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Effect of temperature on mechanical behavior of AZ31 magnesium alloy

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Abstract: Strain rate sensitivity and tension/compression asymmetry of AZ31 magnesium alloy at different temperatures and strain rates were investigated. Both of mechanical behaviors are temperature dependent. Strain rate sensitivity increases with increasing temperature. Thermally activated slip is the source of strain rate sensitivity. At the temperature below or near 373 K, strain rate sensitivity is very little. Tension/compression asymmetry in yielding decreases with increasing temperature. Twinning is the reason of tension/compression asymmetry. At the temperature above or near 573 K, the material shows little tension/compression asymmetry of the flow stress.

Key words: AZ31 magnesium alloy; strain rate sensitivity; tension/compression asymmetry; temperature effect

1 Introduction

Magnesium and its alloys have some advantageous properties that make them an excellent choice for a number of applications. Magnesium has a high specific strength with a density that is only 2/3 that of aluminum and 1/4 that of iron. Magnesium also has high thermal conductivity, high dimensional stability, good electromagnetic shielding characteristics, high damping characteristics, good machinability and is easily recycled. These properties make magnesium and its alloys valuable in a number of applications including automobile, aerospace components and so on[1−4]. Under some conditions, the mechanical behaviors are determinant whether they can be used effectively[5−6]. AZ31 is one of the most frequently used commercial alloys[7]. There is few investigation on the strain rate sensitivity and tension/compression asymmetry at different temperatures. But under impact and pressure loading condition, all these properties are important. The purpose of the present paper is to make an effort to make up the insufficiency of this aspect, so the temperature effect of mechanical behavior in AZ31 magnesium alloy is investigated systematically.

2 Experimental

The experimental alloy was a commercial AZ31 (Mg-3%Al-1%Zn, mass fraction) hot rolled plate, which was homogenized at 600 K for 0.5 h. Fig.1 shows the initial microstructure of the hot-rolled AZ31 sheet.

Tensile specimens with a gauge dimension of *d* 5 mm×14 mm were machined from the plate. The tensile direction of the samples is parallel to the rolling direction of the plate, as shown in Fig.2(a). Compressive specimens with a dimension of *d* 8 mm×12 mm were machined from the same plate, as shown in Fig.2(b). And the axis direction of the samples is along rolling direction.

Tensile tests and compressive tests were conducted on a Gleeble 1500D at temperatures of 373, 473 and 573 K, and at the strain rates of 1×10^{-3}, 1×10^{-1} and 1×10^{1} s^{-1} under constant cross-head speed control.

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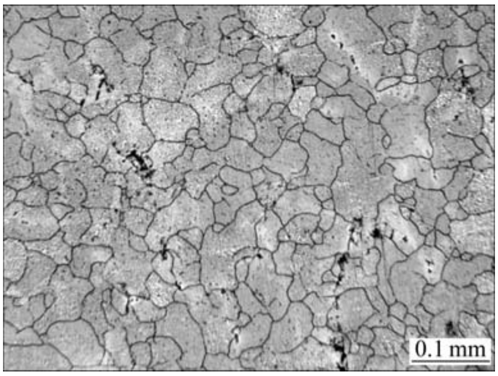

Fig.1 Initial microstructure of hot-rolled AZ31 sheet

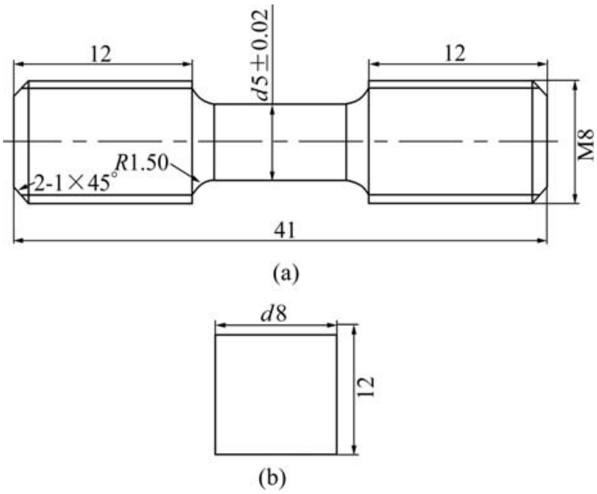

Fig.2 Specimen for tensile test (a) and for compression test (b)

