled solidification technology developed by combining physical fields such as electromagnetic and ultrasonic fields with traditional semi-continuous casting processes can prepare high-quality magnesium alloy ingots with uniform microstructure and no cracks. This article mainly summarizes the technical principles of external field assisted casting process, including electromagnetic field, ultrasonic field, and combined physical field. The focus is on elaborating the refinement mechanism of different types of external field in magnesium alloy solidification.

Keywords: Magnesium alloy; Semi-continuous casting; Electromagnetic fields; Ultrasonic fields;

Introduction

Semi-continuous casting (DC casting) is an effective method for stable production of magnesium alloy ingots. Due to the characteristics of low heat capacity, low melting heat, and low thermal conductivity of magnesium alloy, it is difficult to dissipate heat during the solidification process. The large temperature difference between the center and edge of the casting cavity results in problems such as coarse and uneven microstructure, severe segregation, poor surface quality, large cutting amount, and serious tendency for solidification cracking. With the improvement of product specifications and quality requirements, traditional DC casting technology as the main method for magnesium alloy ingots can no longer meet the needs of fine-grained and homogeneous microstructure.

Research has shown [1-3] that applying physical field during the solidification process can significantly improve the solidification conditions of the melt, thereby achieving the goal of refining the microstructure and improving casting defects. For example, electromagnetic stirring, electromagnetic oscillation, ultrasonic treatment, electric pulse technology, etc. This method mainly achieves the goals of degassing, refining grain size, improving ingot density and mechanical properties by introducing appropriate stirring or fluctuation during the solidification process of the melt. The team led by Qichi Le from Northeastern University has conducted in-depth research on the solidification behavior of magnesium alloy ingots under external physical fields for over twenty years. This article summarizes the principles and latest research progress of magnesium alloy DC casting technology under external field, elucidates the mechanism of external field in the casting process.

The application of electromagnetic field in DC casting of magnesium alloy

The researchers found that the as-cast microstructure of magnesium alloys can be significantly refined by applying an electromagnetic field. Le [4] found that the electromagnetic DC process of magnesium alloy can refine the microstructure, improve the grain size uniformity and inhibit the generation of macroscopic segregation and cracks.

In recent years, the Le's team has further improved the magnetic field type of magnesium alloy electromagnetic DC casting and proposed differential pulse magnetic field (DPMF). Jia [5] studied the effects of harmonic magnetic field (HMF), pulsed magnetic field (PMF), differential harmonic magnetic field (DHMF) and DPMF on metal crystalline liquid region and paste region by numerical simulation, and found that pulsed current generates stronger magnetic field than harmonic current under the same conditions. It was found that differential magnetic field can effectively reduce the temperature of the melt in the liquid pool and DPMF has both larger velocity vibration amplitude and lower temperature, making the temperature distribution more uniform [6]. Fig. 1 displays the microstructure of AZ31 magnesium alloy ingot under different electromagnetic fields. Therefore, the DMF shows great potential in refining the microstructure and suppressing columnar crystals in large-sized ingot casting.

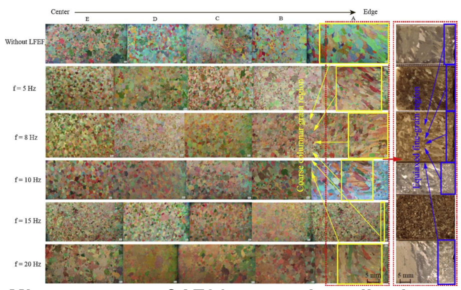

Fig. 1 Microstructure of AZ31 magnesium alloy ingot under different electromagnetic fields [6]

The application of ultrasonic field in DC casting of magnesium alloy

Ultrasonic fields can refine the solidification structure of metals because the cavitation effect and acoustic flow effect generated by the introduction of ultrasonic waves into the melt can change the solidification behavior of the melt. Shao [7] used ultrasonic treatment in AZ80 alloy melt with different intensities and found that the average grain size of the alloy decreased from 303 μm to 148 μm. Chen found that traditional single-frequency ultrasound has problems such as difficult resonance and serious attenuation in metal melt. On this basis, they developed a way to apply dual-frequency ultrasound combinations. Chen [8] found that the as-cast microstructure was significantly more refined after dual frequency ultrasonic field (DUF) treatment, as shown in Fig. 2. Moreover, the yield strength, ultimate tensile strength and elongation after 1400w DUF treatment reached 153 MPa, 239 MPa and 13.9%, respectively, which were 20.5%, 20.7% and 30.0% higher than those after single frequency ultrasonic field (SUF) treatment.

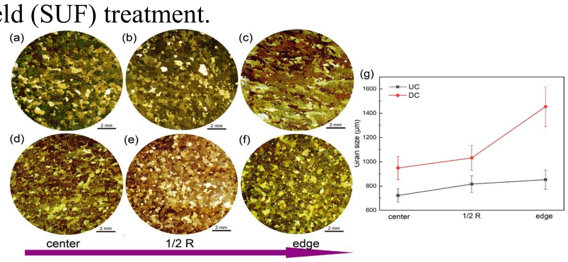

Fig. 2 Microstructure of AZ80 ingots from center to edge: (a)-(c) for DC casting, (d)-(f) for DUF casting and (g) grain size. [8]

The application of combined external field in DC casting of magnesium alloy

The researchers applied the two external fields in the magnesium alloy melt at the same time to achieve better refinement effect. Shao [9] found that simultaneous application of ultrasonic vibration to the melt resulted in significant refinement and uniform distribution of the as-cast microstructures, and ultimately improved mechanical properties. Chen [10] studied the effects of traditional fixed frequency ultrasonic field (FUF), LFEF, variable frequency ultrasonic field (VUF), and ultrasonic+electromagnetic combination field (VUF+LEF) and found that the combination of ultrasonic and electromagnetic fields had the best refining effect and the grain size refined from 679~1454 μm to 116~141 μm.

Conclusions

(1) Applying electromagnetic and ultrasonic fields during the semi-continuous casting process of magnesium alloys can significantly refine the microstructure, as well as achieve degassing and reduce segregation.

(2) The refinement effect of LFEF is remarkable, but the effect is mostly limited by the size of the ingot. For large-sized ingots, the refinement effect of DPM on the entire domain is better.

(3) Applying DUF can significantly improve the refining ability of the as-cast microstructure and expand the refining range.

(4) Compared to applying electromagnetic or ultrasonic fields separately, the combination of electromagnetic and ultrasonic fields has the best refining effect on the as-cast microstructure of magnesium alloy.

Acknowledgments

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