Deformation behavior of AZ31 magnesium alloy at different strain rates and temperatures

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Abstract: The deformation behavior of AZ31 was examined by compression and tension testes over a wide strain rate and temperature range, strain rate from 10^{-3} to $10^3 \, s^{-1}$, temperature from 300 to 623 K. Analysis of flow behavior and microstructural observations indicate that in tension tests dislocation glide is the most important deformation mechanism in the test strain rate and temperature range, while in compression tests twinning deformation mechanism is important at lower temperature when the strain rate ranges from 10^{-3} to $10 \, s^{-1}$. At $10^3 \, s^{-1}$ strain rate, dislocation glide and twinning are present at the same time. At the strain rate of $2\,964 \, s^{-1}$, adiabatic shear band can be found easily, even at the strain rate of $1\,537 \, s^{-1}$ adiabatic shear localization zone can be found. In adiabatic shear localization zone, there are fine recrystallization grains. But in adiabatic shear band, the grains cannot be identified by optical microscopy.

Key words: AZ31 magnesium alloy; compression; tension; twinning; adiabatic shear band

1 Introduction

During the last years magnesium alloys have attained an increasing interest due to the possibility of applying them as structural materials in many industries for saving mass, such as automotive, aerospace and defense industries[1−2]. AZ31 alloy is the most widely used wrought magnesium alloy, because this alloy shows a good combination of high strength at room temperature, good hot rolling or hot extrusion property, and excellent corrosion resistance. In order to optimize the processing for plastic forming and use the alloy in different conditions better, it is important to understand the effect of temperature and strain rate on flow stress. However, deformation behavior of AZ31 alloy at high strain rate of $10−10^3 \, s^{-1}$, where the plastic forming may be performed, has been investigated so little. Until today, only limited result can be available for high strain rate deformation behavior even in all of the magnesium alloys[3−5].

In this work, the deformation behavior of AZ31 was examined by compression tests over a wide strain rate and temperature range, strain rate from $10^{-3}−10^3 \, s^{-1}$, temperature from 300−623 K. Then the deformation mechanisms were discussed.

2 Experimental

The material employed in the present work was commercial quality AZ31.

Uniaxial compression and tension tests were conducted on an Instron material testing machine at room temperature, and high temperature tests were conducted on a Gleeble 1500D machine, then high strain rate tests of $10^3 \, s^{-1}$ were performed using a Hopkinson pressure bar. To check the repeatability of the results, three or four experiments were conducted under the same condition.

3 Results and discussion

3.1 Mechanical response

True stress—strain curves obtained from samples compression tested at 300, 373, 423, 473, 523 and 573 K are presented in Fig.1. It is clear that the flow curve shape can be divided into two kinds, "concave" and "convex", according to the sign of the second differential of the curve strain in the range of 0.05−0.15.

At temperature from 300 K to 473 K, strain rate $10^{-3}\,s^{-1}$, the compression curves are all concave. But at temperature from 523 K to 623 K the curves are convex at the same strain rate. When the strain rate reaches $10^{-1}\,s^{-1}$, the convex curves at temperature 523 K and 573 K change to concave curves. When the strain rate reaches $10\,s^{-1}$, all the curves are concave.

