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Recrystallization model for hot-rolling of 5182 aluminum alloy①

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[Abstract] A recrystallization model for hot-rolling of 5182 aluminum alloy was presented by means of the fractional softening during double interval deformation. It is found that the recrystallization rate depends on strain rate more sensitively than deformation temperature, and the time for full recrystallization is very short as strain rate is greater than 1 s^{-1}. Using the recrystallization —time —temperature curves, the desirable hot rolled microstructure can be obtained by controlling the rolling speed, temperature and cooling rate before cooling during the last pass in reversing mill.

[Key words] 5182 aluminum alloy; hot-rolling; recrystallization; modeling; microstructure control
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1 INTRODUCTION

During hot-rolling, alloys are deformed for various passes at different temperature. Recrystallization ocurred at every pass can influence many properties of alloys such as the occurrence of precipitation, preferred orientation and grain size[1, 2].

Usually, the static recrystallization process is determined by either the metallographic examination (Unloaded → Held → Quenched, UHQ) or mechanical softening method (Unloaded → Held → Reloaded, UHR)[3~6]. In this paper, the recrystallization processes between passes during hot-rolling of 5182 aluminum alloy are determined by means of the fractional softening during double interval deformations on Gleeble 1500 type machine.

2 EXPERIMENTAL

All specimens were cut from cast slab with chemical composition of Mg 4.33, Mn 0.24, Cu 0.03, Fe 0.22, Si 0.10 and Al balanced (mass fraction, %) and homogenized at 540 ℃ for 2 h in resistance-heated furnace, then rapidly quenched in water. The dimension of the sample was d10 mm × 15 mm with grooves on both sides filled machine oil mingled with graphite powder as lubricant to reduce friction between the anvil and specimen during deformation.

The fractional softening (X_S) is measured as follows[3~9].

$$X_S = \frac{(\sigma_u - \sigma_r)}{(\sigma_u - \sigma_y)} \times 100\% \qquad (1)$$

where σ_y and σ_r are the yield stresses at the first deformation pass and the second one, respectively; σ_u is the flow stress at the end of the first pass.

In isothermal double interval deformation tests were conducted on Gleeble 1500. The strain rate was 0.5 s^{-1}, the strain of each pass was kept at 0.4 and the temperature were 300 ℃, 400 ℃ respectively. All specimens were heated to the deformation temperature at the rate of 1 ℃/s and held for 240 s before deformation.

3 RESULTS AND DISCUSSION

3.1 Fractional softening during double interval deformations

The flow stress curves obtained from isothermal double interval deformation tests at strain rate of 0.5 s^{-1} at different temperature are presented in Fig. 1 and Fig. 2, respectively. The dependence of the fractional softening on the time between passes (t_p) is shown in Fig. 3. All indicate that the fractional softening increases with increasing time between passes and elevating deformation temperature. The fractional softening at 400 ℃ increased from 33.5% at 30s to 83.6% at 180 s; the fractional softening at 60 s increased from 48.5% at 300 ℃ to 57.2% at 400 ℃.

3.2 Recrystallization model

Since softening includes static recovery and the static recrystallization, the recrystallization fraction must be calibrated by microscopy. The kinetics of it follows the normal Avrami relationship[3, 4], that is the rate of the static recrystallization increases with increasing Zener-Hollomon parameter. Sellars et al[5] determined that 70% softening was correspondance to about 50% recrystallization, and a simple recrystallization model suggested by Hirsh was used in this study:

