EFFECTS OF TEMPERATURE TREATMENT ON MICROSTRUCTURE AND PROPERTIES OF ZA27 ALLOY①

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ABSTRACT The effects of melt superheating and thermal-rate treatment on the mechanical properties, composition segregation, underside shrinkage and intergranular corrosion of ZA27 alloy were studied. The results showed that through proper treatment, the microstructure of the alloy was refined and well distributed, the tendencies of segregation, formation of underside shrinkage defects and intergranular corrosion were reduced, and the tensile strength and the hardness were improved obviously. According to the theory of multicrystal transformation, the mechanism of the property changes of ZA27 alloy was discussed.

Key words ZA27 alloy high-Al Zn-based alloy thermal-rate treatment of melt

1 INTRODUCTION

ZA27 alloy as a representative of the high-Al Zn-based alloys, which possesses advantages in mechanical properties, technological properties and cost, can be used as a new type of structural material and wear-resisting material. It can compete with some high-strength cast irons, bronzes and aluminium alloys. In recent years, it has been developed rapidly and used widely[1,2]. However, this alloy has low ductility, and is likely to age and form underside shrinkage defects. It is generally considered that the melting temperature of the alloy should not be higher than 700 ℃, but little work has been done on the solidification structure under superheating and its effects on properties of the alloy. This paper studied the effects of the temperature treatment on the microstructures and properties of ZA27 alloy so as to improve its properties.

2 EXPERIMENTAL

The mother alloy with composition (%) of 26～28 Al, 2.0～2.5Cu, 0.03～0.05Mg, and balance Zn was smelted in a SG-5-12 crucible resistance furnace. The tensile test was conducted on a 60 t universal strength tester. The examinations of the morphologies and microstructures were performed using JXA-840 SEM equipped with electron microprobe, 3080 X-ray fluorescence spectrometer, D/Max-rc X-ray diffractometer and XJG-04 optical microscope.

The centrifugal segregation test was carried out with a self-made apparatus: put the test alloy in a d15 mm Al_2O_3 tube and closed the two ends, heated the alloy up to the test temperature, placed the tube on an apparatus driven by frequency regulator and alternating generator, rotated the tube horizontally at a rate of 750 r/min for 1.5 min, then quenched the tube containing the alloy melt into the 20 ℃ water.

The conventional melting technique was adopted to melt the alloy and heat the alloy melt to 620 ℃. The melt was held at this temperature for 10 min before casting. The thermal-rate treatment procedures were as fol-

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lows: melted 70%~80% of the furnace charge and heated it to the predetermined superheating temperature; held it at the temperature for 10 min; added the rest charge preheated at 200 ~ 300 ℃; quickly stirred the melt; cast the alloy at 620 ℃.

The differential thermal analysis test was carried out with a DT-28 thermal analyser: placed the sample in an Al_2O_3 crucible protected by nitrogen atmosphere; heated the sample from room temperature to 990 ℃ at a rate of 10 ℃/min; recorded the ΔT-T curve (ΔT stands for the temperature difference between the test sample and the standard Al_2O_3 sample; T for the temperature of furnace.).

3 RESULTS

3.1 *Microstructures at Different Superheating Temperatures*

The alloy melts at 840 ℃ and 700 ℃ were cast into d15 mm metal molds. The morphologies were shown in Fig. 1. Electron microprobe analysis was carried out on the three main phases presented in Fig. 1(b). The results were given in Table 1. The black structure is Al-rich primary α-phase, namely, the Zn-containing aluminium solid solution. The grey structure is Zn-rich transitional α'-phase. The net-like white phase is Zn-Al-Cu eutectic structure. The bright blocks at the grain boundaries are ε-phase, namely the electronic compound-$CuZn_4$ based solid solution. Under different superheating temperatures, the dendritic morphologies and distributions are different. At higher temperatures, the boundaries of the black phase are indistinct, the amounts of the α'-phase is more and that of the Al-rich α-phase and the Zn-rich eutectic phase decrease. This implies that after higher temperature superheating, the micro-compositions of the alloy tends to be homogeneous, the microstructures are obviously refined, the amount of the eutectic phase decreases, and the eutectic phase presents discontinuity. It can be seen from Fig. 1(c) that speeding-up solidification rate of the alloy would make this phenomenon more significant.