True stress—strain curves obtained from samples tension tested at 300, 373, 423, 473, 523, 573 and 623 K are presented in Fig.2. All the curves are convex. And when the test temperature increases, the plasticity of the AZ31 magnesium alloy increases obviously. But the
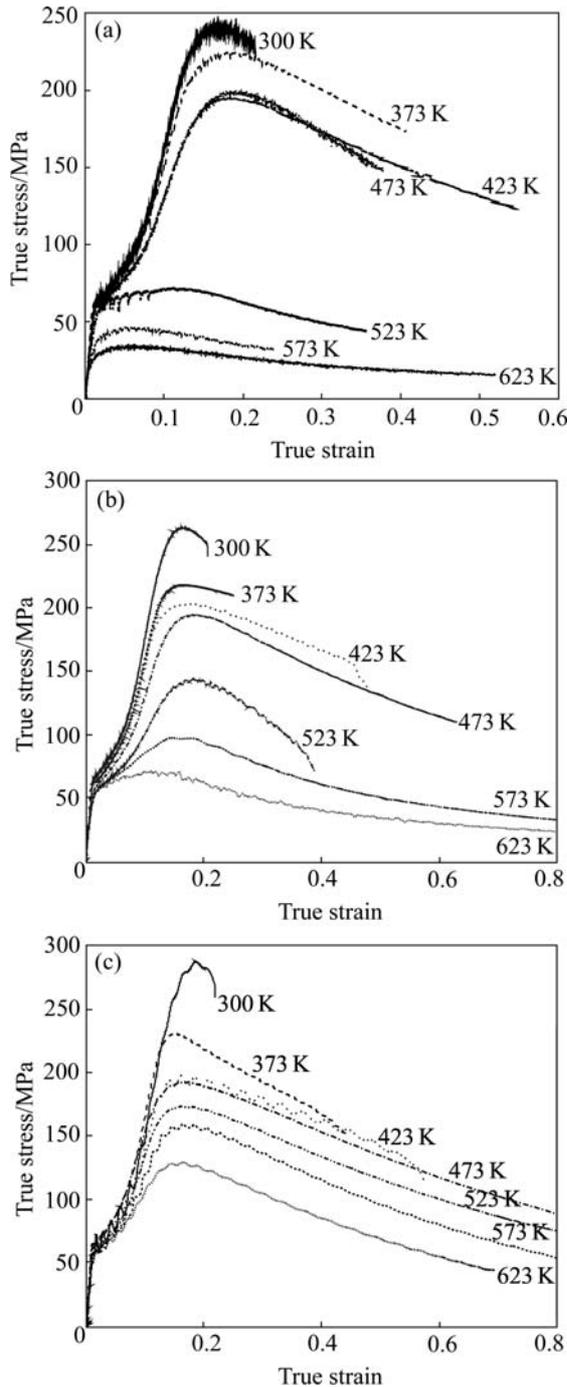

Fig.1 Compressive true stress—strain curves obtained at 300, 373, 423, 473, 523, 573 and 623 K at strain rates of $10^{-3}\,s^{-1}$ (a), $10^{-1}\,s^{-1}$ (b) and $10\,s^{-1}$ (c)
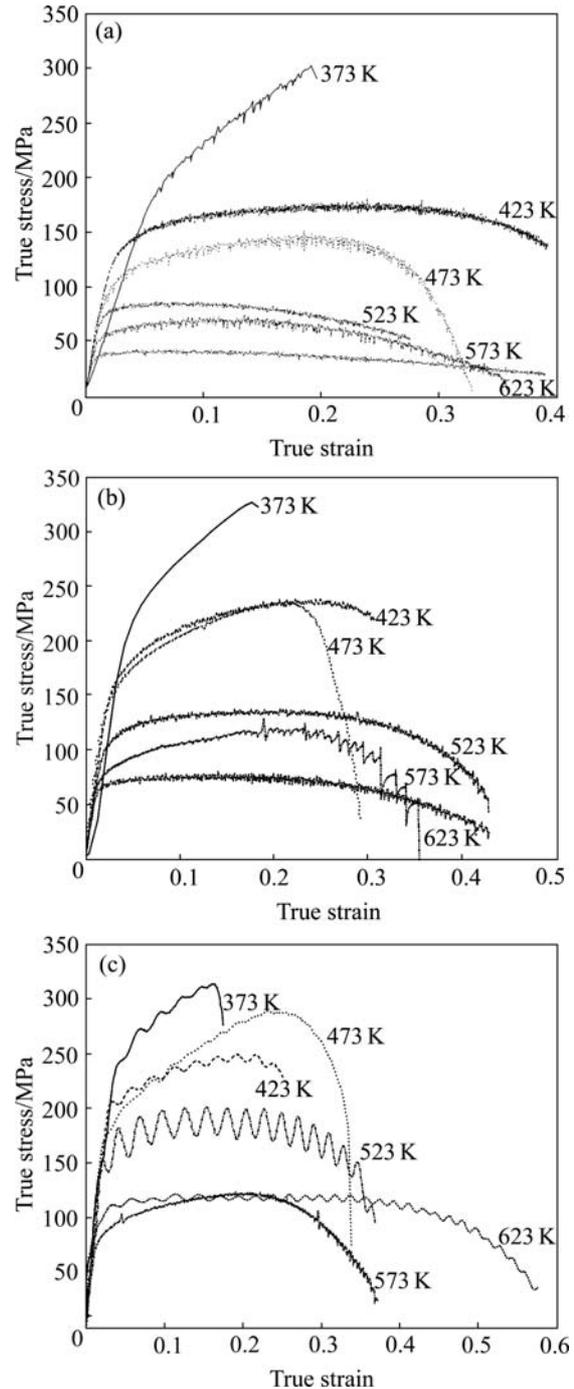
Fig.2 Tensile true stress—strain curves obtained at 300, 373, 423, 473, 523, 573 and 623 K and strain rates of $10^{-3}\,s^{-1}$ (a), $10^{-1}\,s^{-1}$ (b) and $10\,s^{-1}$ (c)

temperature 473 K is a special case. The plasticity at 473 K is smaller than those at the other temperatures except that 373 K at 10^{-3} s^{-1} and 10^{-1} s^{-1} strain rates.

