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ESTABLISHMENT OF CONSTITUTIVE EQUATION OF MEDICAL AZ81 MAGNESIUM ALLOY

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The hot deformation characteristics of deformed AZ81 magnesium alloy were studied by hot compression deformation on Gleeble-3800 thermal simulation test machine. The deformation temperatures were set at 300, 350, 400 and 450 °C, and the deformation rates were 0,01, 0,1 and 1s-1, respectively. Using the experimental data, the constitutive equation is obtained by friction correction and a series of formulas, and the constitutive equation is compared with the experimental data to verify its accuracy.

Keyword: AZ81 magnesium alloy, hot compression test, stress-strain, temperature, constitutive model

INTRODUCTION

AZ81 magnesium alloy is an important hot working material with excellent mechanical properties and heat treatment properties. It has a wide application prospect in aerospace, automobile manufacturing, electronic equipment and other fields. With the development of modern industry, the demand for lightweight materials is increasing. AZ81 magnesium alloy has attracted much attention due to its low density, high specific strength and good corrosion resistance [1]. However, the hot processing behavior of AZ81 magnesium alloy is affected by many factors, such as temperature, deformation rate, strain and so on. Therefore, it is very important to understand the hot processing characteristics of AZ81 magnesium alloy for optimizing the processing technology and improving the material properties [2, 3].

The purpose of this paper is to systematically study the hot processing behavior of medical AZ81 magnesium alloy, and to establish its stress-strain distribution under different process parameters through hot compression experiments. The constitutive equation is constructed to describe the stress-strain behavior, which provides a reliable reference for engineering practice, and provides theoretical guidance for optimizing the processing technology and improving the material properties [4-6].

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LAB MATERIALS AND THEIR METHODS

The alloy used in the experiment is AZ81 wrought magnesium alloy, and its chemical composition is Mg-8,0 Al-1,0 Zn-0,5Sb (mass fraction/ %). The AZ81 magnesium alloy was processed into a cylindrical specimen with a height of 150 mm and a diameter of 100 mm by a wire cutting machine, and the hot compression experiment was completed on a Gleeble-3800D thermal simulation machine. The hot compression is first heated to the set temperature at a constant speed of 10 °C/s, followed by heat preservation for 150 s, and then hot compression is performed. During the period, the set temperature is kept unchanged, and the compression is performed according to the set strain rate. The cooling method uses water quenching, which is beneficial to preserve the microstructure of the magnesium alloy. The deformation temperatures T are 300, 350, 400 and 450 °C. The strain rates are 0,01, 0,1 and 1 s^{-1}. The maximum deformation is 0,7. The experimental scheme is shown in Figure 1.

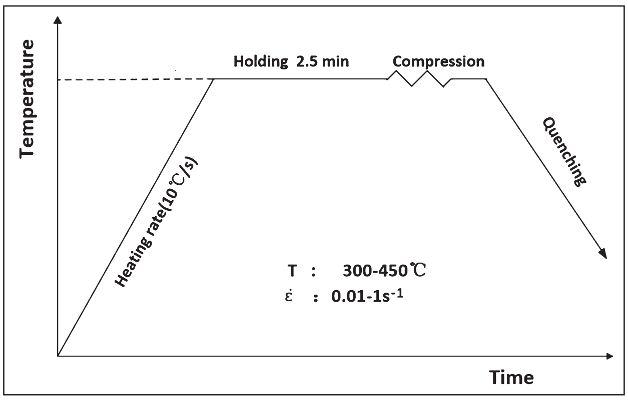

Figure 1 Experimental scheme

FRICTION CORRECTION OF FLOW STRESS CURVE

The true stress-true strain curve of AZ81 at 300°C is shown in Figure 2. It can be seen from Figure 2 that when the true strain exceeds 0,6, the true stress increases with the increase of strain at all experimental temperatures. In the process of hot compression test, with the progress of thermal deformation, the lubrication effect of the sample will gradually weaken, which makes the friction between the end face of the sample and the indenter increase, which is not conducive to the plastic deformation of the material, resulting in the increase of flow stress, which is manifested as the end of the true stress true strain curve upturned. Therefore, in order to obtain the true stress-true strain data of AZ81 magnesium alloy which is consistent with the actual and reliable, it is necessary to correct the flow stress curve by friction.

