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Negative creep during compressive creep of as-cast ZA27 alloy ①

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Abstract: The negative creep during compressive creep deformation of as-cast ZA27 alloy was investigated at the temperature range of 20-160 ℃ and at compressive stress levels from 50-137.5 MPa with special apparatus. Results show that the negative creep in the alloy occurred respectively at 20 ℃ (50 MPa, 87.5 MPa and 100 MPa), 60 ℃(50 MPa and 87.5 MPa) and 100 ℃(50 MPa). According to the phase transformation and theoretical analysis, the negative creep resulted from volume expansion caused by four-phase transformation $\alpha+\varepsilon \rightarrow T'+\eta$ in the alloy. The theoretical analysis is consistent with the experiment results. And the values of negative creep depended on the difference between the compressive creep deformation and the volume expansion.

Key words: ZA27 alloy; compressive creep; negative creep; four-phase transformation
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1 INTRODUCTION

Among zinc-aluminum cast alloy, ZA27 alloy exhibits attractive physical and mechanical properties combined with good friction and wear resistance properties making it a bearing alloy replacing some copper alloys [1, 2]. However, some properties of this alloy which must be taken into account are comparatively low resistance to creep deformation, poor strength and its dimensional instability at moderately elevated temperatures[3-5]. The dimensional changes of as-cast ZA27 alloy on ageing were studied by some workers[1, 3, 6], but these results were obtained from the specimens without applied stress. During the researches on tensile stress creep deformation[7-11], since the creep deformation direction of ZA27 alloy was as the same as that of linear expansion of the alloy, the negative creep in the alloy could not occurred. However, in the case of ZA27 alloy, compressive loading is more common, the compressive creep behavior has become important in the alloy applications. Presently, the studies on compressive creep in the alloy are so scarce[12], the negative creep (negative plastic deformation during compression) has not been reported especially. However, the occurrence of the negative creep in ZA27 alloy was found at some temperatures and under some stresses used during our researches on the compressive creep, which is analyzed in this paper.

2 EXPERIMENTAL

2.1 Materials

The alloy (Zn-27% Al-2% Cu-0.01% Mg) for testing specimens was prepared using commercial-purity Zn (99.99%), Al (99.88%), Cu (99.0%) and Mg (99.85%) in a resistance furnace (SRJG-3-9) and degassed with a commercial degasser. The melt was poured into a Y-shaped sand mould at 580 ℃, and then the specimens with a dimension of d8 mm × 10 mm were machined from the Y-shaped ingots, the chemical composition and the tensile properties are listed in Table 1.

2.2 Procedure

Compressive creep test was carried out with special apparatus composed of constant pressurization, heating and temperature controller, collecting data and record devices, as shown in Fig. 1. The temperature could be maintained to within ±0.5 ℃ and the compressive creep deformation parameters were obtained by displacement transducer, and then recorded by a computer for the whole period of the test. The precision of the compressive creep deformation could be up to 0.000 1 mm. Different temperatures (20, 60, 100 and 160 ℃) and various compressive stress (50, 87.5, 100 and 137.5 MPa) were used respectively.

Table 1 Chemical composition and tensile properties of ZA27 alloy

w/%				Tensile properties	
Al	Cu	Mg	Zn	σ_b/MPa	δ/%
26.3	2.15	0.015	Bal.	408	5.4

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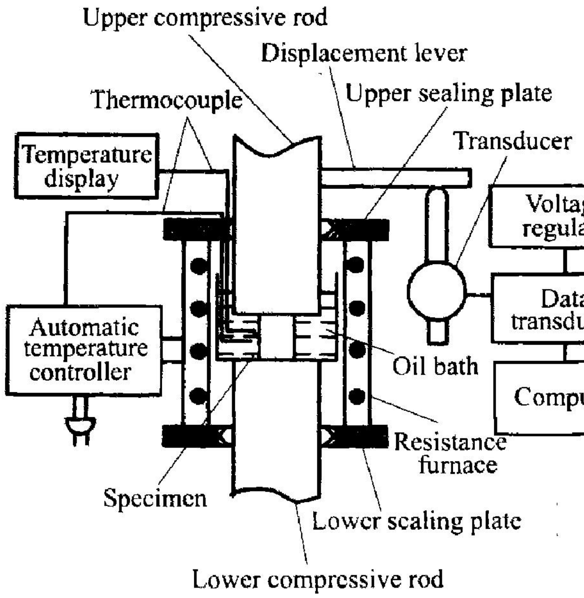

