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CREEP CHARACTERISTICS OF HIGH SILICON ZA27 ALLOY PREPARED BY SPRAY DEPOSITION ①

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ABSTRACT The elevated temperature creep properties(90~ 150 ℃) of spray deposited ZA27 alloy containning 6% silicon have been investigated by means of ball hardness testing method. The experiment results showed that the material prepared by spray deposition has notable creep properties, comparing with that of the conventional ZA27 alloy. The creep activation energy of the spray deposited material is 3.9~ 5.7kJ/mol higher than that of the conventional cast ZA27 alloy. A creep formulation was derived as $HB^{-2} - HB_0^{-2} = K \cdot \exp(-Q/(3RT))(t^{1/3} - t_0^{1/3})$. The reason for the improvements of the creep resistance is also analyzed.

Key words spray deposition zinc-based alloy creep microstructure

1 INTRODUCTION

High aluminium zinc-based alloys are widely used in industry for their superior ambient mechanical properties and excellent wear resistance. However, they are very poor in high temperature performance. How to improve the properties of the alloy in 75~ 150 ℃ is still a challenge now[1]. In recent years continuous attempts have been made, particularly in area of the alloy design and adopting of novel techniques, to develop advanced materials as a substitute for traditional engineering alloys. The spray deposition is one of the promising techniques. It is well known that this solidification processing has greatly improved mechanical properties of many kinds of alloys[2-4]. In this paper, alloying and spray deposition shall be used to improve the high-temperature properties of ZA27 alloy. The ball hardness testing method will be used to evaluate high temperature(90~ 150 ℃) properties.

2 EXPERIMENT DETAILS

2.1 *Material Design*

The solidification temperature range of the ZA27 alloy is from 375 ℃ to 484 ℃. Supposing that 375 ℃ is the melting temperature(T_m), the relative working temperature coefficients (which is the ratio of the working temperature T and melting temperature T_m) can be worked out, as dispicted in Table 1. Since the temperature range (75 ~ 150 ℃) investigated is approaching to the half of the melting temperature, either the strengthening of dispersed secondary phases or the strengthening of composites may improve the elevated temperature properties according to the metal strengthening theory.

Table 1 The relative working temperature coefficient of ZA27 alloy(T/T_m)

working temperature/ ℃	75	90	120	150
coefficient	0.53	0.56	0.60	0.65

Spray deposition is an effective processing to manufacture advanced materials which are strengthened by secondary dispered phases. Qjha′s experimental results showed that spray deposition could be used to increase the amount of dispersed silicon phases in Al-Si alloys′

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matrixes which results in the elevated temperature properties being improved greatly[2]. In case of adding silicon to ZA27 alloy and using spray deposition to obtain more stable eutectoid matrix strengthened by many secondary dispered phases (Si phases), the creep properties of the new material could be notably improved.

2.2 *Sample Preparing*

There is two methods to get dispersed silicon phases: one is the spray co-deposition, the other is the immediately separating out from liquid metal during spray deposition. In the present experiment, the latter method was used. Firstly the prepared ZA27 alloy was melted in the resistance furnace, then 6% silicon was added into it and the melt was superheated to 780 ℃ for 15~20 min. At last the molten metal was transferred into the middle package of the spray deposition installation to prepare the deposits. In order to contrast, the samples of conventional cast ZA27 alloy were also made. The number, composition and processing of the specimen are shown in Table 2.

Table 2 Composition and processing method of the material investigated

No.	Composition	Processing
1	ZA27	conventional casting
2	ZA27+ 6% Si	conventional casting
3	ZA27+ 6% Si	spray deposition

2.3 *Creep Experimental*

The relationship between the hardness HB and the depth can be expressed as follows:

$$HB = P/F = P/\pi d\varepsilon \qquad (1)$$

where P is the load, F is the indentation area of the sample pressed by the indenter, d is the diameter of the steel ball

Since the hardness value decreases as the loading time increases, the relationship between the hardness and the holding time can be gotten. Therefore the creep characteristic of materials is reflected by changes of hardness value[6].

Experiments in the present paper were carried out on the HBE- 750 ball hardness device. The load is 250 kg and the diameter of indenter is 5 mm.

3 EXPERIMENTAL RESULTS AND DISCUSSION

3.1 *Creep Curve Formulation*

The creep curve of the materials investigated is shown in Figure 1. The creep law of the samples is very similar to the typical creep curve except that there is no third stage of the creep curve.

The former investigations have shown that the creep processing can be expressed by the creep formula which could be written as a product of separated functions of time(t), temperature(T) and stress(σ). Based on the above, Atkins considered the creep rate could be expressed as follows[6].

$$\dot{\varepsilon} \propto \sigma^{m/3} \cdot \exp(-Q/(3RT)) \qquad (2)$$

where m is the constant related to both the loading method and the stress state, Q is the creep activation energy, R is the gas constant