$$t_{0.5} = a \cdot Z^b \cdot \exp(E_r / RT_h) \qquad (2)$$

where Z is Zener-Hollomon parameter which can be

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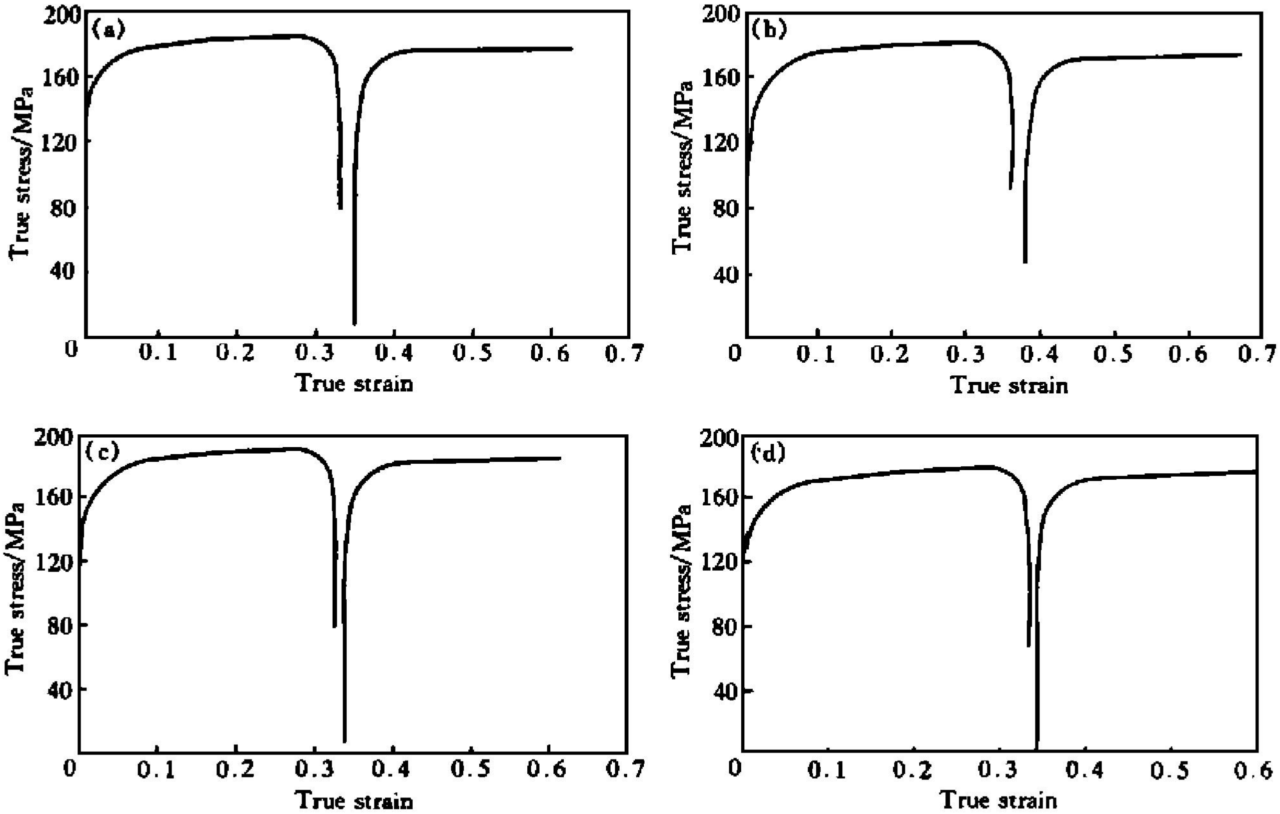

Fig. 1 Stress—strain curves for 5182 aluminum alloy under isothermal double interval deformation at 300 ℃
(a) —30 s; (b) —60 s; (c) —120 s; (d) —180 s