Fig. 1 Schematic of apparatus

3 RESULTS

The conditions of negative creep occurrence for ZA27 alloy are listed in Table 2. It shows that negative creep occurred for some combination of different compressive stress (50, 87.5 and 100 MPa) and temperature used. The typical negative creep curves for ZA27 alloy at 60 ℃(50 MPa) are shown in Fig. 2, and the temperature and stress range in which the negative creep occurred are shown in Fig. 3. Fig. 3 shows that the negative creep occurred at lower temperature and lower stress, and did not at higher temperature and higher stress.

Table 2 Negative creep deformation of ZA27 alloy at different temperature and stress

Temperature/ ℃	Stress/ MPa	Negative creep/ %	Negative creep time/ min
20	50	0.03	818
	87.5	0.06	63
	100	0.07	48
60	50	0.08	53
	87.5	0.15	37
100	50	0.12	32

4 ANALYSIS AND DISCUSSION

4.1 Phase transformation in ZA27 alloy

According to phase diagram of Al-Zn system, the structure of as-cast ZA27 alloy is composed of dendritic Al-rich α phase with the edge of β phase, and decomposed η′ phase in the interdendritic region, as well as a few ε ($CuZn_4$) phase[13]. Both β and η′ are metastable phases and decomposed after

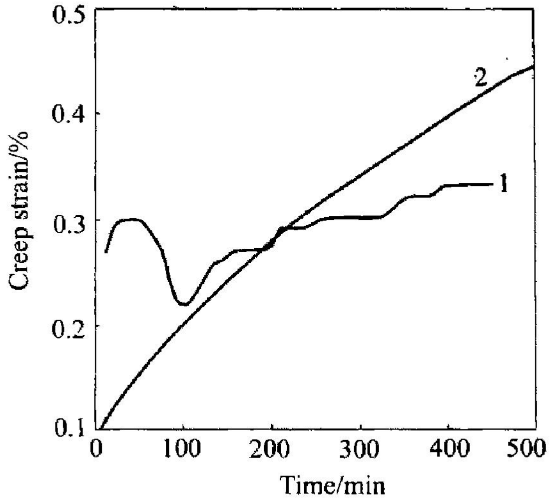

Fig. 2 Negative creep curves of ZA27 alloy at 60 ℃(50 MPa)
1 —Negative creep;
2 —Stabilized by heat treatment

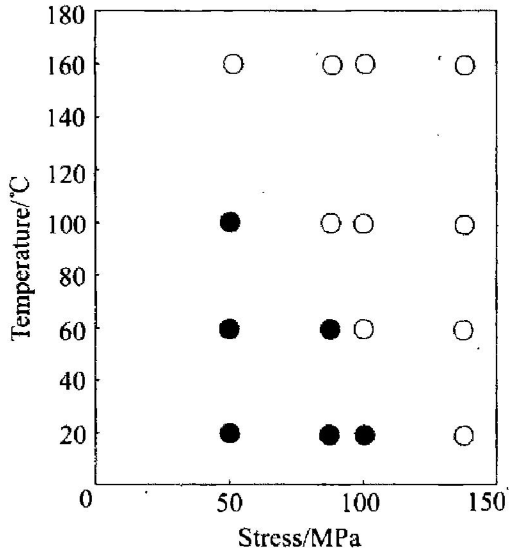

Fig. 3 Range of negative creep of ZA27 alloy
● —Negative creep;
○—Without negative creep

5 min aging at 90.4 ℃ into three phases α, ε and η phase[13], respectively, i.e. β → α+ ε+ η, η′ → α + ε+ η. ε phase is an instable phase at lower temperature and tends to transform into stable phase T' (Al_4Cu_3Zn) with a four-phase transformation, α+ ε → T' + η, at 268 ℃[14]. The studies in Refs. [13 - 15] showed that the four-phase transformation was the fastest at 250 ℃, thus, the volume expansion of the alloy needs long time at room or lower temperature because of less activation energy and dynamics for the phase transformation. However, under the conditions of tensile stress, the microstructure of Zn-Al-Cu alloy changed during creep deformation[15-17]. The higher applied stress involves the formation of more important density of defects, such as lattice defects and dislocations, which results in the four-phase reaction of α+ ε → T' + η and the reaction of T → θ′ + η in the zone of defects in ZA27 alloy.

