Rapid Preheating to Preserve the Initial Microstructure of the Squeeze Casting AZ31 Billet and Effect on Subsequent Hot Extrusion

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Abstract: In this investigation, the squeeze casting process was employed to fabricate AZ31 magnesium alloy billets instead of the traditional semi-continuous casting method. The high-temperature melt was rapidly solidified under pressure. A rapid preheating method was utilized to quickly adjust the temperature of the newly solidified billet to the corresponding extrusion temperature within 10 minutes, bypassing the need for cooling to room temperature. Without homogenization treatment, the fine secondary phase particles were preserved, grain coarsening was avoided, and the microstructure of the AZ31 extruded magnesium alloy was refined, enhancing its mechanical properties. This study helps broaden thecasting process's application range and provides a new strategy for designing thermoplastic deformation processes for different alloys.

Keywords:AZ31 magnesium alloy; Squeeze casting; Hot extrusion; Homogenization; Rapid preheating.

1 Introduction

In addition to producing practical castings, various casting methods are used to create semi-finished materials for manufacturing processes. For example, billets of extruded magnesium alloys are typically made via the semi-continuous casting (SCC) process. This method often results in severe segregation and coarse secondary phases due to non-equilibrium solidification. Therefore, an additional homogenization treatment is performed before hot extrusion to eliminate defects and improve extrudability, though this can lead to grain coarsening and reduced effectiveness of secondary-phase particles in recrystallization nucleation. The low plastic deformation capability of magnesium alloys requires elevated extrusion temperatures, necessitating a preheating process between homogenization and hot extrusion to reach the desired temperature. Both thermal processes affect the billets' microstructure.

The squeeze casting (SC) process, an advanced casting technology, involves the rapid solidification of liquid or semi-solid melt under high pressure, yielding a higher cooling rate that refines matrix grains and produces high-density fine precipitates. This makes SC an ideal method for preparing high-quality billets for hot extrusion. However, the required homogenization and preheating processes in traditional hot extrusion can diminish the benefits of squeeze casting.

This study investigated the effects of homogenization and preheating treatments on the microstructure of various billets. A novel rapid preheating method was developed to adjust the temperature of the squeeze casting billet to the extrusion temperature within 10 minutes. By avoiding homogenization treatment, fine secondary phase particles were preserved, grain coarsening was prevented, and the microstructure of the AZ31 extruded magnesium alloy was refined, enhancing its mechanical properties.

2 Experimental procedure

Figure 1 illustrates the rapid preheating process for squeeze casting billets. The squeeze casting was performed on a hydraulic machine at a pressure of 100 MPa. AZ31 melt at 690 °C was poured into a permanent mold that matches the extruded billet size. After holding the pressure for 10 seconds, the billet was ejected and air-cooled for about one minute. It was then placed in a heat-holding furnace with graphite particles as a heat transfer medium to improve heat transfer. After 10 minutes, the SC billet was hot extruded with an extrusion ratio of 16 and a ram speed of 7 mm/s to produce an extruded rod.

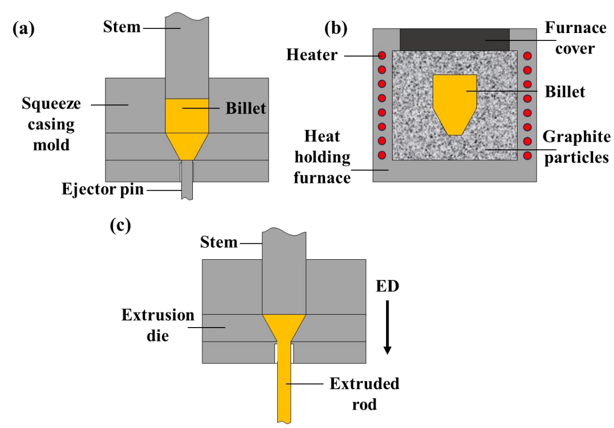

Fig. 1Schematic diagram of therapid preheating process for squeeze casting billets: (a) squeeze casting; (b) rapid preheating; (c) hot extrusion.

The extrusion temperature was set at 380 °C, with the heat-holding furnace and extrusion mold preheated to the same temperature. Homogenization (420 °C for 10 h) was performed on both SC and SSC billets, the latter cut from a commercial AZ31 SSC ingot. Additionally, traditional preheating (380 °C for 1 h) was conducted for the SC billet.

3 Result and discussion

3.1 Microstructure of the billets before and after various heat treatments.

Figure 2 shows the microstructure of the SCC and SC billets. The element distribution maps in Fig. 2(b) indicate that the secondary phase particles are Mg-(Al, Zn) and Al-(Mn, Fe). The SC billet displays denser and finer particles.

