Investigation of Quench Sensitivity of High Vacuum Die Casting AlSi10MgMn Alloy

Wenhui Bai, Yueqin Lei, Haidong Zhao*
National Engineering Research Center of Near-Net-Shape Forming for Metallic Materials, South China University of Technology, Guangzhou 510640, China
*Corresponding address: e-mail: hdzhao@scut.edu.cn

Abstract: In this study, the quench sensitivity of high vacuum die casting (HVDC) AlSi10MgMn alloy was investigated through time-temperature-transformation (TTT) and time-temperature-property (TTP) curves. The mechanical properties during different quenching rates were predicted by quench factor analysis (QFA). Phase transformation kinetics was analyzed by Avrami equation. The results show that the sensitivity temperature range is 295~445°C and the nose temperature is 370°C. During the isothermal treatment, a number of rod-shape β-Mg_2Si phases precipitate and grow up with the extension of time. The number density of the age-induced precipitates β″reduce after aging treatment. Based on simulated results of TTT and continuous cooling transformation (CCT) curves, the accuracy of QFA methods was validated. To obtain good mechanical properties, the critical cooling rate should be higher than 7.7 °C/s.

Keywords: AlSi10MgMn alloy; high vacuum die casting; quench sensitivity; quench factor analysis; microstructure

1 Introduction

Al-Si alloy is a typical age hardening alloy [1]. Solution, quenching, and aging treatment are usually used to improve alloy mechanical properties. However, the quenching cooling rate is essential for the supersaturation of the solid solution [2]. A low cooling rate may precipitate coarse phases from the supersaturation solid solution, leading to a decrease of strength [3]. This phenomenon is called quench sensitivity. When the quenching cooling rate is relatively high, residual stress would generate in the die castings, which is harmful to the mechanical behavior. Therefore, the quenching cooling rate should be controlled and well-studied to balance the mechanical properties and residual stress [4]. Unfortunately, there are little literature about the evolution of mechanical properties and microstructure of HVDC AlSi10MgMn during the quenching.

In this paper, TTT and TTP curves of HVDC AlSi10MgMn alloy were obtained by interrupted quenching method. QFA methods was verified by the simulated TTT and CCT curves. Microstructure evolution was studied, and the microstructure transformation during isothermal treatment was analyzed by phase transformation kinetics.

2 Experimental procedure

In this study, commercial AlSi10MgMn alloy and Al-50%Mg mater alloy were used to prepare the experimental alloy. The compositions of this alloy are shown in Table 1. A TOYO BD-350V5 cold chamber HVDC machine was used in this experiment. As for interrupt quenching experiment, the solution treatment was performed at 530°C for 3h and the isothermal temperature was 280-460°C with isothermal time of 0-1200 s. In addition, the aging treatment was performed at 185°C for 7 h.

Table 1. Compositions of the experimental alloy

Si	Mg	Fe	Mn	Ti	Zn	Al
10.58	0.42	0.07	0.61	0.08	0.04	Bal.

3 Result and discussion

Performance prediction by QFA

As can be seen in Fig.1, the quench factor decreases, and alloy hardness increases with the cooling rate increases. When the cooling rate is higher than 7.7 °C/s, the alloy hardness can reach 95% maximum value (102HB). Below this cooling rate, the hardness decreases rapidly with the cooling rate decreasing.

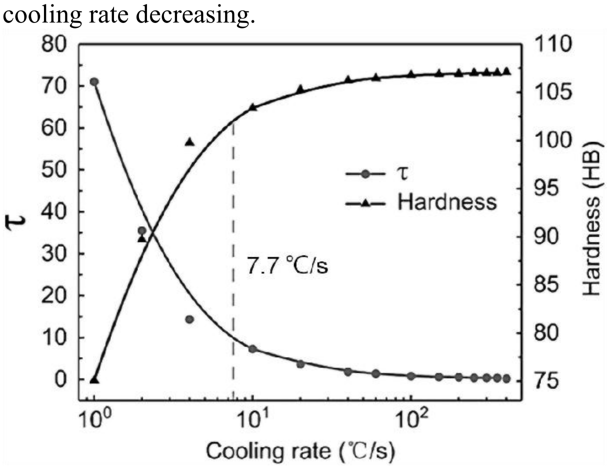

Fig. 1. Effect of average cooling rate on the quench factor and predicted hardness of the alloy.

Microstructure evolution during isothermal treatment

As shown in Fig.2, after isothermal treatment for different time at 370°C, the number density of point-like β″ phase is obviously different. As the isothermal treatment progresses, solute atoms precipitate from the solute solution and the rod-shaped β phase forms. Especially for 1200 s, there are almost no β″ phase, only the β phase.