As an example, the tension and compression true stress—strain curves at the strain rate of 10^{-3} s^{-1} were contrasted. When the temperatures are higher than 523 K, the compression curves are similar to tension curves. When the temperatures are lower than 473 K, the curve shape and yield stress are different, the tension yield stress is about 2 times the compression yield, the tension stress—strain curves are convex while the compression curves are concave.
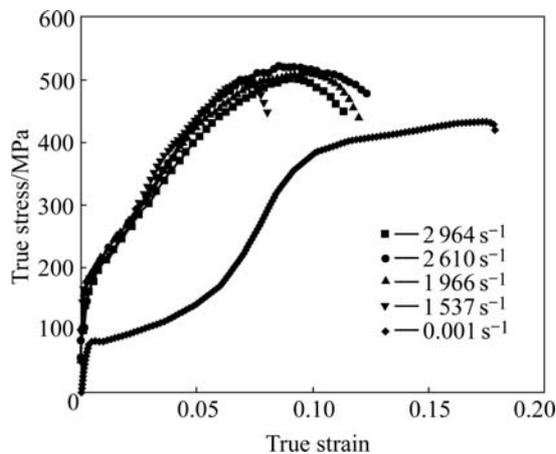
The true stress—strain curves are shown in Fig.3 for

Fig.3 Compressive true stress—strain curves obtained at 300 K and strain rates of 10^3–10^{-3} s^{-1}

materials deformed at strain rates of 10^{-3} s^{-1} and 10^3 s^{-1}.

It is clear that the curves deformed at strain rate of 10^3 s^{-1} are convex as tensile curves deformed at strain rates of 10^{-3}–10 s^{-1}. And when the strain rate increases from 1 537 to 2 610 s^{-1}, the strain increases gradually. But the strain becomes smaller suddenly than that at 1 537 s^{-1} when the strain rate reaches 2 964 s^{-1}.

3.2 Metallograph analysis

Fig.4 shows the optical micrographs taken near the yield point for compressive samples tested at strain rate of 10^{-1} s^{-1}. At the temperatures of 300, 373 and 473 K, a lot of twinnings can be observed, but at 573 K, only a few twinnings can be observed. According to the results by BARNETT et al[6−8] and JIANG et al[9−10], the twining should belong to {10$\bar{1}$2} extension twinning.

Fig.5 shows the optical micrographs taken near the yield point for compressive samples tested at strain rate of 10 s^{-1}. Compared with Fig.4, there are many intersecting twins.

Fig.6 shows the optical micrographs taken near the yield point for tensile samples tested at strain rates of 10^{-1} s^{-1} and 10 s^{-1}. No twins can be found in any conditions.

