Microstructures Evolution and Mechanical Properties of Semi-Solid AZ91D Alloy at Different Injection Temperatures

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Abstract: In this work, the semi-solid AZ91D alloy was prepared by injection molding method near the liquidus temperature. The microstructure evolution and mechanical properties of the alloy were analyzed by optical microscopy (OM), scanning electron microscopy (SEM/EDS) and X-ray diffraction (XRD). The results indicated that the semi-solid AZ91D alloy was mainly composed of α-Mg matrix and β-$Mg_{17}Al_{12}$ phase, and the precipitates were small and dispersed when the injection temperature is 595 ℃. At this time, the tensile strength (R_m), yield strength ($R_{p0.2}$) and elongation (A) of the semi-solid AZ91D alloy was 273MPa, 160MPa and 7.3%, respectively, which are higher than the lower limit of liquid die-casting specified in the national standard.

Keywords: AZ91D magnesium alloy; injection molding; semi solid state; liquidus temperature.

1 Introduction

Magnesium alloy is the lightest metal structural material in engineering applications, and the environmental friendly material in the 21st century[1-2]. At present, the near liquidus semi-solid injection molding technology for aluminum alloys has becoming increasingly mature, while the technology applying in the magnesium alloy, which is also belongs to the light alloy, is also gradually attracting attention. The temperature range of the solid-liquid phase line of AZ91D alloy is 470 ℃ to 595 ℃[3-5]. This study integrated the near liquidus injection molding technology with semi-solid injection molding equipment, and investigated the microstructures evolution and mechanical properties of semi-solid AZ91D alloy under different near liquidus temperatures. The research results are helpful for providing basis for the formation of semi-solid magnesium alloys.

2 Experimental procedure

Adopted the UNI300MG II magnesium alloy injection molding machine produced by YIZUMI company, this study prepared the semi-solid AZ91D alloy with the commercial AZ91D alloy. Transfer and shear the alloy particles with a size of 4mm × 1.5mm × 1.5mm through a rotating screw to obtain slurry. The injection molding was performed separately, when the slurry temperature was 580 ℃, 595 ℃ and 610 ℃. Among them, the mold temperature was 280 ℃, the injection speed was 2.3m/s, and the locking force was 3000kN. The working principle of the injection molding is shown in Fig. 1, and the actual chemical composition of the alloy is shown in Table 1.

Table 1. Composition of semi-solid AZ91D alloy (wt.%)

Al	Zn	Mn	Si	Cu	Ni	Fe	Mg
9.13	0.73	0.25	0.035	0.002 5	0.00 04	0.00 5	Bal

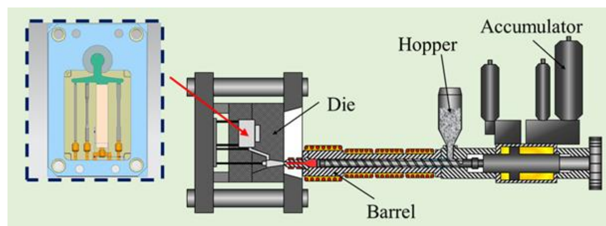

Fig. 1 Schematic diagram of the preparation process for semi-solid AZ91D alloy

The mechanical properties of semi-solid AZ91D alloy were tested by the electronic universal material testing machine with a tensile rate of 2.5mm/min. The microstructure of the semi-solid AZ91D alloy were characterized by Zeiss optical microscopy (Smart-zoom 5), field emission electron scanning electron microscopy (S4800), and X-ray diffraction (Smart Lab 9kw XRD). Using Image Pro Plus software to statistic and calculate the primary phase α-Mg. The solid phase fraction (S) and shape factor (F) of Mg were calculated using the following formulas[3]:

$$S=NA_0/A_s \quad (1)$$

$$F = [\Sigma p_0^2 \;/\; (4\pi A_0)] \;/\; N \quad (2)$$

3 Result and discussion

Microstructures evolution of semi-solid AZ91D alloy at different injection temperatures

Fig. 2 shows the OM images of AZ91D alloy. It can be seen that as the injection temperature increases, both of the solid phase fraction *S* and shape factor *F* decrease. When injected at 580 ℃ and 595 ℃, the alloy exhibits a semi-solid structure with similar shape factors. Among them, the *S* reaches to 30.4% at 580 ℃, which is the highest, and the α-Mg primary phase has formed and grown, while the *S* at 595 ℃ is 3.1%, and the grain sizes are smaller and uniform.

