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Effect of specific pressure on microstructure and mechanical properties of squeeze casting ZA27 alloy

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Abstract: The effect of specific pressure on the microstructure and mechanical properties of ZA27 squeezed castings with high height-to-thickness ratio was studied. The results of DTA and SEM show that at high specific pressure the eutectic reaction of squeeze casting ZA27 alloy is restrained, and the final solidified structure is (η+ε) phases instead of eutectic phase (β+η+ε). At the same time, the primary reaction is promoted in squeeze casting ZA27 alloy solidified at high pressure, and the fine microstructure is obtained with the increase of pressure. Al and Cu elements are homogeneously distributed in matrix of squeeze casting ZA27 alloy. The homogenously distributed high-density fine ε phase can effectively hinder dislocation motion, and then the strength and plasticity of squeeze casting ZA27 alloy are increased.
Key words: ZA27 alloy; squeeze casting; specific pressure

1 Introduction

Zinc-based alloys containing 8%−27% aluminum, 1%−3% copper and a marginal quality of magnesium are potential substitute for bronzes, aluminum alloys, cast irons and steels for a variety of engineering applications[1−2]. In spite of a number of merits, such as good castability, high mechanical properties and excellent wear resistance, the alloys suffer from porosity, especially for ZA27 alloy, due to its wide range of solidification temperature[3].

In recent years, a new forming technology, squeeze casting, has been developed. Squeeze casting is also known as liquid metal forging, squeeze forming, extrusion casting and pressure crystallization. It is a casting process in which liquid metal solidifies under the direct action of pressure. The major advantages of squeeze casting are: 1) produced parts are free of gas porosity or shrinkage porosity; 2) feeders or risers are not required and therefore less metal wastage occurs; 3) alloy fluidity (castability) is not critical in squeeze casting as both common casting alloys and wrought alloys can be squeeze cast to net shape with the aid of pressure; and 4) squeeze castings can have enhanced mechanical properties as wrought products[4−6]. On the other hand, some results show that the mechanical properties of squeeze casting alloys increase; the grain size and the dendrite arm spacing decrease and more dendrites appear with the increase of applied pressure[7−9].

Many researchers have carried out research work on squeeze casting of Zn-Al alloy[10−11]. The squeeze castings with small height-to-thickness ratio (<3) have been studied extensively, such as high-strength Zn-Al alloys in squeeze casting used for some gears[12]. However, little work has been reported on the squeeze castings with high height-to-thickness ratio[13]. In this work, the effect of pressure on microstructure and mechanical properties of ZA27 alloy with high height-to-thickness ratio prepared by squeeze castings was studied.

2 Experimental

Aluminum, zinc and magnesium of 99.99% (mass fraction) purity and Al-50%Cu master alloys were used to produce Zn-Al alloy ingots. The composition of sample is as follows: Al, 27.1%; Cu, 1.61%; Mg, 0.02%, Zn balance (mass fraction). Plunger type direct squeeze casting unit is used in this study. The unit consists of cylindrical type steel die, crucible surrounded by induction

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coil and 5 000 kN hydraulic press. The cylindrical squeeze castings with high height-to-thickness ratio (*d* 50 mm× 350 mm) were obtained finally. The processing parameters of squeeze casting are as follows. The height-to-thickness ratio of castings is 7; the mold temperature is (170±5) ℃; the pouring temperature is (630±5) ℃ and the dwell time is 45 s.

Each specimen was sectioned longitudinally at mid-width using a wheel cutter, ground by SiC papers and polished with 0.05 mm alumina powder. Microstructures were examined using a scanning electron microscope S−570 equipped with an EDX system for element analysis. The DTA analysis was performed at a scanning rate of 10℃ /min in a TGA/SDTA851^e apparatus under protective argon atmosphere. Hardness measurement was preformed by Brinell hardness tester with a load of 2.45 kN and a dwell time of 30 s. Tensile specimens were made according to GB145—59. Tensile strength and elongation measurement were preformed on WE−10A tester with a tensile speed of 0.1 mm/s.