In the process of hot compression experiment, in order to reduce the friction constraint between the end face of the sample and the indenter and prevent the sample from ‘bulging‘, different types of lubricants are usually used to treat the surface of the mold according to the deformation temperature. However, even if lubrication and other measures are taken, the friction constraint of the sample cannot be completely avoided, and the flow stress curve obtained from the experiment cannot correctly reflect the flow stress behavior of the material. Therefore, it is necessary to correct the friction effect to determine the real flow stress characteristics.

The B values of AZ81 magnesium alloy under different deformation conditions are shown in Table 1. From Table 1, it can be seen that the bulging coefficient B value in the deformation interval is almost all greater than 1.1, and the bulging coefficient of individual smaller values is also close to 1.1, so it is necessary to correct the flow stress value of the sample.

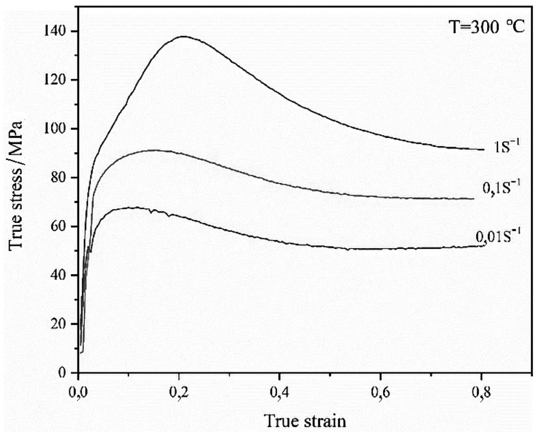

Figure 2 True stress-true strain curves of AZ81 magnesium alloy at 300 °C

Table 1 **B value of belly coefficient**

deformation temperature /°C	strain rate / s-1		
	0,01	0,1	1
300	1,142151	1,154687	1,109925
350	1,135691	1,122314	1,145213
400	1,089875	1,202014	1,111452