Fig. 1 Microstructures of ZA27 alloy at different states

(a)—cast at 840 ℃, ×200;
(b)—cast at 700 ℃, ×200;
(c)—liquid-quenched from 840 ℃, ×1 000

Table 1 Composition analysis of ZA27 alloy

Structure	Content/%		
	Al	Zn	Cu
α (black)	50.37	47.03	1.10
α' (grey)	26.43	70.34	1.89
Eutecticum (white)	1.97	92.69	3.64

3.2 *Solidification Segregation*

Under conventional smelting conditions, the composition segregation tendency of the ZA27 alloy is relatively serious, which is due to the fact that the solidification range of this alloy is wideded up to 110 ℃, thus the primary α-phase of smaller density floats upward and the eutectic phase of larger density sinks downward. In order to examine the influence of the temperature of the melt on the structural segregation, centrifugal solidification tests were carried out with the 840 ℃ and 600 ℃ melts. The micro-composition analyses were performed on different cross-sections along the axis of centrifugal solidification, as shown in Table 2, which indicates that under the actions of the centrifugal forces, there occurs composition segregation for each element in the high- and low-temperature samples to some extent. But the segregation in the 840 ℃ melt is greatly reduced. As compared with that in the 600 ℃ melt, the segregations of Al, Zn and Cu at a distance of 45 mm from the axial center are reduced by 45%, 54% and 28% respectively. This means that higher-temperature superheating can improve the composition homogeneity. If this feature of the melt at higher temperature can be retained, it can reduce the segregation of the alloy, underside shrinkage defects and intergranular corrosion caused by the composition segregation. Metallographic examinations show that the σ-phase at the center of the 600 ℃ centrifugally solidified sample is much more than that on the surface; but this phenomenon in the 840 ℃ centrifugally solidified sample is not evident, namely the composition segregation is slighter. Therefore, the composition homogeneity is closely related with the structure and the temperature of the melt.

3.3 *Mechanical Properties*

According to the study on the structures of melts, cooling the alloy melts rapidly can restrain the reverse transition of the higher-temperature structures to a great extent[3,4]. For this purpose, the thermal-rate treatment was used to examine the effects of the superheating temperature of the melt on the mechanical properties of the alloy. The results are given in Fig. 2. It is clear that the superheating temperatures of the melts affect the mechanical properties of the castings; after 840 ℃ superheating treatment the maximum σ_b and δ values are achieved at the same time.

3.4 *Tendency of Formation of Underside Shrinkage Defects*

Because of its wide solidification range, ZA27 alloy is likely to form underside shrinkage defects. Sahoo *et al*[5] and Barhurst *et al*[6] have tried to remove these defects by improving the casting technology and adding alloying elements. This paper studied the effect of the thermal-rate treatment on the removal of these defects. Fig. 3 shows the morphologies of the underside shrinkage defects of ZA27

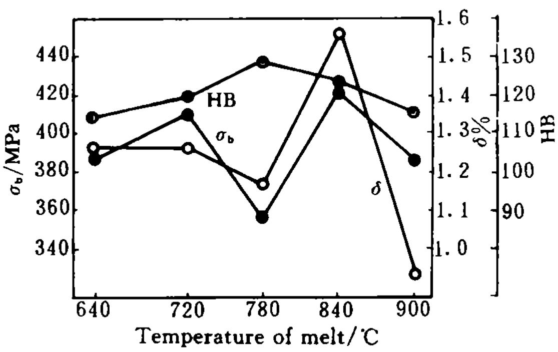

Fig. 2 Effects of superheating temperature on mechanical properties

Table 2 Composition segregation of centrifugally solidified samples (%)

Composition	Distance from center (600 ℃)/mm			Distance from center (840 ℃)/mm		
	0	22	45	0	22	45
Al	30.86	26.18	22.74	31.19	29.14	26.73
Zn	67.17	71.40	74.82	67.51	68.82	71.01
Cu	1.98	2.21	2.44	1.93	2.04	2.26

alloy after different technological treatments. It can be seen that the sample obtained from the conventional smelting technology have larger and deeper underside shrinkage defects, while those treated by the thermal-rate treatment have much smaller and more shallow underside shrinkage defects. This demonstrates that the thermal-rate treatment can significantly remove the underside shrinkage defects.