3 Results

3.1 Microstructure

Fig.1 shows microstructures of ZA27 alloy in different specific pressures. The ZA27 alloy prepared by gravity casting consisted of primary α phase, peritectic β phase and ternary eutectic ($\beta+\eta+\varepsilon$), where α phases solidified as coarse fir-tree crystal and even second dendrite appeared on them (Fig.1(a)). The primary α phases became finer in squeeze cast specimen (seen in Figs.1(b) and (c)) and with the increase of specific pressure the microstructure of ZA27 alloy became fine, and even primary α phases appeared as nodular when the pressure reached 1 000 MPa (seen in Fig.1(d)).

In the gravity casting specimen the lamellar eutectic structure ($\beta+\eta+\varepsilon$) distributed between coarse dendrites (Fig.2(a)). However, the eutectic structure ($\beta+\eta+\varepsilon$) was not found in specimen squeeze cast at 1 000 MPa, while the ($\eta+\varepsilon$) phases appeared between dendrites (Fig.2(b)).

3.2 Distribution of alloying elements

The effects of specific pressure on distribution of Al and Cu elements in matrix of ZA27 alloy are shown in Fig.3. In gravity castings, Al element mainly distributed in the center of α crystal grains and the β phases (seen in Fig.3(a)). Inversely, there were few Cu atoms dissolved in α and β phases and the majority of them were released to eutectic composition and finally formed coarse $\varepsilon(CuZn_4)$ particles on boundary.

While in squeeze castings, Al and Cu elements were homogeneously distributed (seen in Fig.3(b)). At high pressure, due to the decrease of diffusion coefficient of alloying elements, the solid solubility of Cu in α and β phases increased largely, finally the high-density fine $\varepsilon(CuZn_4)$ phases homogenously precipitated on α and β phases. Then, the Cu atoms which dissolved in η phase formed fine ε phase with Zn atoms. Thus, these high-density fine ε phase which homogenously distributed on