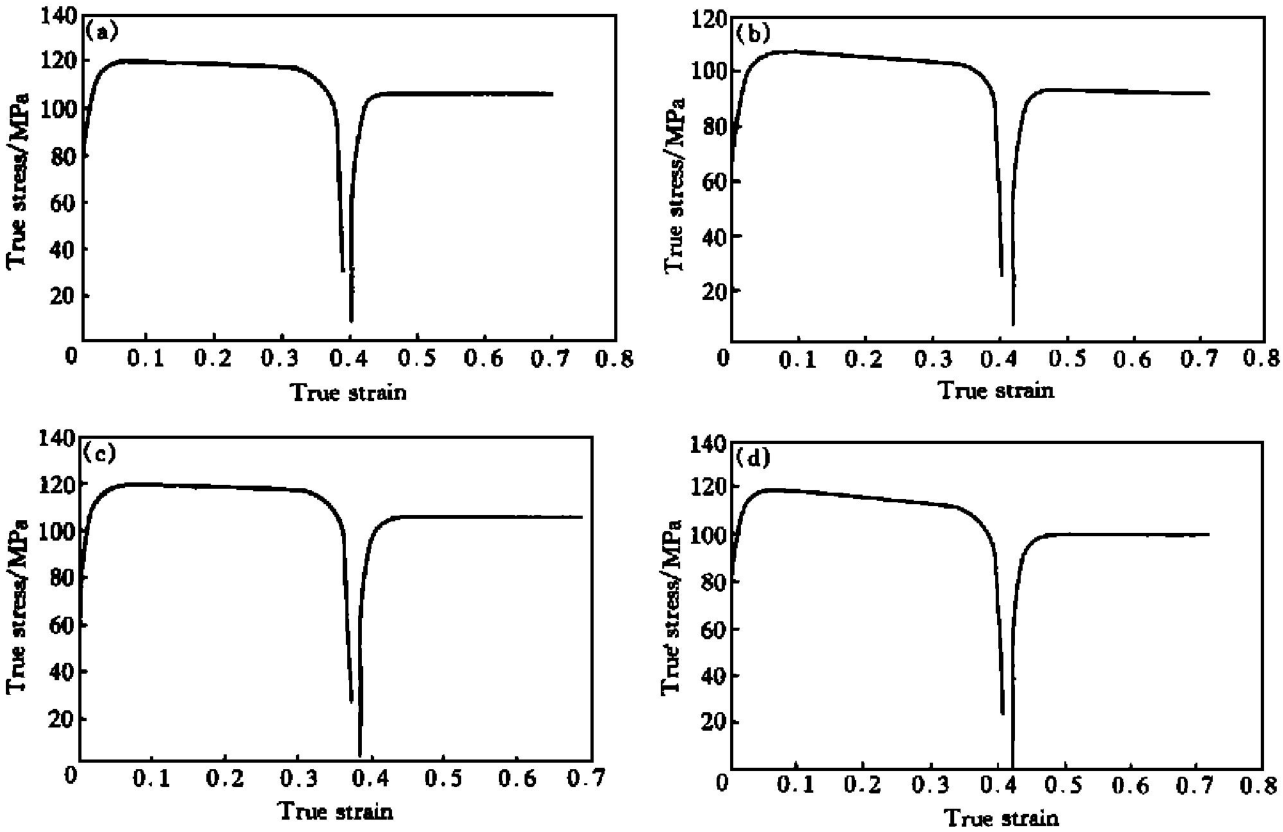

Fig. 2 Stress—strain curves for 5182 aluminum alloy under isothermal double interval deformation at 400 ℃
(a) —30 s; (b) —60 s; (c) —120 s; (d) —180 s

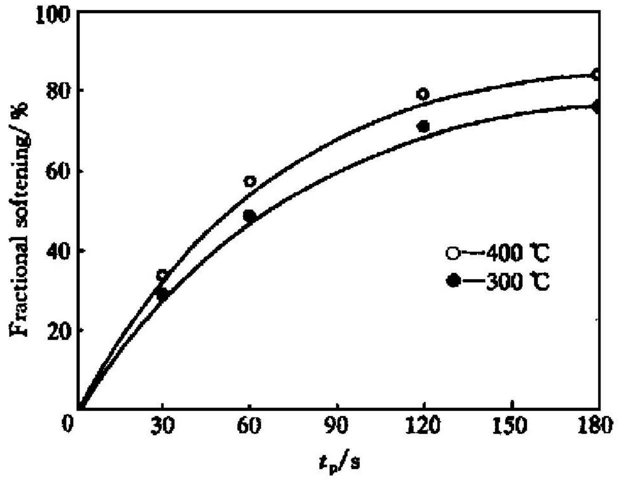

Fig. 3 Dependence of fractional softening on times between passes

expressed as $Z=\dot{\varepsilon}\exp(E_d/RT_d)$; a and b are materials constants strongly dependent upon compositions and homogenization treatment condition; E_r and E_d are the activation energy for recrystallization and hot deformation receptivity; T_h is the holding temperature between passes and T_d is deformation temperature; R is a gas constant; $\dot{\varepsilon}$ is the deformation rate.