3 Results and discussion

3.1 Strain rate sensitivity

The index of strain rate sensitivity (m) is used to evaluate strain rate effect of AZ31 magnesium alloy. Based on the equation[8−9], it yields

$$\sigma = K\dot{\varepsilon}^m \tag{1}$$

m can be calculated as

$$m = \frac{\partial \ln \sigma}{\partial \ln \dot{\varepsilon}} \tag{2}$$

where σ is the tensile or compressive flow stress and $\dot{\varepsilon}$ is the strain rate. By different strain rate tests, m can be calculated by

$$m = \frac{\ln(\sigma_1 / \sigma_2)}{\ln(\dot{\varepsilon}_1 / \dot{\varepsilon}_2)} \tag{3}$$

Fig.3 shows the true stress—strain curves at different temperatures and strain rates. The strain rate sensitivity can be obtained from the tensile and compressive curves. For contrast expediently, all the σ values are obtained when the ε values equal to 0.2. The calculated m values are listed in Table 1. The results indicate that, the strain rate sensitivity of AZ31 alloy is temperature dependent, for both tensile and compressive tests, and the strain rate sensitivity increases with increasing temperature, suggesting a transition of different controlling deformation mechanisms. On the other hand, at the same temperature, the tensile m value is less than the compressive one, that is, there are different deformation mechanisms also.

Table 1 Strain rate sensitivity (m) of AZ31 alloy corresponding to different temperatures (ε=0.2, strain rate $10^{-1}-10^{1}$ s^{-1})

Test	Temperature/K		
	373	473	573
Tensile	0.058	0.233	0.648
Compressive	0.074	0.332	0.750

Basal slip is the dominant deformation mechanism in magnesium alloys, and it is athermal in the interested temperature range[10−11]. So the basal slip mechanism is not the reason for the strain rate sensitivity change. The non-basal slips increase with increasing temperature because they are strongly thermally activated. So the strain rate sensitivity is controlled by non-basal slips. When the temperature is less than 373 K, only the basal slip system (0001) <11$\bar{2}$0> is operated, and the m value is almost equal to zero. When the temperature is less than 473 K but more than 373 K, prism slip $\{10\bar{1}0\}$<11$\bar{2}$0> is operated also, and the m value increases. At the temperature above 473 K, pyramidal slip $\{10\bar{1}1\}$ <11$\bar{2}$0> and $\{11\bar{2}2\}$ <11$\bar{2}$3> are operated, the number of slip systems increase from 4 to 10 or 15, so the m value increases from 0.233 (0.332) to 0.648 (0.750). Thermally activated slip is the source of strain rate sensitivity.

3.2 Tension/compression asymmetry in yielding

Tension/compression asymmetry in yielding for wrought magnesium alloy is an important property, which has been considered only at the room temperature [12−13]; while there is few investigation on the asymmetry at different temperatures. Fig.4 shows the tensile/compressive yield asymmetry evolution with temperature. Tension/compression asymmetry in yielding can be estimated by the factor s_{tc}, defined as follows:

$$s_{tc}=\sigma_{yt}/\sigma_{yc} \tag{4}$$

where σ_{yt} and σ_{yc} are the tensile and compressive yield stresses, respectively. For wrought magnesium alloy, tensile yield stress is bigger than compressive yield stress. So s_{tc} is more than or equal to 1, and when s_{tc} equals 1, there is not tension/compression asymmetry.