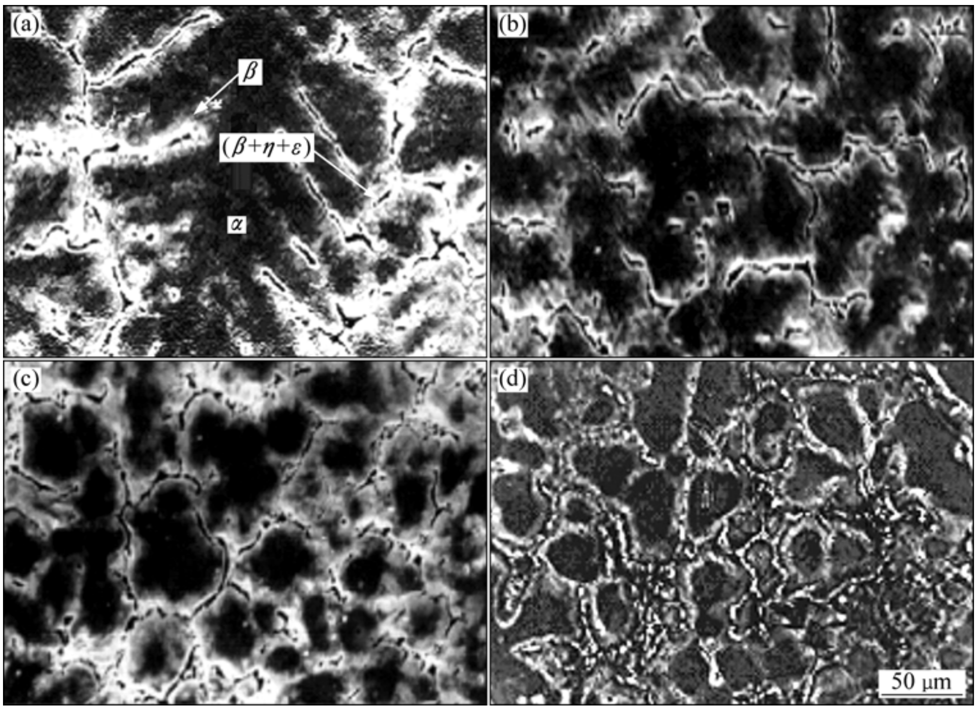

Fig.1 Microstructures of ZA27 alloys squeeze cast at different specific pressures: (a) 0 MPa; (b) 500 MPa; (c) 750 MPa; (d) 1 000 MPa

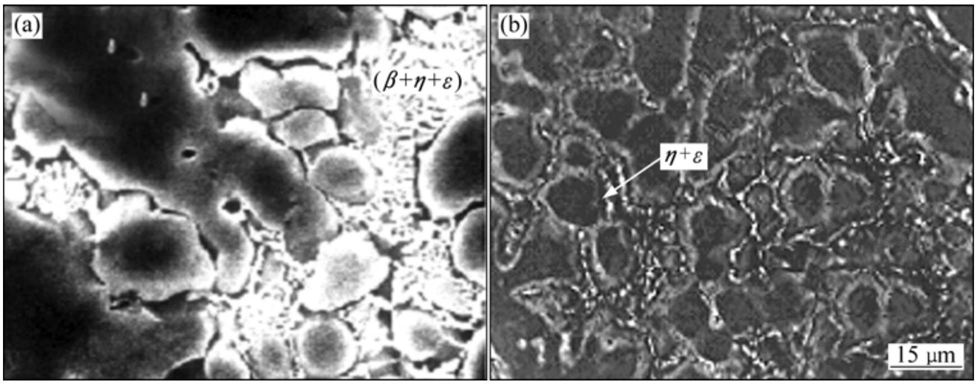

Fig.2 Effect of specific pressure on eutectic structure of ZA27 alloy: (a) 0 MPa; (b) 1 000 MPa