When injected at 610 ℃, the *S* is 0, but there are some pores in the matrix.

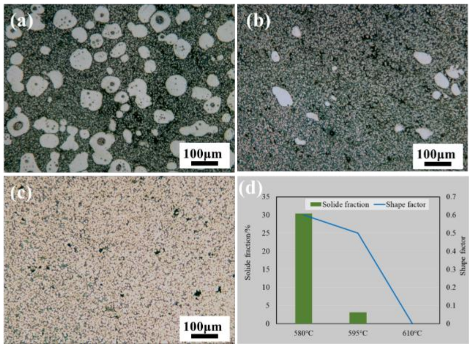

Fig.2 OM images of the semi-solid AZ91D alloy: (a) 580 ℃; (b) 595 ℃; (c) 610 ℃; (d) S and F

Fig. 3 shows the SEM images and XRD patterns of the semi-solid AZ91D alloy. It can be seen that the three injection temperatures have no effect on the phase composition, which are α-Mg matrix and β-$Mg_{17}Al_{12}$ phase, but affect the phase morphology significantly. At 580 ℃, the second phases are rounded, distributing along the grain boundaries with continuous network structures; At 595 ℃, the second phases are mostly pinned to grain boundaries, small and dispersed; At 610 ℃, the second phases are mostly distributed in the matrix, forming a semi-continuous network structure.

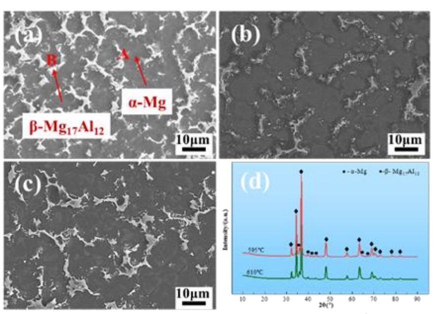

Fig.3 SEM images (a-c) and XRD patterns (d) of the semi-solid AZ91D alloy: (a) 580 ℃; (b) 595 ℃; (c) 610 ℃

Mechanical properties of semi-solid AZ91D alloy at different injection temperatures

Mechanical properties and fracture surfaces at room temperature are shown in Fig. 4. It can be seen that as the injection temperature increases, the mechanical properties of the alloy first increase and then decrease, besides, the fracture surfaces are composed of cleavage planes, tearing edges and a small amount of ductile dimples, showing typical brittle fracture. When injection molding is carried out at 595 ℃, the obstruction to the dislocations movement by the small and dispersed second phases is the strongest[4-5], and the mechanical properties of the alloy are the best, with R_m of 273MPa, $R_{p0.2}$ of 160MPa, and *A* of 7.3%, respectively, which are higher than the lower limit values specified in the national standard GB/T 25747-2022 for liquid die-casting parts.

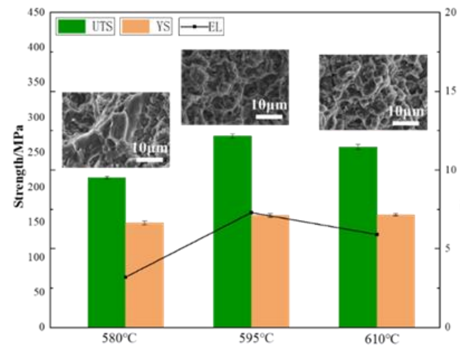

Fig. 4 Mechanical Properties and fracture surface of semi-solid AZ91D alloy at room temperature

4 Conclusion

(1) The semi-solid AZ91D alloy is mainly composed of α-Mg matrix and β-$Mg_{17}Al_{12}$ phases. The phase type is not affected by injection temperature, but when injection molding at 595 ℃, the second phase is the smallest and most dispersed.

(2) The semi-solid AZ91D alloy, formed by injection molding at 595 ℃, has the best mechanical properties, with R_m of 273MPa, $R_{p0.2}$ of 160MPa, and *A* of 7.3%, respectively, which are higher than the lower limit values specified by the national standard for liquid die-casting parts.

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