Simply, a and b can be obtained from the experimental data of fractional softening in Fig. 3, then the recrystallization model for 5182 aluminum alloy can be rewritten as follows.

$$t_{0.5}=7.772Z^{-1.267}\cdot\exp\left(\frac{230\,000}{RT_h}\right),$$

$$Z=\dot{\varepsilon}\exp\left(\frac{174\,200}{RT_d}\right) \quad (3)$$

So the recrystallization fraction at interval between passes during multipass hot-rolling of 5182 aluminum alloy can be expressed as

$$X_R=1-\exp\left[-0.693\left(t_p/t_{0.5}\right)^2\right] \quad (4)$$

where t_p is time between passes.

3.3 Application

In general, there are three typical microstructures during multipass hot-rolling of aluminum alloys.

1) $X_R\leqslant 0.05$, a full recovered substructure;

2) $X_R\geqslant 0.95$, a full recrystallization;

3) $0.05\leqslant X_R\leqslant 0.95$, a partial recrystallization.

From Eqn. (4),

$$t=t_{0.5}\left[\ln\left[\frac{1}{1-X_R}\right]^{-0.693}\right]^{\frac{1}{2}} \quad (5)$$

For a given deformation condition, when $t_p\leqslant 0.272t_{0.5}$, a full recovered substructure can be obtained; $0.272t_{0.5}\leqslant t_p\leqslant 2.079t_{0.5}$, a partial recrystallization is happened and $t_p\geqslant 2.079t_{0.5}$, a full recrystallization and possibly grain growth occur.

Recrystallization —time —temperature diagrams for 5182 aluminum alloy from Eqn. (5) are shown in Fig. 4. It can be seen that the time for full recrystallization decreases with increasing the deformation temperature at a given strain rate, indicating recrystallization is accelerated. This can be implied that time between passes should be shortened to prohibit