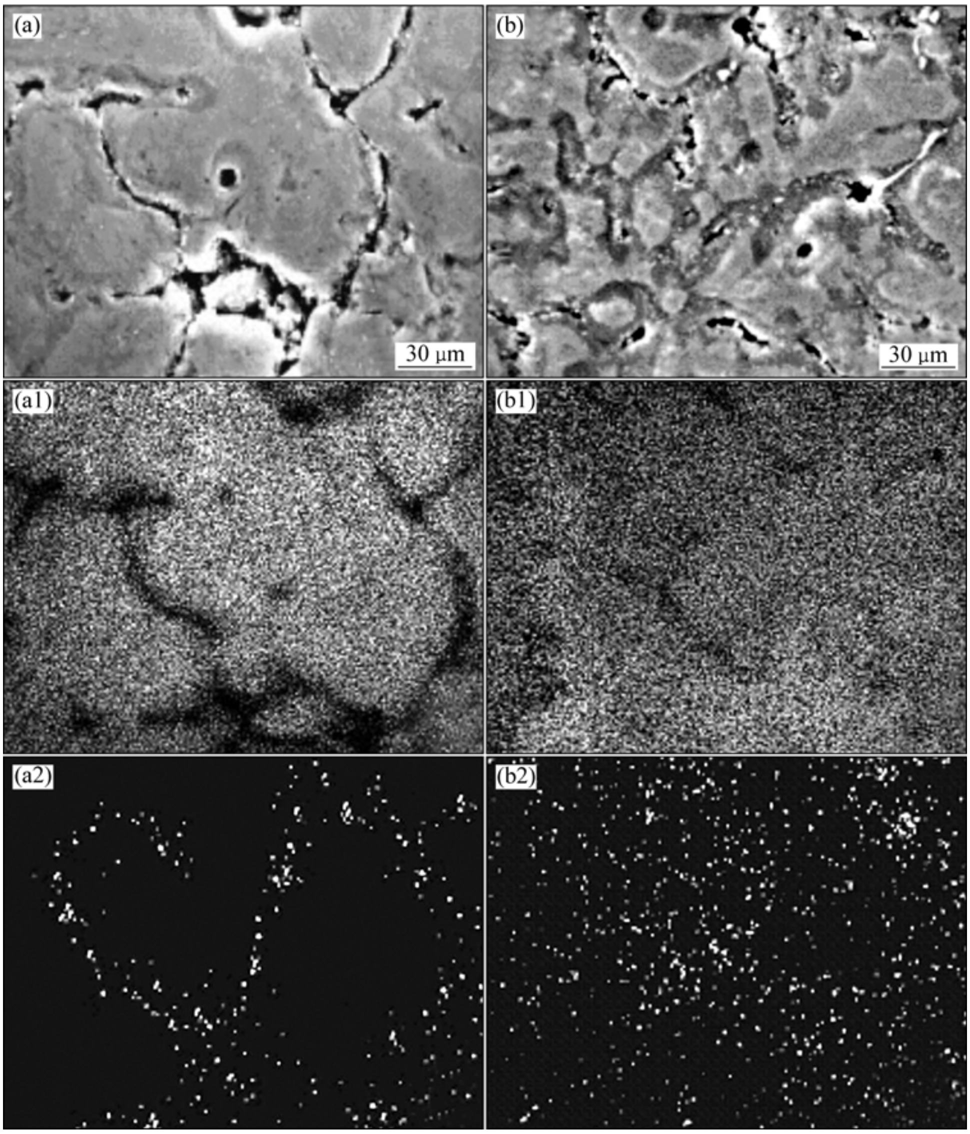

Fig.3 Image mapping of ZA27 alloy at different specific pressures by EDS: (a) 0 MPa; (b) 750 MPa: (a1), (b1) Distribution of Al element; (a2), (b2) Distribution of Cu element

matrix of alloy could effectively restrict dislocation motion, and then increased the strength and plasticity of ZA27 alloy[14−16].

3.3 Differential thermal analysis

Fig.4 shows the DTA curves of specimens squeeze cast at different specific pressures. There were three

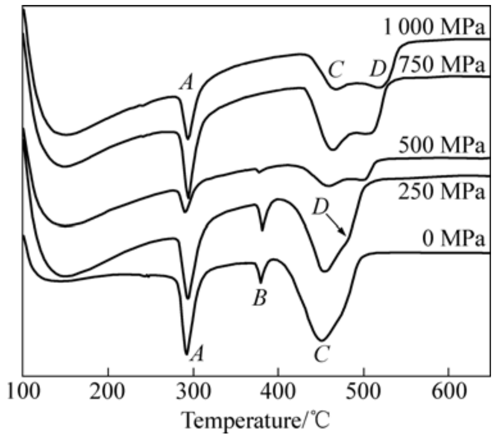

Fig.4 DTA curves during remelting for squeeze casting ZA27 alloy prepared at different specific pressures

endothermic peaks marked as *A*, *B* and *C* on DTA curves of gravity castings corresponding to eutectoid reaction, eutectic reaction and peritectic reaction, respectively.

With the increase of pressure, some phenomena were observed on DTA curves. Firstly, endothermic peak *B* corresponding to eutectic reaction became small with the increase of pressure, and eventually disappeared when the specific pressure exceeded 500 MPa. Secondly, on DTA curves of squeeze castings, another endothermic peak marked as *D* appeared beside peak *C*. On DTA curves of 250 MPa, endothermic peak *D* and *C* overlapped. With the increase of specific pressure, the endothermic peak *D* appeared clearly. The temperatures of endothermic peaks on DTA curves are listed in Table 1. With the rise of specific pressure, all peak temperatures increase. This result is consistent with the report of melting point of alloy increase with the pressure[11]. On DTA curves of 750 MPa and 1 000 MPa, there were three endothermic peaks *A*, *C* and *D*, corresponding to eutectoid reaction, peritectic reaction and primary reaction, respectively.

