STUDY ON MICROSTRUCTURE AND MECHANICAL PROPERTY OF SQUEEZE CASTING AZ91D MAGNESIUM ALLOY

Yanda Li [1], Zhiqiang Han [1], Alan A. Luo [2], Anil K. Sachdev [2], Baicheng Liu [1, 3]
[1] Key Laboratory for Advanced Materials Processing Technology (Ministry of Education), Department of Mechanical Engineering, Tsinghua University, Beijing 100084, China
[2] Chemical and Materials Systems Laboratory, General Motors Global Research and Development Center, Warren, MI 48090-9055, USA
[3] State Key Laboratory of Automotive Safety and Energy, Tsinghua University, Beijing 100084, China

Keywords: Squeeze casting, Magnesium alloy, Cooling curve, Microstructure, Mechanical property

Abstract

Squeeze casting characterized by gentle die filling and solidification under high pressure is recognized one of the potential processes for the production of thick-walled parts that are amendable for heat treatment to enhance mechanical properties of magnesium alloys. In this study, squeeze casting experiments under different applied pressures were carried out for AZ91D magnesium alloy and the temperature variations at different locations in the casting were measured during the solidification process. The microstructure morphology was observed by using OM. The grain size and mechanical property of the casting were determined. The effects of pressure on the cooling curves, microstructure and mechanical property were discussed.

1. Introduction

Magnesium alloy is an important lightweight structural material and has a great application potential in automotive industry. High pressure die casting technology has been widely used in manufacturing magnesium alloy components [1]. However, porosity is a major defect in high pressure die casting due to the air entrapment caused by turbulent die filling in the casting process. High vacuum die casting where the air in the mold is removed before the die filling process to avoid air entrapment has been developed to reduce porosity defects in the castings [2]. It is suitable to produce pore free castings with good mechanical properties. However, for a thick-walled casting, it is still difficult to obtain a pore free product by using high vacuum die casting technique due to the solidification shrinkage. Squeeze casting is a process in which the die is filled gently, which means almost no air entrapment happens, and the casting solidifies under an external pressure, which causes plastic deformation compensating the internal volume shrinkage. Thus, it is an effective technology for producing thick-walled parts that are amendable for heat treatment to enhance mechanical properties of magnesium alloys. Some researchers have investigated the influence of process variables on the microstructure and mechanical properties of squeeze cast magnesium alloys [3-6], still the studies are relatively limited and the understanding on the formation mechanism of microstructure is inadequate. In this study, squeeze casting experiments of magnesium alloy under different applied pressures have been carried out. The temperature variations inside the casting during solidification process were measured and analyzed, the as-cast microstructure was observed and the mechanical property of the castings was tested.

2. Experimental Procedure

2.1 Experimental Materials

Commercial AZ91D magnesium alloy was selected in the squeeze casting experiments. The composition of the alloy is shown in Table 1.

Table 1 The chemical composition (wt. %) of magnesium alloy

Al	Zn	Mn	Si	Fe	Cu	Ni	Mg
8.9	0.76	0.26	0.01	0.0033	0.001	0.0008	Balance

2.2 Casting and Die-set Design

The casting geometry and the die-set configuration are shown in Figure 1. The step-shaped casting geometry produces significant difference in cooling rate inside the casting (Figure 1a). The die-set containing a patented technique was employed to measure the temperature variation in the casting during solidification [7] (Figure 1b). The locations of the thermocouples for temperature measurement are shown in Figure 1a.

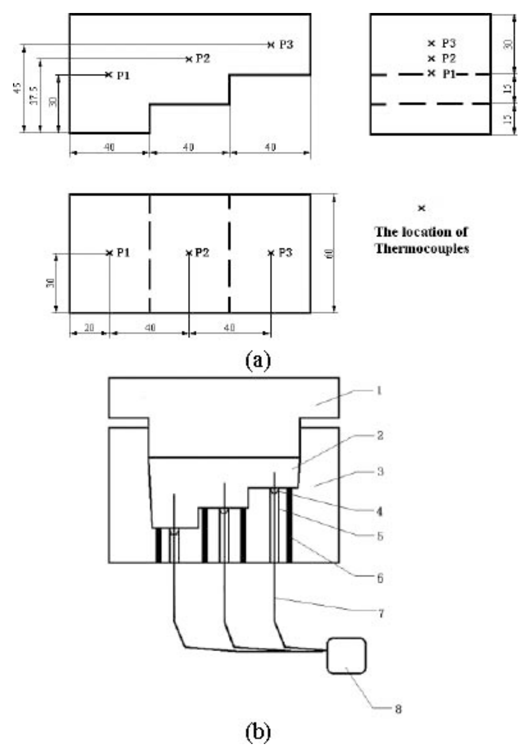

Figure 1. The casting geometry, the location of the thermocouples for temperature measurement, and the die-set configuration,

where 1 is the punch, 2 the casting, 3 the lower die, 4 the fixer for thermocouples, 5 the channel for inserting the thermocouples into the die, 6 the ejector, 7 the thermocouples, and 8 the data acquisition instrument.