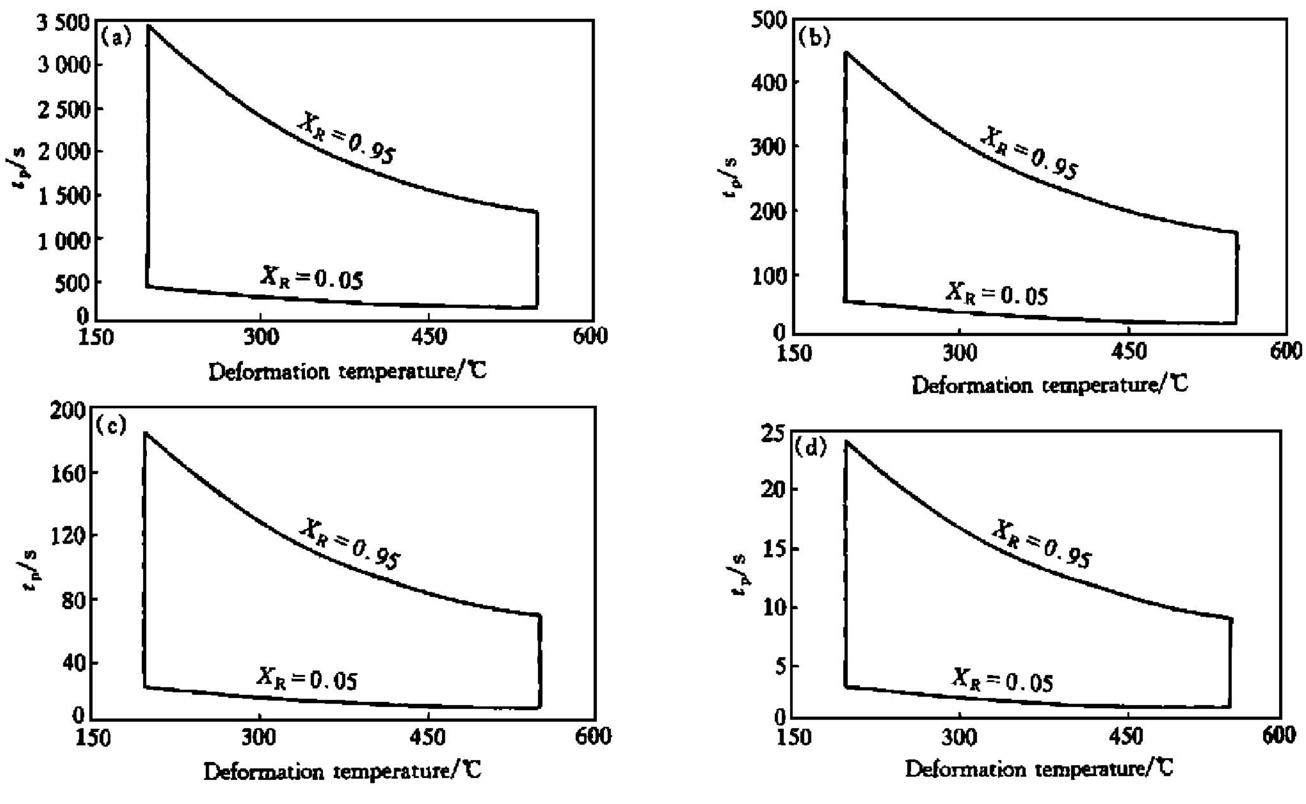

Fig. 4 Recrystallization —time —temperature diagrams for 5182 aluminum alloy
(a) —$\dot{\varepsilon}=0.1\ s^{-1}$; (b) —$\dot{\varepsilon}=0.5\ s^{-1}$; (c) —$\dot{\varepsilon}=1\ s^{-1}$; (d) —$\dot{\varepsilon}=5\ s^{-1}$

the grain from growing and to reduce formability and cracking at high deformation temperature and strain rate. Especially, the greater inhomogeneity of deformation occur as a result of friction between the billet and rolls and geometrical factor in the deformation zone, resulting in inhomogeneity of the microstructures such as substructure and recrystallization during the early passes. Inhomogeneous deformation band is a main microstructural configuration that can be an important factor in promoting the growth rate of nuclei during the recrystallization process[10]. Hence, controlling time between passes becomes more important in industrial rolling schedule.

Recrystallization—time—strain rate diagrams for 5182 aluminum alloy are shown in Fig. 5. It can be seen that the holding times for complete recrystallization reduces with increasing strain rate, especially the strain rate is greater than 1 s^{-1}. Hence, a complete recrystallization is happened under the deformation at the lower deformation temperature (lower than 0.5 T_m) and higher strain rate, this is very similarly to the finished rolling condition. It become very important to control the cooling rate before cooling at the last pass in reversing mill.

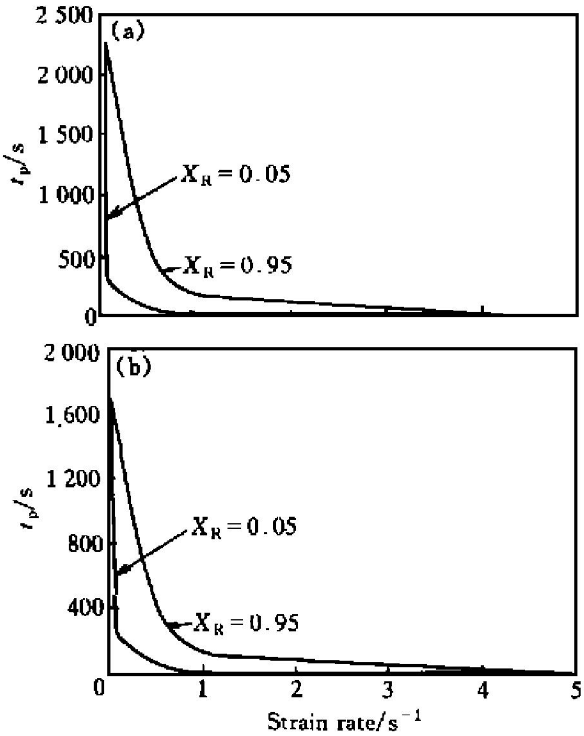

Fig. 5 Recrystallization—time—strain rate diagrams for 5182 aluminum alloy
(a) —θ= 300 ℃; (b) —θ= 400 ℃