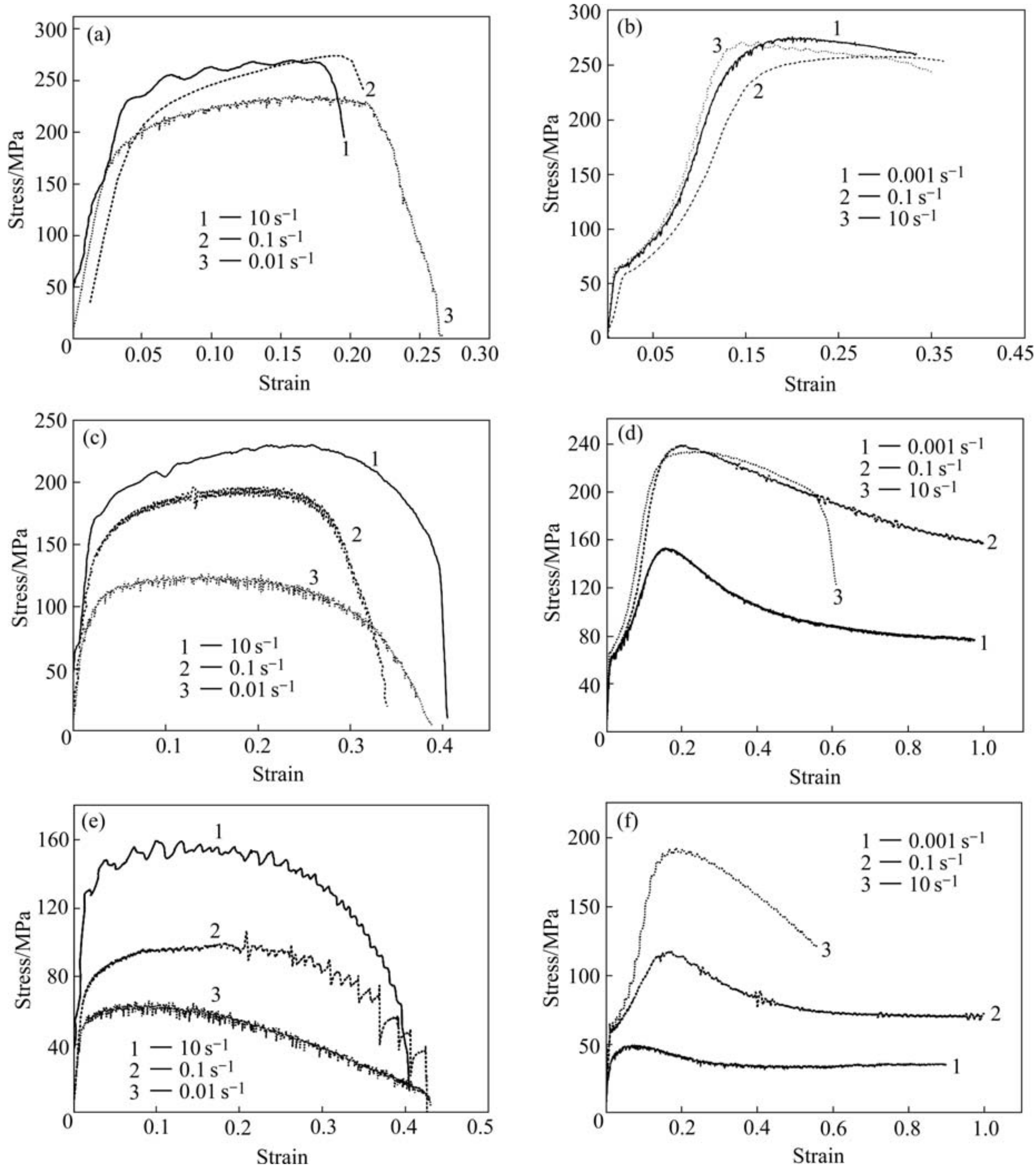

Fig.3 True stress—strain curves of AZ31 alloy at different temperatures: (a) 373 K, tensile; (b) 473 K, tensile; (c) 573 K, tensile; (d) 373 K, compressive; (e) 473 K, compressive; (f) 573 K, compressive

The s_{tc} values are listed in Table 2. The results indicate that, the tension/compression asymmetry in yielding is temperature dependent, and decreases with increasing temperature.

Table 2 s_{tc} values corresponding to different temperatures and strain rates

Strain rate/s^{-1}	Temperature/K		
	373	473	573
0.001	2.26	1.39	1.22
0.1	2.27	1.91	1.15

According to Von-Mises theory, only five independent active systems are necessary in order to accomplish an arbitrary shape change when polycrystalline materials are deformed. But there are only two independent slip systems for basal slip in Mg alloys deformed at room temperature or high a little, and others depend on twinning[14−15]. Generally, the yield strength for tension is asymmetric to that for compression in the case that both slip and twinning take place or only twinning happens. With the temperature increasing, non-basal slip systems are operated easily.