Considering Fig.4, Fig.5 and Fig.6 together, we can conclude that the concave curves are connected with {10$\bar{1}$2} twinning; the {10$\bar{1}$2} extension twinning has a strong influence on the rate of work hardening; the intersecting twins may cause stronger work hardening.
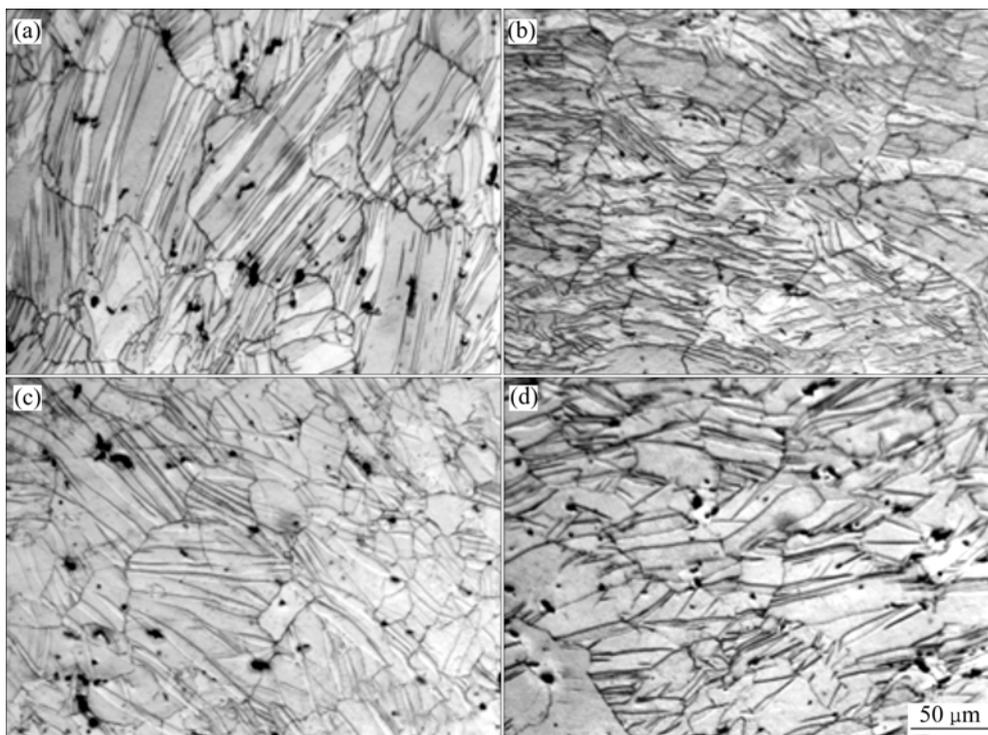

Fig.4 Optical micrographs taken near yield point for compressive samples tested at strain rate of 10^{-1} s^{-1}: (a) 300 K; (b) 373 K; (c) 473 K; (d) 573 K
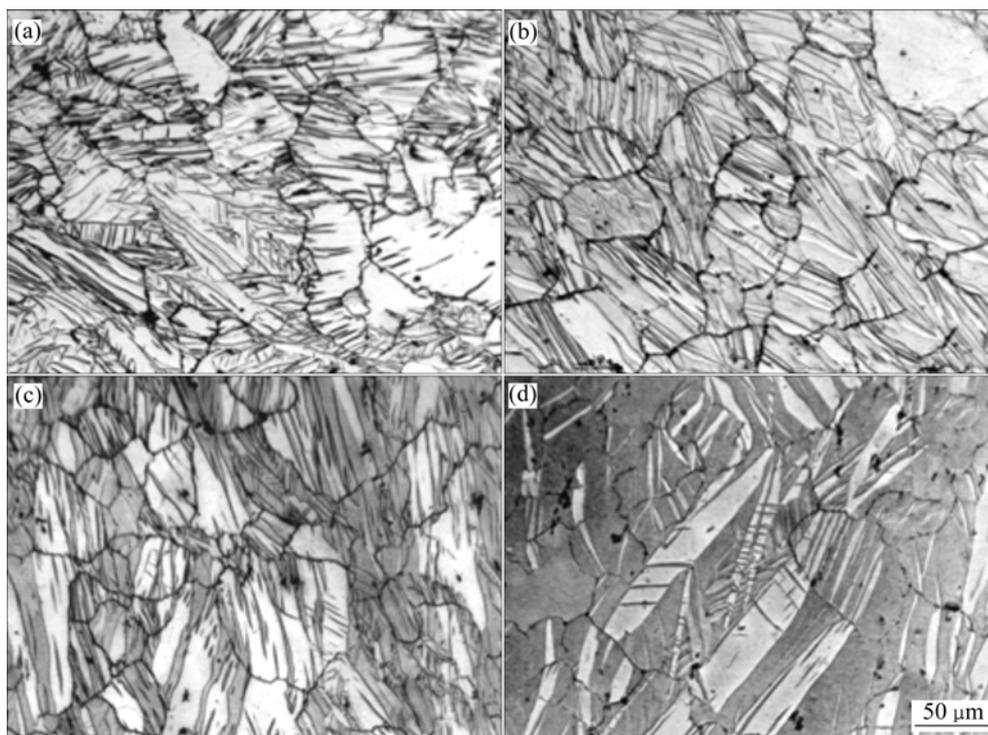
Fig.5 Optical micrographs taken near yield point for compressive samples tested at strain rate of 10 s^{-1}: (a) 300 K; (b) 373 K; (c) 473 K; (d) 573 K