3.5 *Densities of Castings*

The densities of ZA27 alloy after different treatment obtained by the balance weighing method were given in Table 3. The results show that the densities of the sand mold sam-

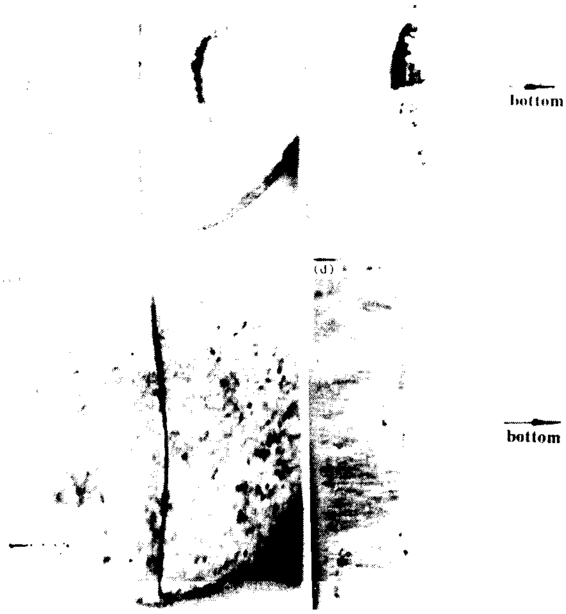

Fig. 3 Morphologies at the sample bottom of ZA27 alloy after different treatments
(a) Morphology at the bottom after conventional technology treatment;
(b)—vertical section at the bottom after conventional technology treatment;
(c)—morphology at the bottom after temperature treatment(superheating temperature 840 ℃);
(d)—vertical section at the bottom after temperature treatment

ples and the metal mold samples follow the same tendency, namely in the sequence of lower-temperature superheating, thermal-rate treatment and higher-temperature superheating from small to large.

3.6 *Intergranular Corrosion*

Because the phases presented in Zn-Al alloys have different electric potentials, the intergranular corrosion is likely to occur in these alloys. This contributes mainly to the aging of these alloys[7]. The weight changes of ZA27 alloy caused by the corrosion are given in Table 4. It is clear that the weight changes follow the samle tendency as the density changes.

3.7 DTA *Test*

Fig. 4 shows the differential thermal analysis (DTA) pattern of ZA27 alloy, in which the first peak represents the eutectoid change; the second peak represents the decomposition change of the solid solution; the third peak corresponds to the melting of the alloy; the last strong exothermic peak corresponds to a strong phase transformation. By means of X-ray diffraction, it is demonstrated that there occured an oxidation reaction of zinc at this temperature, and there were formed ZnO and micro Zn_3N_3. There are also present peaks of weak heat effects in the range 815 ℃ to 880 ℃, which represents the changes of the structures of the melt. The thermal-rate treatment was performed in this temperature range.

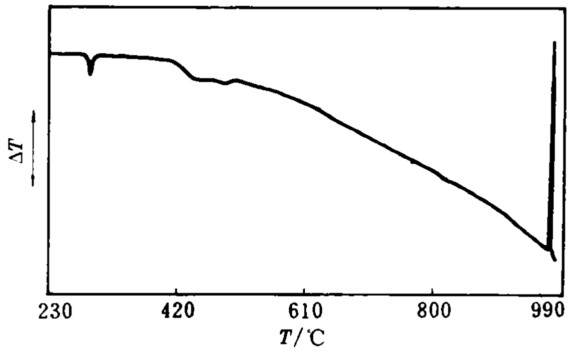

Fig. 4 DTA curve of ZA27 alloy

4 DISCUSSION

The experimental results show that proper treatment of the melt can bring about changes in the structures of ZA27 alloy, thus affecting the properties. How to understand and explain those phenomena?