Table 1 Temperature (℃) of endothermic peaks corresponding to DTA curves

Pressure/MPa	A	B	C	D
0	288.61	377.30	447.61	475.20
250	289.27	378.23	450.59	479.55
500	288.47	376.25	456.50	502.60
750	290.06	−	458.73	509.68
1 000	290.19	−	460.71	515.93

Form above results, it can be deduced that eutectic reaction was restrained while the primary reaction was promoted in ZA27 alloy during solidifying at high pressure. This viewpoint agreed with the results of SEM.

3.4 Mechanical properties

Fig.5 shows the variation in mechanical properties with specific pressure for the ZA27 squeeze castings with high height-to-thickness ratio. Hardness, tensile strength and ductility increased with the applied pressure, similar to other works[7−9]. Also, comprehensive mechanical properties of squeeze castings attained peak values at 750 MPa.

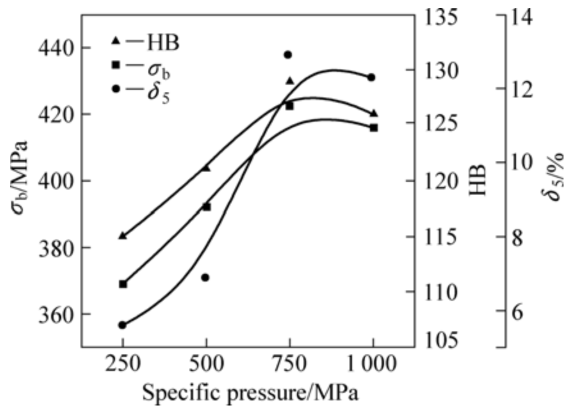

Fig.5 Effect of specific pressure on mechanical properties of squeeze cast ZA27 alloys

4 Discussion

In the solidification process of ZA27 alloy, primary phase *α* precipitates firstly from liquid phase and then peritectic reaction $L+\alpha\rightarrow\beta$ happens. However, at high specific pressure, the degree of these two reactions becomes greater due to the fact that the eutectic point of ZA27 alloy removes to right (the direction of rich Zn), thus the quantity of remaining liquid phase is reduced greatly. On the other hand, because the melting point of ZA27 alloy is elevated at high pressure, the degree of super-cooling increases[6], thus the nucleate rate of primary reaction increases largely during solidifying. This is also the reason of microstructure refining. In addition, the remaining phase is in deep super-cooling state when temperature is dropped to eutectic point. Therefore, the new *β* phases need not nucleate again but grow up directly attached on peritectic phase *β* which is directly contacted with remaining liquid metal. At the same time, *η* phase forms directly in the remaining phase because solid solubility of Al in *η* phase is increased largely at high pressure.

The improvement of mechanical properties is attributed to eliminating of micro-pores in the alloy caused by applied pressure[9]. On the other hand, this is because the microstructure refining as the applied pressure is increased as mentioned above. Both of the increased tensile strength and hardness are attributed to not only the microstructure refining, but also the enhancement of solubility of solute atom such as Cu, Mg and Al.

5 Conclusions

1) Hardness, tensile strength and ductility of ZA27 squeezed casting with high height-to-thickness ratio are greatly affected by applied pressure.

2) The results of DTA and SEM show that at high specific pressure the eutectic reaction of squeeze cast ZA27 alloy is restrained, and the final solidified structure is (η+ε) phases instead of eutectic phase (β+η+ε).

3) The primary reaction is promoted in squeeze cast ZA27 alloy solidified at high pressure and the fine microstructure is obtained with the increase of pressure.

4) Al and Cu elements are homogeneously distributed in matrix of squeeze cast ZA27 alloy. The high-density fine ε phase which is homogenously distributed on matrix of alloy can effectively block the movement of dislocation, and then the strength and plasticity of ZA27 alloy are increased.

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