In our tests, the specimen was held at constant temperature for 1.5 ~ 2 h before a load was applied to the specimen. Because the combination of temperature and stress provided the conditions of activation energy and dynamics for the four-phase transformation, the negative creep caused by the four-phase transformation occurred at lower temperature, and the extent of four-phase transformation, compressive creep rate and the time varied with temperature and stress used. The value of negative creep deformation (ζ) can be expressed as the difference between the compressive creep deformation (v_1) and volume expansion (v_2), i.e. $\zeta = v_1 - v_2$, when $v_1 < v_2$, the negative creep could be found. However, at higher temperature or stress, $v_1 > v_2$, the negative creep can not occur. The possible reason for this is that the volume expansion was cancelled by the compressive creep deformation. We have found that the negative creep was removed from the alloy specimens that were stabilized by heat treatment of 9 h at 250 ℃ and then 8 h at 80 ℃, as shown in Fig. 2. According to the X-Ray diffraction and SEM test, the ε phase was not found in the specimens stabilized by heat treatment, and T' phase occurred, shown in Fig. 4 and Fig. 5. It is believed that the negative creep in ZA27 alloy indeed resulted from the four-phase transformation.

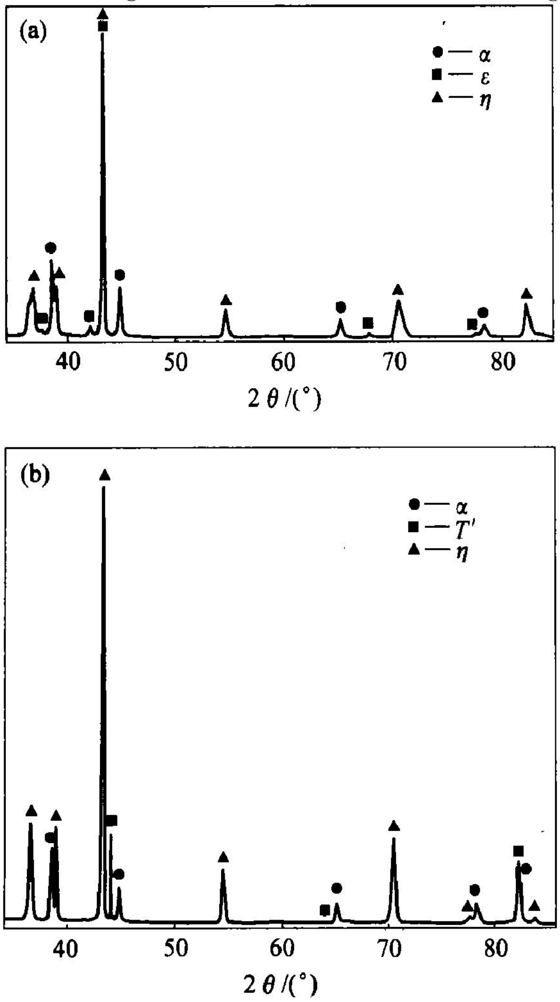

Fig. 4 X-ray diffractograms of ZA27 alloy
(a) —As-cast; (b) —Stablized by heat treatment