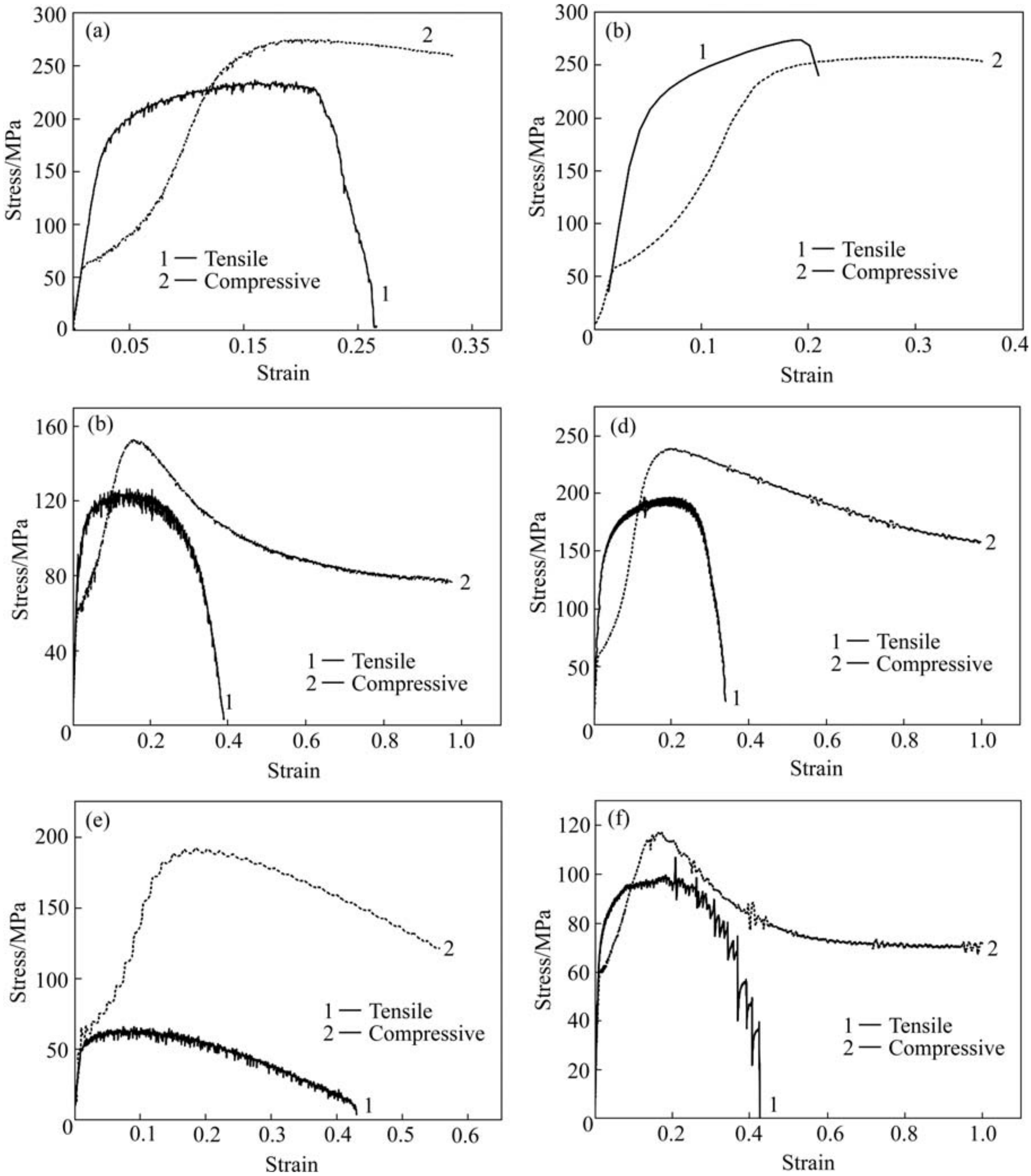

Fig.4 True stress—strain curves of AZ31 Mg alloy at different temperatures and strain rates: (a) 373 K, ε=0.001 s^{-1}; (b) 373 K, ε=0.1 s^{-1}; (c) 473 K, ε=0.001 s^{-1}; (d) 473 K, ε=0.1 s^{-1}; (e) 573 K, ε=0.001 s^{-1}; (f) 573 K, ε=0.1 s^{-1}

The tendency for twinning would be reduced, with a consequent decrease in the tension/compression anisotropy. It can be explained by the symmetry of slip and twinning yield surfaces in stress space. The slip yield surface is symmetric about the origin since the slip direction can be positive and negative; while the twinning yield surface is asymmetric about the origin since the twinning direction is unidirectional. Therefore, the material shows obvious tension/compression asymmetry at 373 K due to the large number of twinning. At the temperature above or near 573 K, the critical resolved shear stress (CRSS) for basal and non-basal slip is almost in the same order. The material shows little tension/compression asymmetry of the flow stress as a result of decreased twinning.

4 Conclusions

1) Hot-rolled commercial AZ31 magnesium alloy is one of strain rate sensitivity materials. The index of strain rate sensitivity (m) increases with increasing temperature. Strain rate sensitivity of 0.058, 0.233 and 0.648 are obtained at 373, 473 and 573 K, respectively. Thermally activated slip is the reason of strain rate

sensitivity.

2) In hot-rolled commercial AZ31 magnesium alloy, tension/compression asymmetry in yielding is temperature dependent and decreases with increasing temperature. The value s_{tc}, which estimates tension/compression asymmetry, of 2.26, 1.39 and 1.22 are obtained at 373, 473 and 573 K, respectively. Twinning is the reason of tension/compression asymmetry in yielding.

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