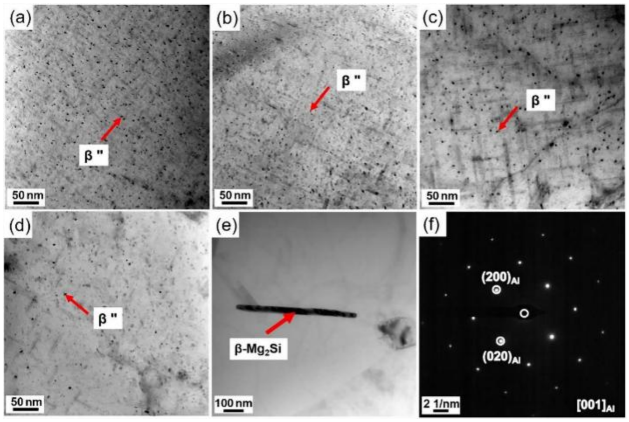

Fig. 2. Effects of different isothermal time at 370°C on β″: (a) 0 s; (b) 20 s; (c) 240 s; (d) 480 s; (e) 1200 s; (f) the corresponding SAED pattern of (a).

Simulated TTT and CCT curves

Fig.3a shows the simulated TTT and CCT curves of HVDC AlSi10MgMn alloy. The simulated TTT curves are also "C" shape with nose temperature of about 360°C. This is close to the experimental result. In addition, as can be seen in Fig. 3b, the critical cooling rate of non-precipitation of β phase is about 0.1 °C/s, and the critical cooling rate of non-precipitation of β' and β″ phase is about 7 °C/s. To hinder the formation of quench-induced precipitates and obtain a comprehensive mechanical property, the cooling rate should be higher than 7 °C/s at the high quench sensitivity zone. At higher/lower temperature, the cooling rate can be reduced appropriately. This result is also agreement with the QFA method.

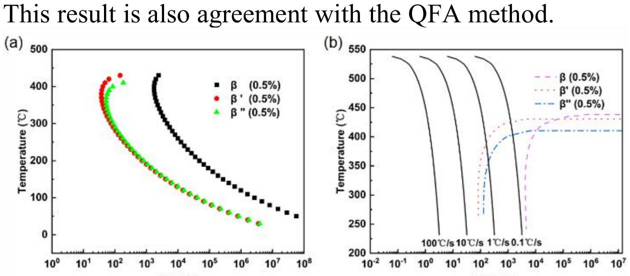

Fig.3. TTT and CCT curves of HVDC AlSi10MgMn alloy simulated by JMatPro 7.0 software: (a) TTT curves; (b) CCT curves.

Phase transformation kinetic analysis

Fig. 4 shows the phase transformation kinetic curves at different temperature. The curves are "S" shape, indicating that there is an incubation period during the phase transformation process. The curve of 370°C is at the far left, indicating the highest transformation rate. As for the curves of 280°C and 460°C, the curve of 280°C is at the far right, indicating that the phase transformation rate at the low temperature zone is lower. Therefore, the quench sensitivity is lower at the low temperature zone.

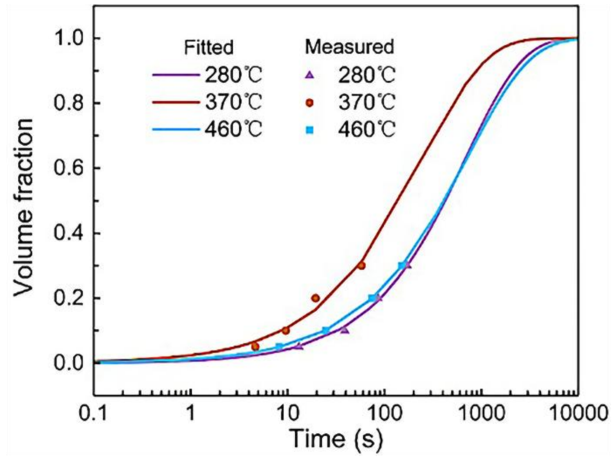

Fig. 4. The phase transformation kinetics curves of AlSi10MgMn alloy.

4 Conclusion

1) The high quench sensitivity range of HVDC AlSi10MgMn alloy is 295-445°C with a nose temperature of 370°C. Quench rate should be higher than 7.7 °C/s to obtain excellent mechanical properties at the high quench sensitivity zone.
2) At the nose temperature of 370°C, the average size of the β phase increases and the number density of β″ phase decreases with the extension of the time, which is detrimental to the mechanical properties.

Acknowledgments

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