An[8] thought that the metallic melts are composed of numerous atomic groups, whose average size and travelling rates are related with the temperature. According to this theory, that the phases in lower-temperature melts are easier to be separated than those in higher-temperature melts in the centrifugal segregation test is related to the differences in their structures. It can be conceived that there exist more Zn-Zn and Al-Al elemental atomic groups, the relatively weighty Zn-Zn atomic groups are swung to the surface and the relatively light Al-Al atomic groups are left at the center of the sample. At higher temperatures,

Table 3 Densities of ZA alloy after different treatments (g/cm^3)

Mould	Superheated at 640 ℃, directly cast	Thermal-rate treated at 840 ℃	Superheated at 840 ℃, directly cast
Metal mould	4.9652	4.9793	4.9842
Sand mould	4.8667	4.9684	5.0243

Table 4 Corrosion weight gain of ZA27 alloy after different treatments (mg/cm^3)

Technology	Sample 1	Sample 2	Sample 3	Mean
Conventional smelting technology	5.691	3.678	4.531	4.633
Thermal-rate treatment (840 ℃)	1.889	2.840	2.114	2.281
Directly cast at 840 ℃	1.753	1.472	1.637	1.621

the interactions between the atomic groups are weakened, the directivity is not strong, and the short-range ordered structures are changing[9]. The specific heat, melting heat and evaporation heat of zinc are much less than those of aluminium, respectively. This implies that the Zn-Zn bondings are much weaker, therefore, the zinc atoms can be easily activated. Increasing the temperature of the melt makes much more zinc atoms be in the activated states, then the Zn-Zn atomic groups are decomposed into finer and more dispersive atomic groups and single atoms and can be combined with the aluminium atoms readily. At the same time, the additional effect of heat also makes other kinds of atomic groups decompose, thus making the microcomposition more homogeneous. Therefore, under the action of the same centrifugal force, the tendency of the composition segregation of the melt at higher temperatures is reduced, the homogeneous contribution of the composition and phases makes the defects of the underside shrinkage and the intergranular corrosion decrease.

The thermal-rate treatment can restrain the polycrystalline transformations on cooling to a large extent, and the structures of the melt at superheating states can be retained, thus helping to obtain refined structures.

In thermal-rate treatment, when the temperature of the melt is in the range from 720 ℃ to 900 ℃, the values of σ_b and δ display skipping changes. According to Fig. 4, the authors think that this may be related to the changes of the structure of the melt at different temperatures. Because of the increasing tendency of hydrogen solution and formation of oxide inclusions and no evident high-temperature structure features, the mechanical properties of the alloy treated at 780 ℃ are relatively lower. However, 840 ℃ is just in the temperature with structure changes in the melt, the effect of the structural changes is predominant, and the structural changes are favourable to the mechanical properties of the alloy at room temperature.

Through the above synthetic effects, the mechanical properties and the quality of ZA27 alloy are obviously improved. Therefore, to take advantages of the structural changes and the heredity of the metallic melt is a new effective way to improve the mechanical properties and the quality of the castings.

5 CONCLUSIONS

(1) Proper superheating treatment for the melt of ZA27 alloy can make the structures refined, the composition homogeneous, the eutectic phase reduced, thus reducing the tendencies of the composition segregations and the formation of shrinkage porosities.

(2) The utilization of thermal-rate treatment can help to improve the mechanical properties of ZA27 alloy. When the melt is superheated at 840 ℃, the alloy has relatively higher σ_b and δ values.

(3) After thermal-rate treatment, the tendency of the formation of the underside shrinkage defects in ZA27 alloy is greatly reduced, its density is increased, and its corrosion resistance is improved.

(4) There exist structural changes in the melt of ZA27 alloy. The thermal-rate treatment was carried out in the temperature range from 815 to 880 ℃, in which there are peaks of weak heat effects.

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