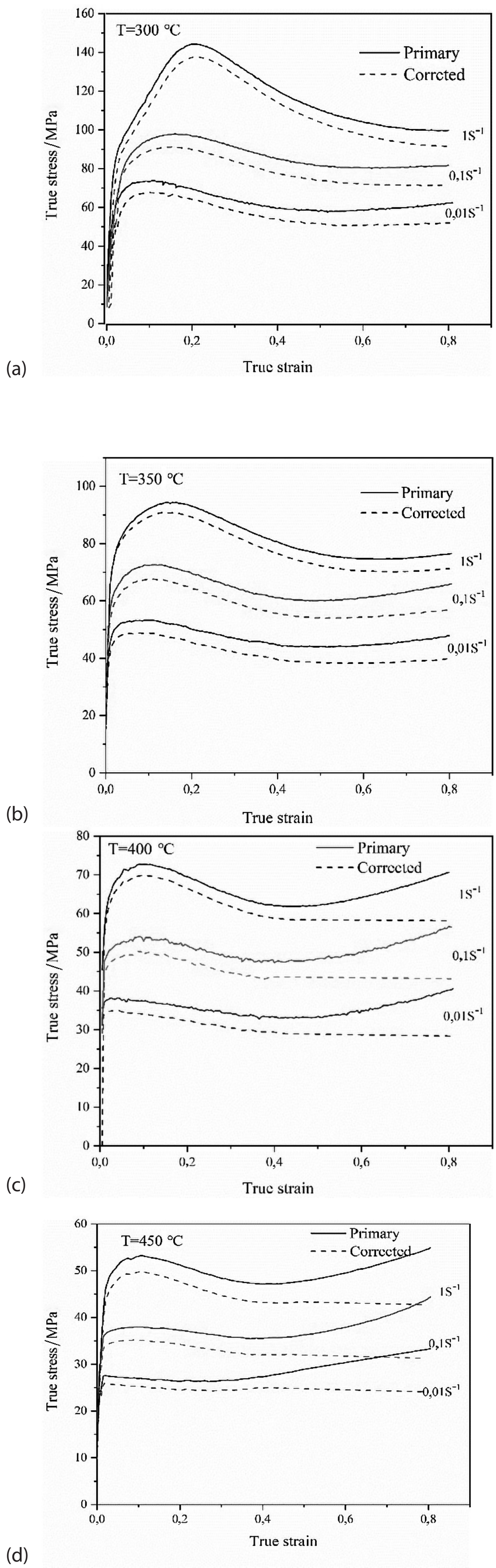

Figure 3 Real flow stress curve and friction corrected curve (a)300 °C; (b) 350 °C; (c) 400 °C; (d) 450 °C

The true flow stress curve of AZ81 magnesium alloy and the curve after friction correction are shown in Figure 3. It can be seen that the flow stress after friction correction is lower than the original flow stress during the whole process of sample compression, and the difference between the two is different with the change of strain. In the early stage of deformation, lubricant was added between the two ends of the sample and the indenter and the base, and the contact area was small, so that the friction force was small, and the difference of true stress before and after correction was small. With the increase of strain, the contact area between the two ends of the sample and the indenter gradually increases, and the influence of friction on the flow stress gradually increases, and the difference also increases.

ESTABLISHMENT OF MATERIAL CONSTITUTIVE EQUATION

The flow stress in the hot forming process of metal materials is related to many factors. It can be divided into two categories: one is the deformation parameters, and the other is the elemental composition of metal materials. In the process of reheat deformation, the composition of metal structure is a fixed value, so the influence factor of stress, namely the thermal deformation parameters, can be expressed by double sine function:

$$\dot{\varepsilon} = f(\sigma)exp(\frac{-Q}{RT}) \quad (1)$$

According to the different stress levels corresponding to different equations:

1) At low stress level ($\alpha\sigma < 0,8$), Equation (1) can be simplified as:

$$\dot{\varepsilon} = A_1\sigma^m\ exp(\frac{-Q}{RT}) \quad (2)$$

Where: $\dot{\varepsilon}$ is the strain rate in the unit of s^{-1}; σ is the flow stress, unit is MPa; Q is the deformation activation energy, the unit is J / mol; T is the deformation temperature, the unit is K; R is a gas constant.

2) At high stress level ($\alpha\sigma > 1,2$), Equation (1) can be simplified as:

$$\dot{\varepsilon} = A_2\ exp(\beta\sigma)exp(\frac{-Q}{RT}) \quad (3)$$

3) Under the full stress level (1) Simplified:

$$\dot{\varepsilon} = A\left[sin\left(\alpha\sigma\right)\right]^n exp(\frac{-Q}{RT}) \quad (4)$$

The peak stress of AZ81 magnesium alloy under different deformation conditions is obtained by stress-strain curve, as shown in Table 2. Based on the origin, the linear regression fitting of the points drawn by $ln\sigma_p - ln\dot{\varepsilon}$ and $\sigma_p - ln\dot{\varepsilon}$ is performed by the least square method. The reciprocal of the slopes of each fitted straight line is selected, and the average value is taken, which is the m value, m=9.3140025. Similarly, β=0.145755 can be obtained. Thus, α=0.015649 in Formula (2) can be obtained from (α=β/m), and the natural logarithms on both sides of Formula (3) are obtained:

$$ln\dot{\varepsilon} = ln\,C + n\,ln\left[sin\,h(\alpha\sigma)\right] - \frac{Q}{RT} \quad (5)$$

Table 2 **Peak stress**

Temperature °C	strain rate $\dot{\varepsilon}$ / s^{-1}	peak stress σ_p/MPa
300	0,01	67,745
	0,1	97,922
	1	137,738
350	0,01	48,770
	0,1	67,637
	1	91,005
400	0,01	35,056
	0,1	50,311
	1	69,949
450	0,01	26,118
	0,1	35,223
	1	50,566