2.3 Squeeze Casting Procedure

The squeeze casting process involves the following steps: (a) The die and the punch were preheated and maintained at a temperature around 470-500K; (b) Ingots of AZ91D magnesium alloy were melted under protective atmosphere (N_2+0.5%SF_6) in a resistance furnace; (c) The liquid metal was poured into the mold at about 970K, and after the pouring process, the die was closed immediately and a prescript pressure (30, 70 or 100MPa) was applied on the liquid metal as quickly as possible to minimize the cooling and solidification before the pressure was applied. The pressure was maintained until the casting fully solidified; (d) After the solidification was fully completed, the casting was ejected from the die.

3. Results and Discussion

3.1 Liquidus Temperature

Figure 2 shows the effect of the applied pressure on the cooling curves. It can be seen for all the three cases that, once the pressure was applied, the temperature increased rapidly until reaching a plateau, i.e., the liquidus temperature. Then, the temperature was kept almost constant for a certain period of time before starting to decrease. The applied pressure influences the attainable level and the duration time of the liquidus plateau. The measured liquidus temperature of AZ91D magnesium alloy is 873.15K, 875.75K and 877.95K for the applied pressure of 30MPa, 70MPa and 100MPa, respectively. Compared with the liquidus temperature of 868K under atmospheric pressure, the present experimental measurement indicates that the liquidus temperature of AZ91D magnesium alloy increased by 5.15K, 7.75K and 9.95K under the pressures of 30MPa, 70MPa and 100MPa, respectively.

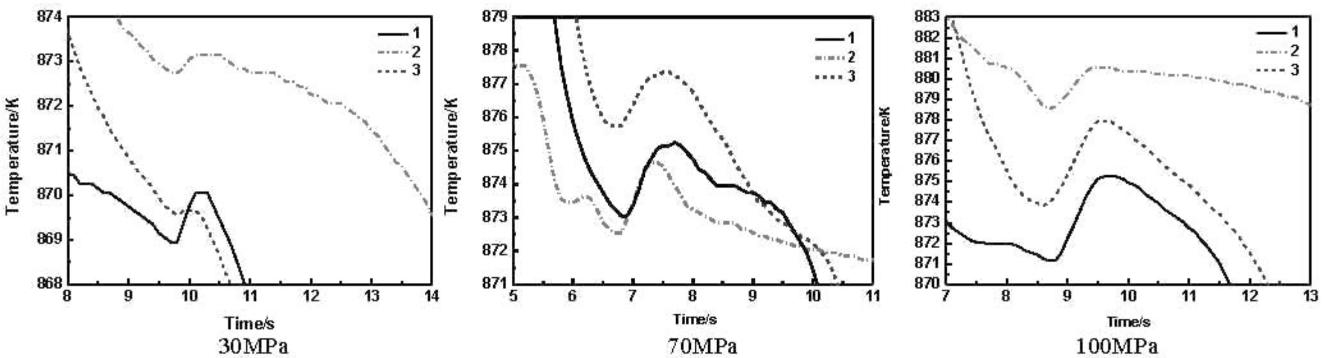

Figure 2 The effect of the applied pressure on the liquidus temperature

3.2 Microstructure characterization

Metallographic samples were taken from the castings as shown in Figure 3. The red face is the position where the microstructure is observed. Polished samples were etched in a solution of picric acid, glacial acetic acid, phosphoric acid and alcohol (0.8g picric acid, 0.01ml glacial acetic acid, 0.01ml phosphoric acid and 20ml alcohol). Examples of as-cast microstructure under different applied pressures are shown in Figure 4. The grains have different color under polarized light and the magnesium dendrite is of six-fold symmetry. With increase of the applied pressure, the microstructure becomes less dendritic.