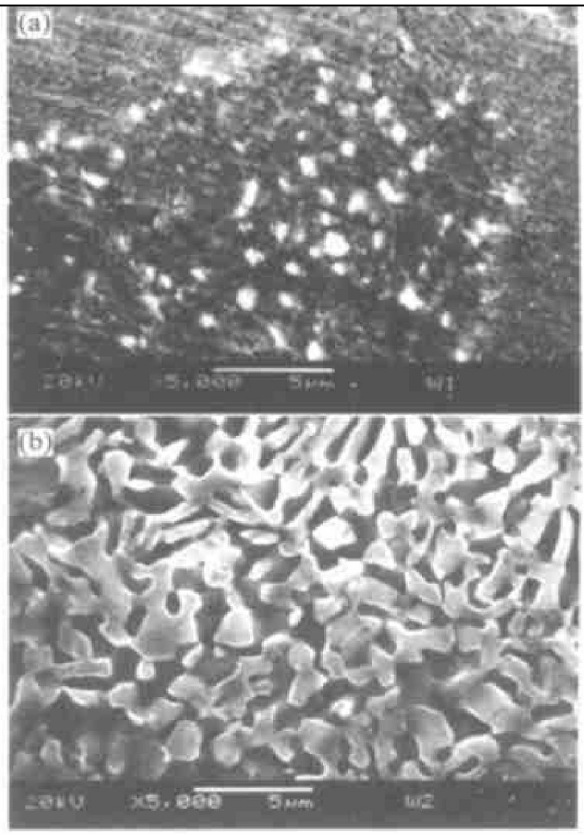

Fig. 5 SEM morphologies of ZA27 alloy
(a) —As-cast; (b) —Stabilized by heat treatment

4.2 Comparison of theoretical calculation with testing results

Theoretically, the dimensional expansion of ZA alloy containing Cu results from a phase transformation, $\varepsilon \rightarrow T'$ (rhomb, $a = 8.676 \times 10^{-10}$ m, $\alpha = 27.41°$[18]). According to some reports correlated to this, the lattice constant and the average volume of each atom can be calculated, and these results were listed in Table 3.

The percentage of atom for ZA27 alloy is 47.33 Al, 1.49Cu and 51.18Zn, the solid solubility of Zn and Cu in Al are (volume fraction, the same below) 1.04% and 0.02% at room temperature, respectively, and 1.25% and 0.03% at 80 ℃, respectively, as well as 4.04% and 0.05% at 150 ℃, respectively. The solid solubility of Al and Cu in Zn is not considered[19]. The percentage of atom for ε phase is 17% Cu, 81% Zn and 2% Al, and formation of ε phase requires one Cu atom, 4.76Zn atoms and 0.12Al atoms. The composition of T' are 50% Al, 37.5% Cu and 12.5% Zn, the formation of T' phase requires one Cu atom, 0.33Zn atoms and 1.33Al atoms. According to these, the percentage of each atom can be calculated at 150 ℃, and it was given by:

$$0.4832\alpha + 0.0735\varepsilon + 0.4420\eta \rightarrow 0.4950\alpha + 0.0282T' + 0.4460\eta$$

Table 3 Lattice constant of each phase and average volume of atom before and after phase transformation

Stage	Phase	Lattice structure	Lattice constant / 10^{-10} m	Average volume of atom / (10^{-10} m^3)
Before transformation	β	fcc	a= 4.006	16.072
After transformation	α	fcc	a= 4.049	16.603
	η	hcp	a= 2.671 c= 4.946	15.301
	ε	hcp	a= 2.767 c= 4.289	13.901
	T'	rhomb	a= 8.676 α= 27.41°	15.079

Based on the average volume of atom in Table 3, the size change of ZA27 alloy before and after the transformation could be calculated. The results are listed in Table 4. Table 4 shows that volume expansion took place during the transformation, and the negative creep occurred at 20 ℃(50, 87.5 and 100 MPa), 60 ℃(50 and 87.5 MPa) and 100 ℃(50 MPa) (also see Table 2) and only resulted from the volume expansion caused by the four-phase transformation in ZA27 alloy. The maximum value of the negative creep deformation in Table 2 is less than that of the theoretical calculated results in Table 4. The reason for this is that the four-phase transformation and compressive creep deformation proceeded at the same time; thus, the value of negative creep should be the difference between the compressive creep deformation and volume expansion of ZA27alloy.

Table 4 Size changes of ZA27 alloy before and after phase transformation

Average volume of atom / (10^{-10} m^3)		Volume changes / (10^{-10} m^3)	Volume change rate/ %	Linear change rate/ %
15.828*	15.937**	0.101	0.69	0.23

* —Before phase transformation;
** —After phase transformation

5 COCULUSIONS

1) The negative creep in ZA27 alloy occurred during the compressive creep at some temperatures and stresses, i.e. at 20 ℃(50, 87.5and 100 MPa), 60 ℃(50 and 87.5 MPa) and 100 ℃(50 MPa) and did not at other temperatures and stresses used. The value of the negative creep deformation depended on the value of temperature and stress.