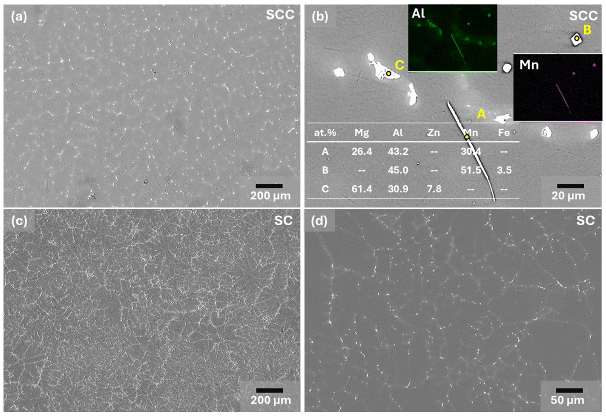

Fig. 2 Microstructure and elements distribution maps of various billets: (a and b) SCC, (c and d) SC.

After homogenization at 420 ℃ for 10 hours, the low-melting-point Mg-(Al, Zn) phase disappeared from both billets, as depicted in Fig. 3(a and b). After preheated at 380℃ for one hour, the Mg-(Al, Zn) phase also vanished in Fig. 3(c). But for the rapid preheating process at 380℃ for only 10 minutes, most of the them remained (Fig. 3(d)).

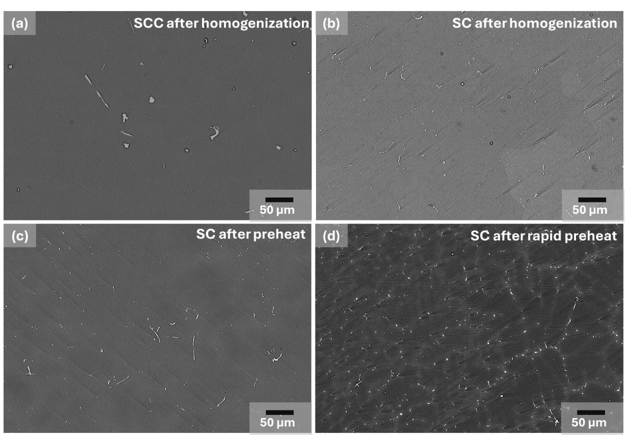

Fig. 3 Microstructure of various billets after different heat treatments: (a) SCC billet after homogenization, (b) SC billet after homogenization, (c) SC billet after preheating, and (d) SC billet after rapid preheating.

Figure 4 analyzes grain size evolution using EBSD. The SCC billet exhibits very coarse grains, with average grain size increasing by 31.4% after homogenization. The SC billet has finer matrix grains. After homogenization and preheating, itsgrain size coarsened by 20.8% and 6.2%, respectively. High-melting-point Al-Mn particles helped suppress coarsening after 10 hours at 420 °C, though it was still significant. Figure 4(f) shows that the grain size of the SC billet after rapid preheating barely increased.

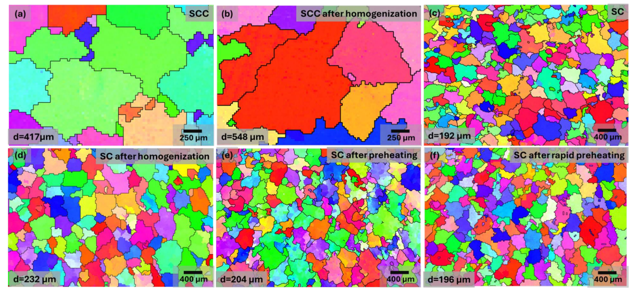

Fig. 4 EBSD maps of various billets after different heat treatments: (a) SCC billet, (b) SCC billet after homogenization, (c) SC billet, (d) SC billet after homogenization, (e) SC billet after preheating, and (f) SC billet after rapid preheating.

3.2 Microstructure and mechanical properties

EBSD maps and tensile mechanical properties along the extrusion direction of extruded rods extruded from various billets are shown in Fig. 5 and Table 1. The rod extruded from the SC billet after rapid preheating shows thefinest microstructure with an average diameter of 5.1 μm.

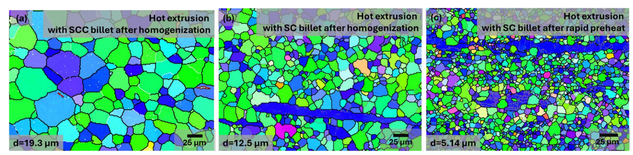

Fig. 5 EBSD maps along the extrusion direction of extruded rods extruded from various billets: (a) SCC billets after homogenization, (b) SC billet after homogenization, and (c) SC billet after rapid preheating.

Table 1 Tensile mechanical properties of extruded rods.

Billet	Heat treatment	UTS/MPa	YS/MPa	EL/%
SCC	Homogenization	259.9±4.4	168.6±2.8	13.8±1.2
SC	Homogenization	274.6±7.2	192.4±7.6	15.2±1.4
SC	Rapid preheating	296.4±5.7	220.8±8.4	15.8±0.7

Conclusion

(1) Both homogenization and preheating processes lead to grain size roughening and dissolution of low-melting-point phases, which is detrimental to subsequent hot extrusion.

(2) A novel rapid preheating method was developed to quickly raise the squeeze billet's temperature to the extrusion level within 10 minutes, preserving its initial microstructure. The solidified squeeze billet was buried in graphite particles at the extrusion temperature, eliminating the need to cool to room temperature. This significantly refined the microstructure of the AZ31 extruded magnesium alloy, enhancing its mechanical properties.