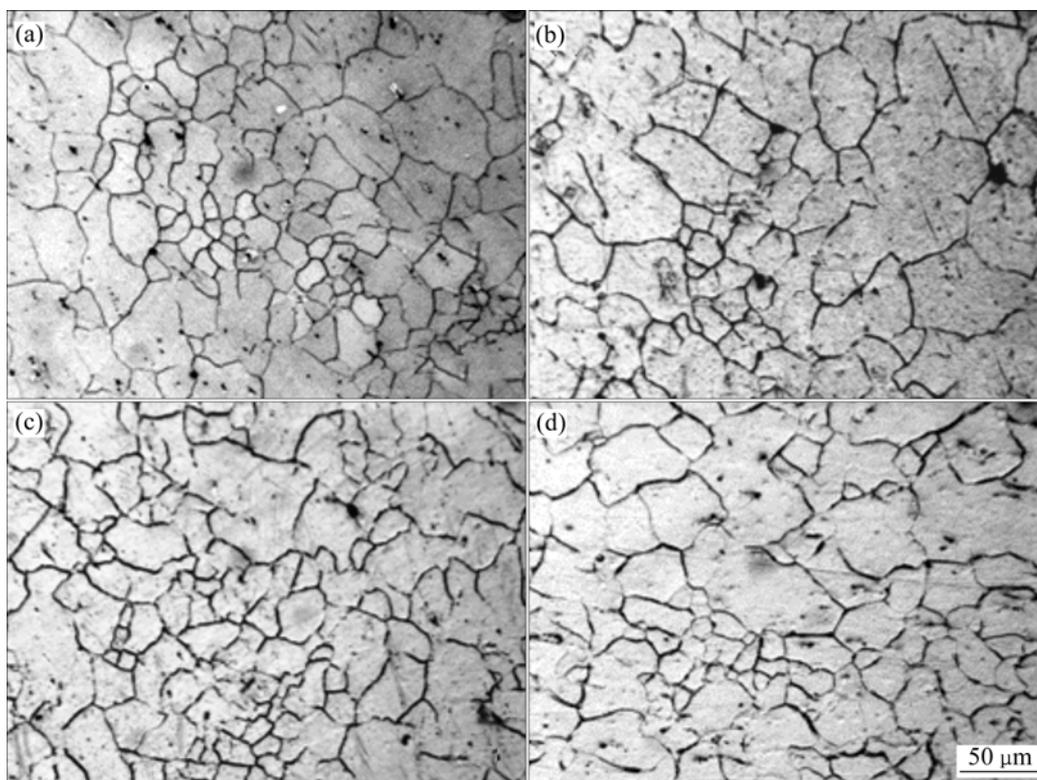**Fig.6** Optical micrographs taken near yield point for tensile samples tested at 300 K, 10^{-1} s^{-1} (a); 373 K, 10 s^{-1} (b); 473 K, 10^{-1} s^{-1} (c); 573 K, 10 s^{-1} (d)