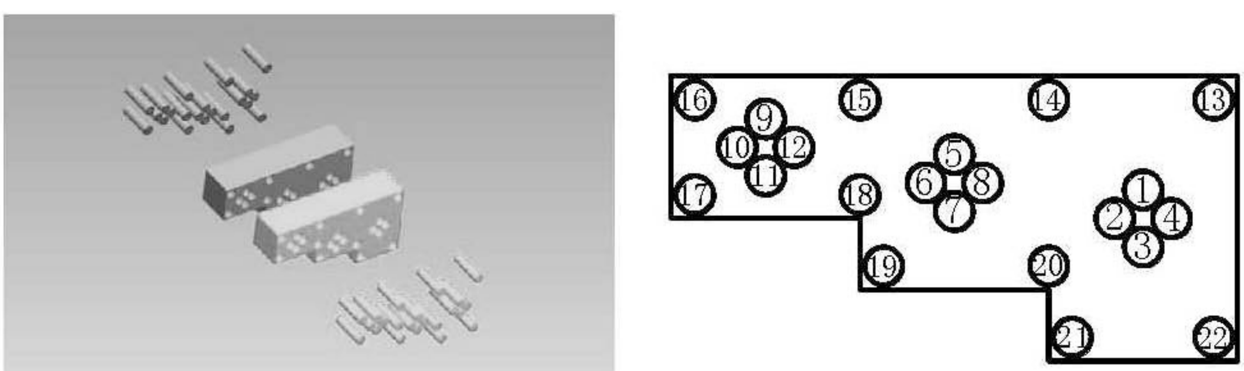

Figure 3 A schematic of sampling for metallographic observation

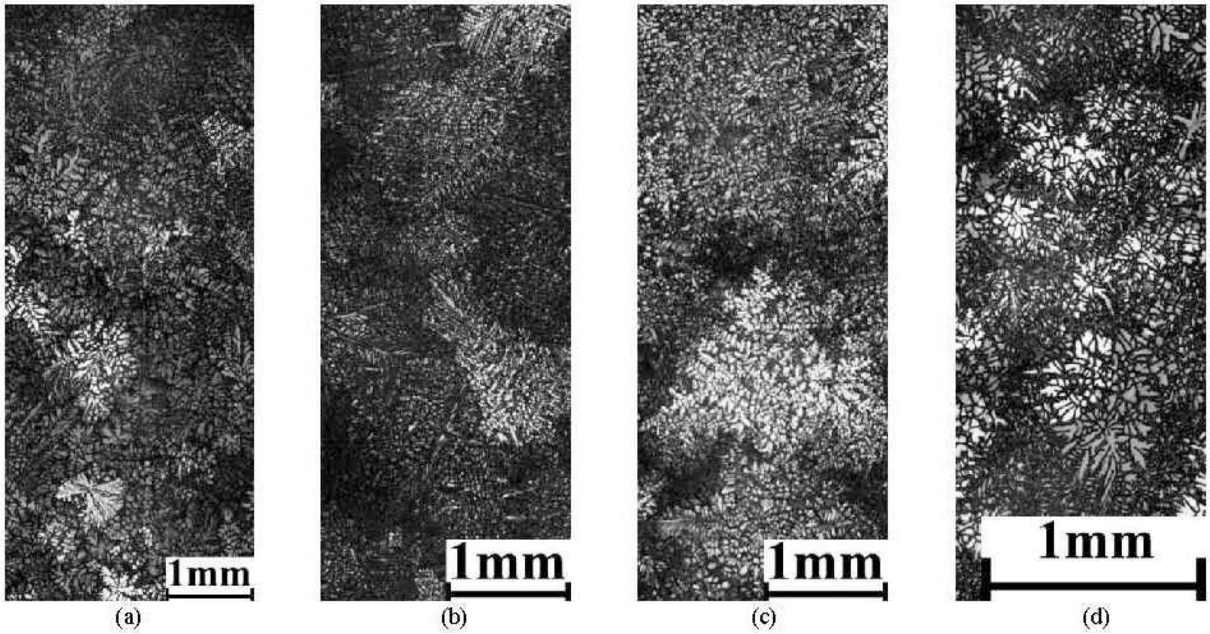

Figure 4 The microstructure of the castings produced under (a) atmospheric pressure, (b) 30MPa, (c) 70MPa, and (d) 100MPa

3.3 Grain size

The grain size of the as-cast microstructure of the castings were measured according to the ASTM E112 [8] intercept method. The grain size data are shown in Figure 5. We can see that with increase of the applied pressure the as-cast grain size decreases and the grain size at different positions in the casting becomes more uniform. The average grain size decreases from 770.5μm to 292.9μm when the applied pressure increases from 30 to 100MPa.

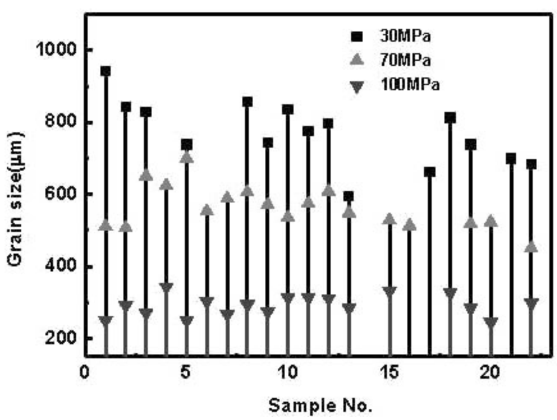

Figure 5 The grain size of the as-cast samples under different applied pressures

3.4 Mechanical property

Tension test specimens were made according to ASTM B557M [9]. The step-shaped casting was cut into samples as shown in Figure 6(a) and each of the specimens has a location coordinate in the casting. The UTS (Ultimate Tensile Strength) of the samples under 30MPa, 70MPa, 100MPa and 130MPa is shown in Figure 6(b).