Time from the beginning of recrystallization to completing of recrystallization is defined to determine the recrystallization rate in this study.

$$t_R = t_{0.95} - t_{0.05} \quad (6)$$

From Eqn. (5),

$$t_R = 1.807 t_{0.5} \quad (7)$$

The dependence of recrystallization rate on the strain rate and deformation temperature for 5182 aluminum alloy are shown in Fig. 6 and Fig. 7, respectively. It is indicated that t_R decreases with increasing strain rate and deformation temperature, but is more sensitively to strain rate.

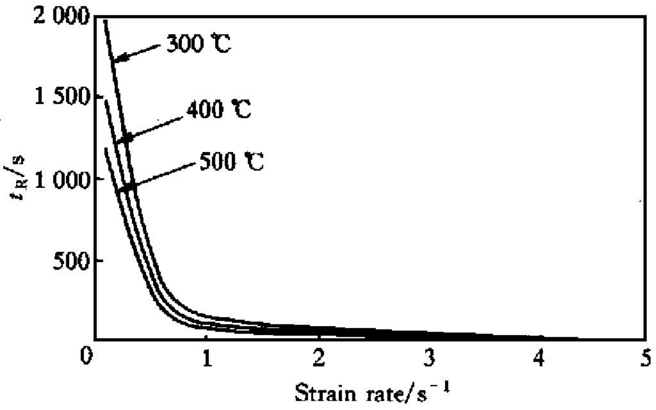

Fig. 6 Relationship between t_R and strain rate for 5182 aluminum alloy

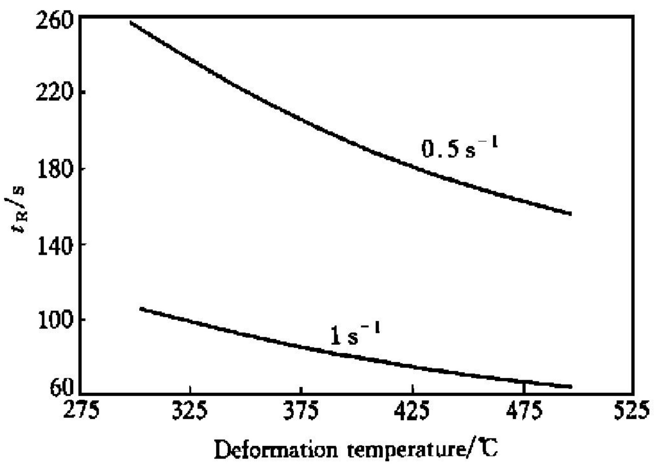

Fig. 7 Relationship between t_R and deformation temperature for 5182 aluminum alloy

The hot-rolled microstructure can be controlled by controlling deformation temperature, deformation speed and time between passes in practice. Using the recrystallization—time—temperature curves (as shown in Fig. 4) to design the hot-rolling schedule, the recovered substructure, partial recrystallization and full recrystallization can be obtained.

4 CONCLUSIONS

1) The fractional softening between passes increases with increasing deformation temperature and time between passes during multipass hot-rolling of 5182 aluminum alloy.

2) A recrystallization model was presented by means of the fractional softening during double interval deformations on Gleeble 1500. It is found that the recrystallization rate depends on strain rate more sensitively than deformation temperature, and the time

for full recrystallization are very short as strain rate is greater than 1 s^{-1}.

3) Using the recrystallization—time—temperature curves, the desirable hot rolled microstructure can be obtained.

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