2) The formation of the negative creep in ZA27 alloy resulted from the volume expansion was caused by the four-phase transformation, $\alpha + \varepsilon \rightarrow T' + \eta$.

REFRENCES

[1] Savakan T, Murphy S. Mechanical properties and lubricated wear of Zn-25Al-Based alloy [J]. Wear, 1987, 106: 211-214.

[2] Lopez Hirata V M, Saucedo Muñoz M, Rodriguez Herandez J C , et al. Milling characteristic of extruded Zn-Al alloy [J]. Materials Science & Engineering, 1998, A247: 8-14.

[3] TIAN Rong-zhang, WANG Zhi-yuan. Research on phase transformation and dimensional stability [J]. Journal of Central South Institute of Mining and Metallurgy, 1992, 23(6): 712-717. (in Chinese)

[4] ZHAO Pei-lian, ZHAO Xing-guo, ZHAO Hao-feng. Effect of rare earths on the high temperature properties of ZA-27 alloy [J]. Journal of The Chinese Rare Earth Society, 1988, 16(1): 41-44. (in Chinese)

[5] SU De-huang. Effect of Fe and Mn added on high temperature tensile properties of ZA27 alloy [J]. Materials Science & Technology, 1998, 6(3): 52-55. (in Chinese)

[6] Lehuy H, Lesperance G. Aging characteristics of dendritic and non-dendritic (stir-cast) Zn-Al alloy (ZA27) [J]. Material Science, 1991, 26: 559-568.

[7] Savaskan T, Murphy S. Creep behavior of Zn-Al-Cu bearing alloy [J]. Z Metallkde, 1982, 74: 76-82.

[8] Zhu Y H, Orozco E, Torres J. Tensile creep deformation and microstructure change in cast Zn-Al alloy [J]. Materials Transaction, 1997, 38(6): 521-525.

[9] Turk Ahmet, Durman Mehmet, Kayali E. Effect of copper on the creep behaviour of gravity-cast zinc-aluminum-based ZA-8 alloy [J]. Z Metallkde, 1998, 89: 351-355.

[10] ZHANG Li-ming, DING Zhi-min, LAO Bin. High temperature creep property of silicon particles reinforced high Al Zn-based alloy [J]. Trans Nonferrous Met Soc China, 1999, 9(3): 519-523.

[11] Durman M, Murphy S. An improved parametric method for the correlation of creep data from commercial pressure die cast zinc-based alloy [J]. Z Metallkde, 1990, 82: 129-134.

[12] Annar M, Murphy S. Creep kinetics in compression of sand cast commercial Zn-Al alloy [J]. Material Science and Technology, 2000, 16: 321-327.

[13] Zhu Y H, Torres G, Pina C. Complex microstructural changes in as-cast eutectoid Zn-Al alloy [J]. Materials Science, 1994, 29: 1549-1552.

[14] Murphy S. Solid-phase reaction in the low copper part of the Al-Zn-Zh system [J]. Z Metallkde, 1980, 71: 96-102.

[15] Terziv L, Lecqueine-Beckers J, Wegria J. Microstructural study of a Zn-Al-Cu alloy after thermal treatment at 100 ℃ and creep [J]. Z Metallkde, 1994, 85(3): 640-644.

[16] Zhu Y H, Juarez Islas J, Orozco E. Creep induced phase transformation in extruded Zn-Al alloy [J]. Journal of Materials Science and Technology, 1997, 6: 503-507.

[17] Zhu Y H, Orozco E, Murphy S. Creep-induced phase transformations in furnace cooled Zn-Al alloy [J]. Materials Science, 1997, 32: 5811-5815.

[18] Lohberg K. Die Volumennanderungen Der zink-aluminum-kupfer-legierungen dem ubergensgleichewicht $\varepsilon + \alpha \rightarrow T' + \eta$ [J]. Z Metallkde, 1983, 74: 456-457.

[19] Mondolfo L F. WANG Zhu-tang transl, Structure and Properties of Aluminum [M]. Beijing: Metallurgical Industry Press, 1988.

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