Microstructure Evolution of the Al-Zn-Mg-Cu Alloy During Solidification under Electric Pulse

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Abstract: In the non-equilibrium solidification process of Al-Zn-Mg-Cu alloy, the distribution of temperature field and flow field is not uniform, which leads to coarse solidification structure and serious component segregation. It is an effective means to further improve the properties of the alloy by refining the solidification structure and improving the segregation degree of the alloy with electric pulse. The effects of pulse current, pulse frequency and pulse application stage on solidification microstructure and properties of Al-Zn-Mg-Cu alloy were studied. The results show that the grain refinement effect and properties of Al-Zn-Mg-Cu alloy solidified under the effect of electric pulse are improved to varying degrees. With the increase of pulse current and pulse frequency, the columnar crystals gradually change to fine equiaxed crystals. The average grain size decreased from 140.3 μm to 102.9 μm after treatment with pulse current of 700 A and pulse frequency of 50 Hz. The tensile strength of the alloy was increased to 210.5 MPa, which is 20.6 % higher than that of conventional solidification.

Keywords: Al-Zn-Mg-Cu alloy, Electric pulse, Microstructure, Mechanical properties

1 Introduction

In the non-equilibrium solidification process of Al-Zn-Mg-Cu alloy, the distribution of temperature field and flow field is not uniform, which leads to coarse solidification structure and serious component segregation. It limits its application. Due to the unique advantages of physical fields such as electric pulse on the microstructure evolution of alloys, it has shown broad application prospects in the field of materials science and engineering, and has attracted extensive attention of foundry workers.

A.K. Misra [1] applied a small pulse current to the solidification process of Pb-15Sb-7Sn alloy with low melting point for the first time, and the microstructure of the alloy was significantly refined after solidification. Cui [2] introduced high density electric pulse during the solidification of LY12 alloy, and found that the larger the current applied, the finer the grain of the alloy after solidification, and the degree of segregation at the grain boundary of the alloy was improved. The optimal electrical pulse treatment parameters and mechanism of different kinds of alloys are not clear. In this paper, the effects of pulse current and pulse frequency on the solidification microstructure and mechanical properties of Al-Zn-Mg-Cu alloy were studied by using control variable method.

2 Experimental procedure

The size of the metal mold is Φ86×150 mm, and two copper electrodes were embedded on the top of the mold. One end of the electrode was inserted into the mold, and the other end was connected with the positive and negative electrodes of the pulse power supply. The molten Al-Zn-Mg-Cu metal liquid was poured into the mold of the same size, and the pulse power supply was turned on. The specific experimental parameters of the electric pulse were determined: the pulse current of 200 A, 700 A, 1200 A, the pulse frequency of 20 Hz, 30 Hz, 50 Hz.

The solidification microstructure and fracture morphology of Al-Zn-Mg-Cu alloy were analyzed by scanning electron microscope (FEI Quanta 200F) and energy dispersive spectrometer. The enthalpy of the alloy after different treatments was measured by a differential scanning calorimeter (METTLER DSC3+), and the dissolution of the phase was analyzed. In the DSC test, the weight of the sample was 15 mg, which was protected by argon. The test temperature ranges from room temperature to 700°C at a rate of 10°C/min. The tensile test was carried out by the MTS-E44304 electronic universal testing machine and the tensile speed of 1 mm/min. In order to ensure the accuracy of tensile test, the average value of each sample was measured four times.

3 Result and discussion

The microstructure of Al-Zn-Mg-Cu alloy under conventional solidification is mainly composed of columnar crystals and a few equiaxed crystals, as shown in Figure 1. A large number of non-equilibrium eutectic structures are distributed on the α-Al matrix in a continuous dendrite network structure. The non-equilibrium eutectic structure composed of Al, Zn, Mg and Cu elements has severe segregation at the grain boundaries. The average grain size of Al-Zn-Mg-Cu alloy under conventional solidification is 140.3 μm.