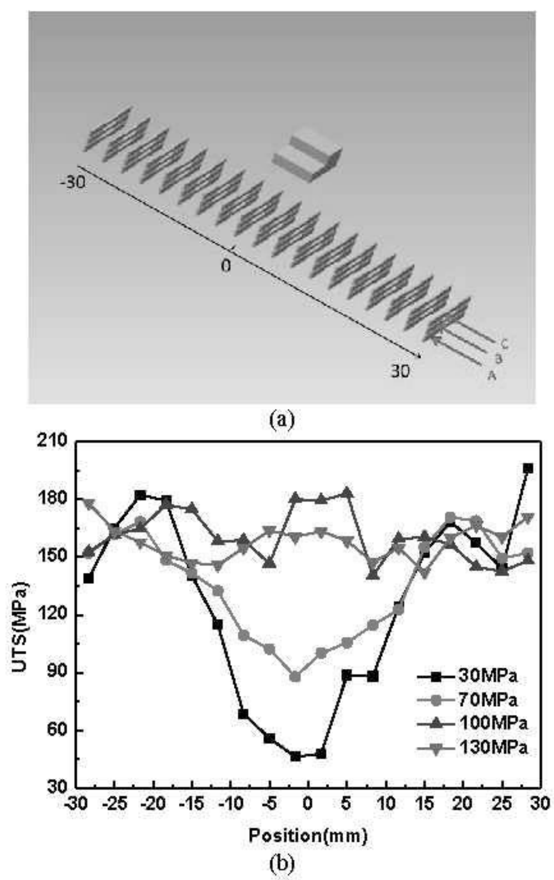

Figure 6 A schematic of the tensile test specimens and the UTS at different locations in the castings produced under different pressures

For the samples of 30MPa, the central part of the casting has much lower UTS than the part near the mold wall. With increase of the pressure, the UTS at the casting center increases remarkably. When the applied pressure reaches 100MPa or a higher level, the UTS in the casting varies at a relatively high level, which means the mechanical property of the whole casting tends to be uniform.

4. Conclusion

1. The application of external pressure affects the solidification process of squeeze casting. The liquidus temperature of AZ91D magnesium alloy rises as the applied pressure increases. The experimental results indicated that the liquidus temperature of AZ91D magnesium alloy increased by 5.15K, 7.75K and 9.95K under the applied pressure of 30MPa, 70MPa and 100MPa, respectively.
2. The grains were refined by applying pressure, and in the range of the applied pressures in the experiments, the grain size decreases with the increase of the applied pressure.
3. The applied pressure improved the mechanical property. An applied pressure higher than 100MPa is required to make the UTS uniform in the whole casting for the geometry employed in the present study.

Acknowledgements

This work is funded by the National Natural Science Foundation of China (Grant No. 51175291), the General Motors Global Research and Development Center, Tsinghua University Initiative Scientific Research Program, and the MoST (Ministry of Science and Technology) of China under the contracts of No. 2010DFA72760 and 2011DFA50909.

References

[1] D. Sachdeva et al., "Microstructure and corrosion characterization of squeeze cast AM50 magnesium alloys", *Metallurgical and Materials Transactions B*, 41(2010), 1375-1383.

[2] B. C. Liu, S. M. Xiong, "High pressure die casting process of magnesium alloys and its modeling and simulation for automobile industry", *Journal of Automotive Safety and Energy*, 1(2011), 1-11.

[3] M. Masoumi, H. Hu, "Influence of applied pressure on microstructure and tensile properties of squeeze cast magnesium Mg-Al-Ca alloy", *Materials Science and Engineering A*, 528(2011), 3589-3593.

[4] S. Kleiner et al., "Microstructure and mechanical properties of squeeze cast and semi-solid cast Mg-Al alloys", *Journal of Light Metals*, 2(2002), 277-280.

[5] Y. L. Yang et al., "Study on microstructure of squeeze casting AZ91D alloy", *Materials Science and Technology*, 27(2011), 189-193.

[6] A. Yu et al., "Pressurized solidification of magnesium alloy AM50A", *Journal of Materials Processing Technology*, 191(2007), 247-250.

[7] Z. Q. Han et al., "A die-set for directly measuring the temperature variation in solidification process of squeeze casting", *China Patent*, 201010249074.0.

[8] ASTM E112-10: Standard Test Methods for Determining Average Grain Size.

[9] ASTM B557M-10: Standard Test Methods of Tension Testing Wrought and Cast Aluminum- and Magnesium-Alloy Products [Metric].