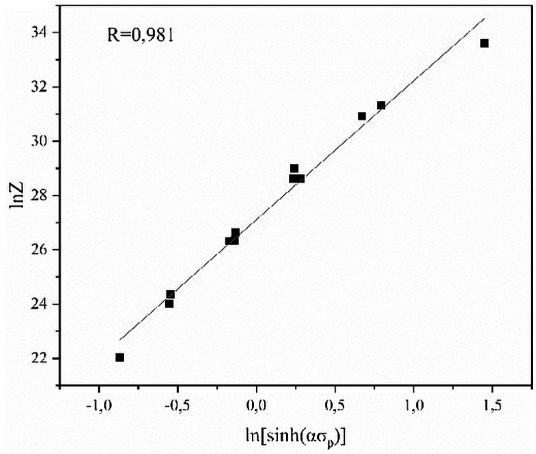

Figure 4 The relationship between lnZ and ln[*sinh*(*ασ*)]

Similarly, when the strain rate is a fixed value, $ln\left[sin\,h(\alpha\sigma)\right]$ and 1/T show a certain linear relationship:

$$\frac{Q}{Rn} = \frac{\partial\,ln\left[sinh(\alpha\sigma)\right]}{\partial(1/T)} \quad (6)$$

Let $ln\dot{\varepsilon}$ be the abscissa, ln[$sin\,h(\alpha\sigma)$] be the ordinate, n = 5.25935, can be obtained from the reciprocal of the slope of the straight line in the graph. Identically plot ln [$sin\,h(\alpha\sigma)$]-1/T. It can be seen that there is a parallel relationship between the straight lines, and the reciprocal average of the slope of the straight line is also taken: Q/nR=3663,6596. After the n value is brought in, Q=160120,97 J/mol is obtained.

The Zener-Hollomon parameter is used to describe the relationship between stress, strain rate and deformation temperature:

$$ln\,Z = ln\,A + n\,ln\left[sin\,h(\alpha\sigma)\right] \quad (7)$$

Draw a scatter plot between lnZ-ln[$sin\,h(\alpha\sigma)$], and perform linear regression on the data points, as shown in Figure 4.

The correlation of the fitting line is as high as 98,1 %. This shows that lnZ and ln [$sin\,h(\alpha\sigma)$] have a good linear relationship. The intercept of the fitting line is 27,11209. This value is the value of lnA, from which A=5.9515×10^{11}.can be obtained. The peak stress constitutive equation of high temperature hot deformation of

AZ81 magnesium alloy can be obtained by substituting the obtained parameters into the equation (4):

$$\dot{\varepsilon} = 5,9515\times10^{11}[0,016\,\sinh(\sigma_p)]^{5,25935}\exp\left(-\frac{160120,97}{8,314T}\right) \quad (8)$$

VERIFICATION OF CONSTITUTIVE MODEL

The flow stress under the corresponding deformation parameters is obtained under different strains. Through this model, the flow stress predicted by the formula is calculated and compared with the experimental data, as shown in Figure 5. It can be seen from figure that the experimental values are in good agreement with the predicted values, indicating that the strain-coupled Arrhenus constitutive equation has high prediction accuracy.

CONCLUSION

The hot compression test of AZ81 magnesium alloy was carried out, and the stress-strain curves at different temperatures and strain rates were obtained, and the stress-strain curves were corrected. The relationship between material coefficients (α, n, Q and lnA) and true strain was established by sixth-order polynomial, and an Arrhenius-type constitutive model with strain compensation was established. The flow stress can be accurately predicted, which provides a basis for the heat treatment of wrought AZ81 magnesium alloy.