When the pulse frequency is 20 Hz, the number of equiaxed crystals increases with the increase of pulse current, and the average grain size decreases to 107.2 μm when the pulse current is 700 A. Similarly, when the pulse current is 700 A, the coarse columnar crystals become fine equiaxed crystals with the increase of pulse frequency, and the refinement effect is remarkable. The average grain size decreased from 140.3μm to 102.9μm after the treatment with pulse current of 700 A and pulse frequency of 50 Hz.

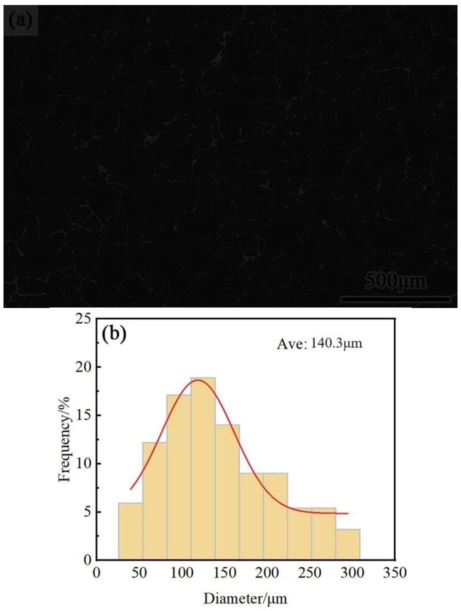

Figure 1. Microstructure of Al-Zn-Mg-Cu alloy under conventional solidification: (a) SEM, (b) average grain size

When the electrical pulse applied during the solidification of Al-Zn-Mg-Cu alloy, the rapidly changing pulsed electric field will generate a pulsed magnetic field in the melt. Due to the interaction of pulsed current and pulsed magnetic field, the metal melt moves in the direction perpendicular to the current, and the columnar crystal will be broken during the movement, and the broken columnar crystal will be used as a new crystal nucleus, which improves the nucleation rate of the alloy. In addition, since the resistivity of liquid Al-Zn-Mg-Cu alloy is higher than that of solid alloy, the current will preferentially select the solid to pass through, and the Joule heat generated by the current segregation at the solid-liquid interface hinders the growth of columnar crystals [3]. The schematic diagram is shown in Figure 2.

The tensile strength and elongation of the alloy after conventional solidification are 174.5 MPa and 4.7%, respectively. When the pulse frequency is 20 Hz and the pulse current is 700 A, the tensile strength and elongation of the alloy are 204.6 MPa and 8.1%, respectively. Compared with the untreated alloy, the tensile strength increased by 17.2%. The tensile strength of the alloy increases to 210.5 MPa when the pulse current is 700 A and the pulse frequency is 50 Hz. Compared with conventional solidification, the tensile strength of the alloy is significantly increased by 20.6 %. In summary, the application of electric pulse during the solidification process of the alloy can significantly improve the mechanical properties of the alloy and improve the microstructure uniformity of the alloy.

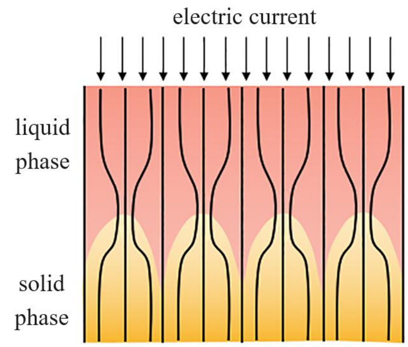

Figure 2. The schematic diagram of current segregation at the solid-liquid interface

4 Conclusion

The microstructure of Al-Zn-Mg-Cu alloy under conventional solidification is mainly composed of columnar crystals and a few equiaxed crystals. The tensile strength and elongation of the alloy after conventional solidification are 174.5 MPa and 4.7%, respectively. The grain refinement effect and mechanical properties of Al-Zn-Mg-Cu alloy solidified under electric pulse are improved to varying degrees. With the increase of pulse current and pulse frequency, the columnar crystals gradually change to fine equiaxed crystals. After electric pulse treatment with pulse current of 700 A and pulse frequency of 50 Hz, the average grain size is reduced from 140.3 μm to 102.9 μm, and the tensile strength of the alloy is increased to 210.5 MPa, which is 20.6 % higher than that of conventional solidification.

5 Acknowledgments

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