Fig.7 shows the typical optical micrographs tested at strain rates of 10^{-3} s^{-1}, 1 537 s^{-1} and 2 964 s^{-1}. At the strain rate of 10^{-3} s^{-1}, twinning is important for the large plastic deformation. But with the strain rate increasing to 10^3 s^{-1}, the frequency of the twins decreases suddenly. And a prominent feature is that almost all the twins dis-
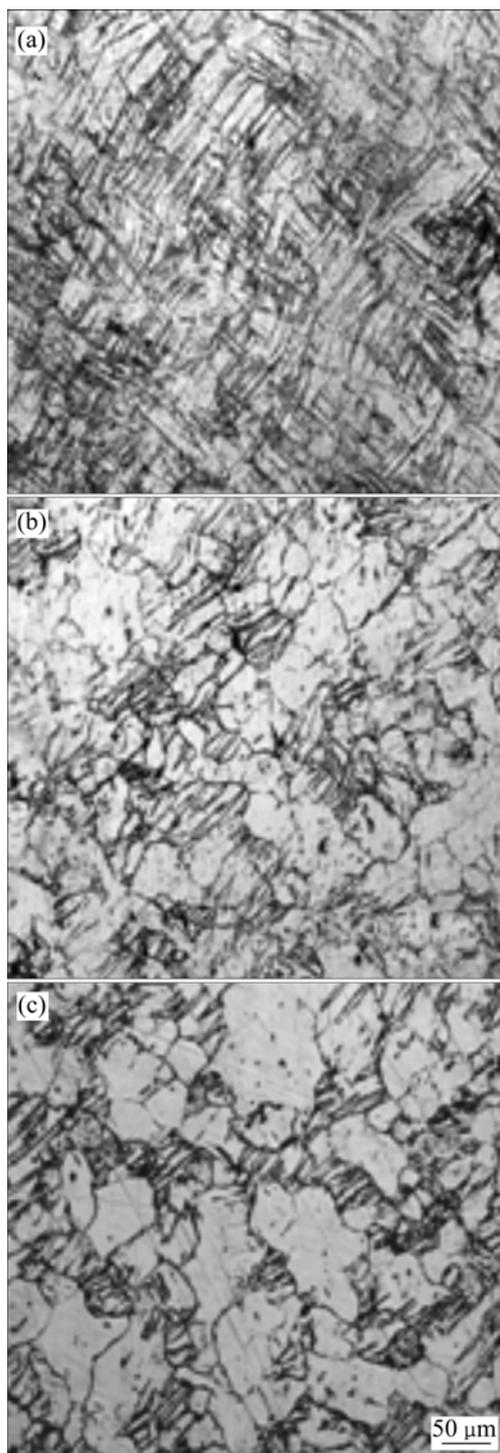
Fig.7 Optical micrographs for compressive samples tested at strain rate of $10^{-3}\,s^{-1}$ (a), $1\,537\,s^{-1}$ (b) and $2\,964\,s^{-1}$ (c)

tribute in smaller grains. By comparing Figs.7(a), (b) and (c), we can know that there is number of critical, in which the flow curves change from concave to convex. The number needs more in-depth study.

Figs.8(a) and (b) show the local optical micrographs of samples tested at strain rates of $2\,964\,s^{-1}$ and $1\,537\,s^{-1}$. The adiabatic shear localization can be seen in the sample at the strain rate of $1\,537\,s^{-1}$, and the adiabatic
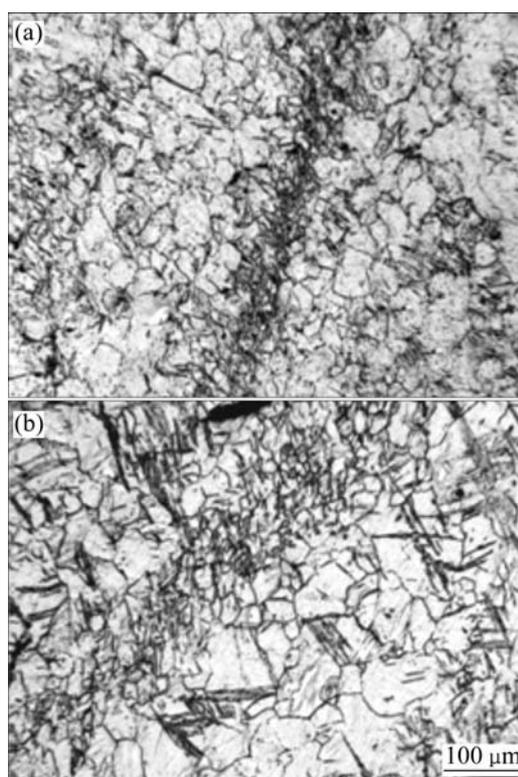

Fig.8 Adiabatic shear bands and adiabatic shear localization zones at strain rates of $2\,964\,s^{-1}$ (a) and $1\,537\,s^{-1}$ (b)

shear band can be found in the sample at the strain rate of $2\,964\,s^{-1}$. As Fig.8(b) shows, in the adiabatic shear localization zone, the grains are cut by twinnings. The grains in the adiabatic shear band almost can not be identified, and the materials will not be loaded. This is the reason why the crack strain decreases at the high strain rate as Fig.3 shows.

4 Conclusions

1) The convex or concave shapes of the flow curves in the AZ31 magnesium alloy are controlled by the number of the twins. There is the number of critical, in which the flow curves change from concave to convex.

2) At the strain rate of about $10^3\,s^{-1}$, the number of twins decreases suddenly, and almost all the twins distribute in smaller grains.

3) At the strain rate of about $10^3\,s^{-1}$, the adiabatic shear band and adiabatic shear localization can be found. The occurring of the adiabatic shear band is the reason why the crack strain decreases at high strain rates.

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