ACKNOWLEDGMENTS

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Note: The responsible translator for English language is Z. W. Wang - Caofeidian College of Technology, China

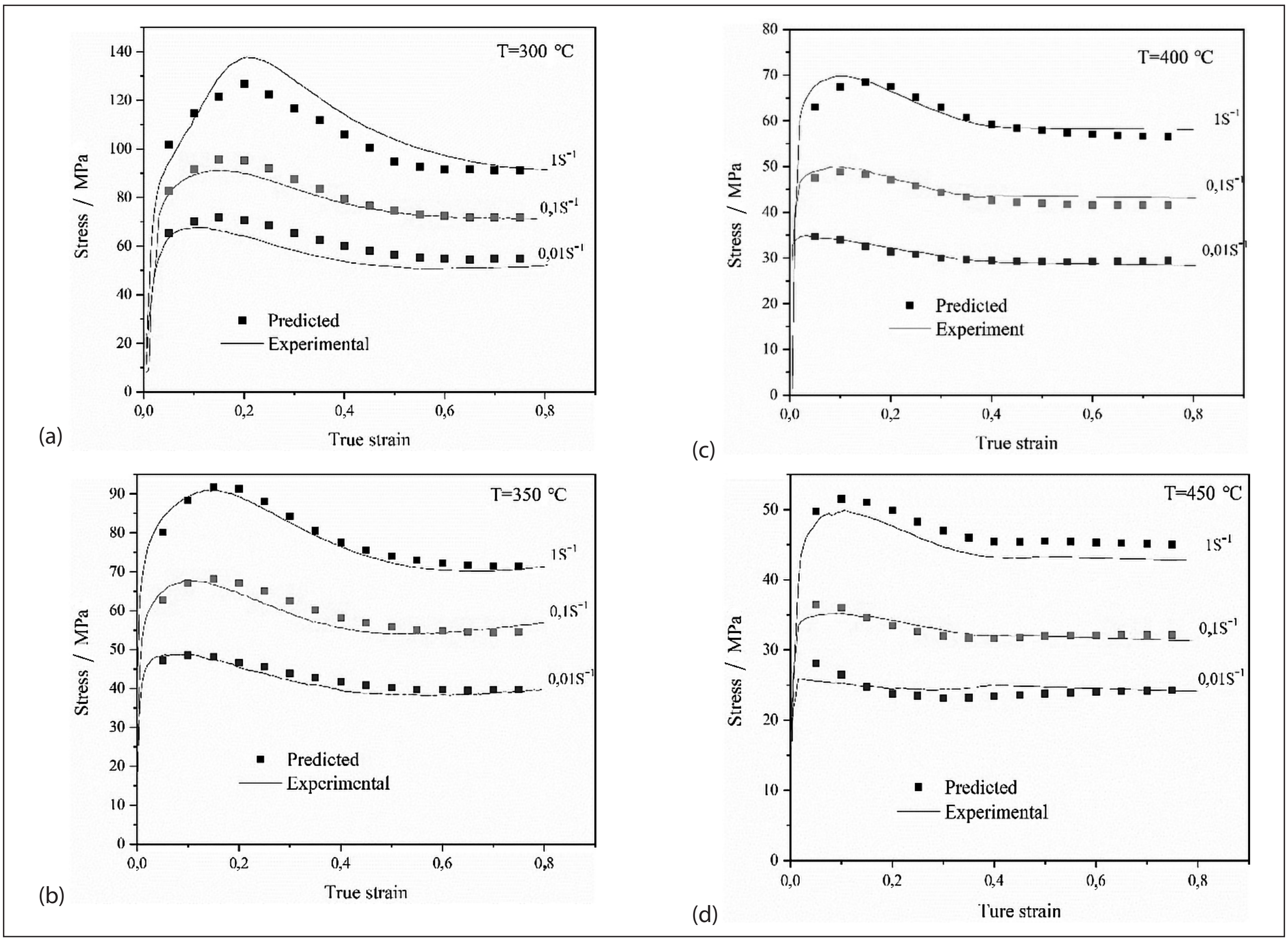

Figure 5 Comparison between experimental data and predicted values (a)300 °C; (b) 350 °C; (c) 400 °C; (d) 450 °C