Supposing that the creep law in present experiment was the same as Atkins′, then the equation (2) can be rewritten as follows:

$$\varepsilon = k_1 \cdot \sigma^{m/3} \cdot t^{-2/3} \cdot \exp(-Q/(3RT)) \qquad (3)$$

where k_1 is a constant. In fact the stress σ is equal to the hardness value HB in this experiment, then

$$d\varepsilon = -\frac{P}{\pi \cdot D} HB^{-2} \cdot d(HB) \qquad (4)$$

From the equations (3) and (4), we can get:

$$HB^{(-3-m)/3} - HB_0^{(-3-m)/3} = K \cdot \exp(-Q/(3RT)) \cdot (t^{1/3} - t_0^{1/3}) \qquad (5)$$

where HB_0 and HB are the hardness values at the moment t_0 and t respectively

Equation (5) is the creep curve formula of the investigated material. In order to get the constant m and the creep activation energy Q, we can rewrite the equation (5) as follows:

$$Y = C + X \qquad (6)$$

where

$$Y = \ln(HB^{(-3-m)/3} - HB_0^{(-3-m)/3});$$

$$C = \ln K - \frac{Q}{3RT};$$

Fig. 1 Creep curve of the materials investigated

(a) —No. 1 specimen; (b) —No. 2 specimen; (c) —No. 3 specimen

$$X = \ln(t^{1/3} - t_0^{1/3})$$

There is a linear relationship between hardness parameter($HB^{(-3-m)/3} - HB_0^{(-3-m)/3}$) and time parameter($t^{1/3} - t_0^{1/3}$) according to equation (6). If we do experiments at a series of temperatures, we shall obtain a series of parallel lines in a double logarithm diagram from which the activation energy Q in the particulate temperature range can be solved out.

Atkins deduced the following formula from his experiment[3]:

$$HB^{-3} - HB_0^{-3} = K' \cdot \exp(-Q/(3RT)) \cdot (t^{1/3} - t_0^{1/3}) \tag{7}$$

where K is a constant. It means that m is equal to 6. However, if we do according to Atkins formula no lines can parallel each other (as shown in Figure 2). This means that the creep formula(7) is not fit for the present experiment by reason that the loading method is different between Atkins and this experiment. Supposing m is equal to 3 in eqn. (5), then

$$HB^{-2} - HB_0^{-2} = K \cdot \exp(-Q/(3RT)) \times (t^{1/3} - t_0^{1/3}) \tag{8}$$

We substitute the data into the above equation, and find that all lines are parallel to one another(see Figure 3). This means that the creep law of the present experiments can be expressed by eqn. (8).

3. 2 *Creep Activation Energy*

According to creep theory, the creep is a thermal activation processing depended on the movement of the dislocation and the stress. The higher the creep activation, the slower the creep rate. In this experiment, the absolute activation energy can not be calculated because of the large experiment temperature intevals, but the relative creep activation energy of the material can be worked out(as listed in Table 3).

From Table 3, we know that there is little difference among the samples at 90 ℃, but not 120 ℃ and 150 ℃ at which the creep activation energy of sample 3 is 5.7 kJ/mol and 3.9 kJ/mol higher than that of sample 1 respectively.

3. 3 *Microstructure and High-temperature Creep Resistance*

The change of the above creep performance is related to the difference of microstructures, as demonstrated in Figure 4. The microstructure of the conventional cast ZA27 alloy is composed of the α (Al) phases and interdendrite eutectic phases. When 6% silicon was added to the ZA27

Fig. 2 The relationship between hardness and time of materials investigated

(after Atking' s eqn. (7))

Fig. 3 The relationship between the hardness and the time of the material investigated

alloy, the microstructure characteristic were nearly the same as the ZA27 alloy except that the bulky Si-rich phases appeared and the volume fraction of interdentrite eutectic phases occupied 15% ~ 20%. The microstructure of sample 3 is made up of the dispersed silicon-rich phases and the eutectoid, which is greatly different from the two other materials.

The creep process is very similar to a continuous movement of steel indenter into the testing materials (Figure 5), and the movement of the indenter will be impeded by micro-phases (Figure 6).

In the conventional cast material the main

Fig. 4 The microstructure of the materials investigated

(a) —No. 1; (b) —No. 2; (c) —No. 3(optical image); (d) —No. 3(SEM image)

Table 3 The relative creep activation energy of the material investigated (kJ/mol)

Temperature/℃	$Q_3 - Q_1$	$Q_3 - Q_2$	$Q_2 - Q_1$
90	0.8	0.6	0.2
120	5.7	1.7	4.0
150	3.9	2.9	1.0

Footmarks 1, 2, 3, represent the sample number of the materials investigated

micro-phases are the α(Al) phases which shall be softened and decomposed at elevated temperature. The effects of solution strengthening is seriously weaked. However, the matrix in the deposites is eutectoid which is the more stable microstructure in the aspectes of therm dynamics. So the microstructure of the eutectoid will not change greatly even if it is heated. The most important point is that a large amount of dispersed silicon rich phases in the matrix, having excellent strength and stability in high temperature, shall strongly impede the plastic deformation of the matrix (Figure 6). This makes the high temperature creep characteristics of the material greatly improved.

Fig. 5 The movement of the indenter in the materials indented

4 CONCLUSIONS

The high-temperature (75~150℃) creep

Fig. 6 The silicon-rich phases impede the movement

properties of high silicon(~ 6%) ZA27 alloy prepared by spray deposition have been investigated by means of ball hardness testing method. The experiment results show that there is a notable creep resistance of the deposits, comparing with that of the conventional casting ZA27 alloy. The experiment results show:

(1) The pressing creep curve can be formulated to a product of separate function of time, temperature and stress as follows:

$$HB^{-2} - HB_0^{-2} = L \cdot \exp(-Q/(3RT)) \times (t^{1/3} - t_0^{1/3}).$$

(2) The creep rate of the high silicon ZA27 alloy manufactured by spray deposition is slower than that of the conventional cast materials when the temperature is above 90 ℃ and the creep activation energy of the deposit is 3.9~ 5.7kJ/mol higher than that of the conventional cast ZA27 alloy.

(3) The dispersed silicon-rich phases and the stable matrix of the deposits contribute to the improvements of high-temperature creep properties.

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