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Dynamic recrystallization during hot compression of α-Fe

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Specimens of high purity α-Fe were deformed in the GLEEBLE-1500 at temperatures of 550°C, 700°C, 800°C and 900°C at strain rates ranging from 0.001 to 10 s^{-1}. The microstructural changes, which occur during the hot compression, have been investigated by optical microscopy and related to the true stress-true strain curves. The experimental results show that the dynamic recrystallization is accelerated with increase of deformation temperature and decrease of strain rate. The relation between the dynamic recrystallization and Z-parameter has been investigated. Dynamic recrystallization takes place approximately in a certain range of Z parameter, i.e., $25 < \ln Z < 37$.

1. Introduction

Microstructure control during hot working is of practical importance in the thermomechanical processing of metallic materials because of the desirable properties of products. One of most important mechanisms for microstructural control is dynamic recrystallization, which can easily take place during hot deformation of a wide range of metals and alloys with lower stacking fault energy.

It is generally considered that during the hot deformation dynamic recovery instead of recrystallization occurs in those metals and alloys which have a high stacking fault energy, including industrial purity α-Fe. However, in high purity α-Fe during hot deformation dynamic recrystallization takes place [1–3]. The difference between pure α-Fe and high purity α-Fe is only in the amount of impurity. However, the restoration mechanisms during hot deformation in pure α-Fe are not well established. It is also not clear that how the deformation conditions affect the restoration process of pure α-Fe. The present work is to determine the restoration mechanism during hot compression at a variety of temperatures and strain rates and to discuss how the deformation conditions affect the dynamic recrystallization.

2. Experimental procedure

The chemical composition (wt%) of the high purity α-Fe used in the investigation was as follows: 0.003% Mn, 0.0020% C, <0.0003% P, <0.0003% S, Bal. Fe. The compression specimens were in the form of annealed pieces and they were deformed at temperatures of 550°C, 700°C, 800°C and 900°C at strain rates ranging from 0.001 to 10 s^{-1} in a GLEEBLE-1500 machine. The strain rates were constant during deformation. The tested samples were water quenched immediately after deformation, and cut along a plane parallel to the compression axis. The microstructural changes that occur during the hot compression have been investigated using true stress-true strain curves and optical microscopy. True stress-true strain curves were calculated under the assumption of uniform deformation. The microstructure for optical microscopy was revealed by etching 5% nital in the mechanically polished surface. The compression tests were not lubricated, nevertheless friction effects were neglected in following calculations.

3. Results and discussion

3.1. True stress-true strain curves

The true stress-true strain curves for pure α-Fe compressed at 550°C, 700°C, 800°C and 900°C at different strain rates are shown in Fig. 1.

The true stress-true strain curves of pure α-Fe compressed at 0.01 s^{-1}, 0.1 s^{-1}, 1 s^{-1} and 10 s^{-1} at the different temperatures are shown in Fig. 2. As specimens are deformed in compression at 550°C the stress keeps rising (Fig. 1a). As specimens are deformed in compression at the temperature of 700°C at strain rates of 0.01 s^{-1} and 0.1 s^{-1} the stress rises to a peak value followed by a decrease leading to a steady state at higher strains (Fig. 2a and b). It is very similar to that reported in the dynamic recrystallization (DRX) of austenite [4].

It is possible that DRX occurs during the hot compression at temperature 700°C at strain rates of 0.01 s^{-1}- 0.1 s^{-1}. With decreasing strain rate the stress peak value decreases.

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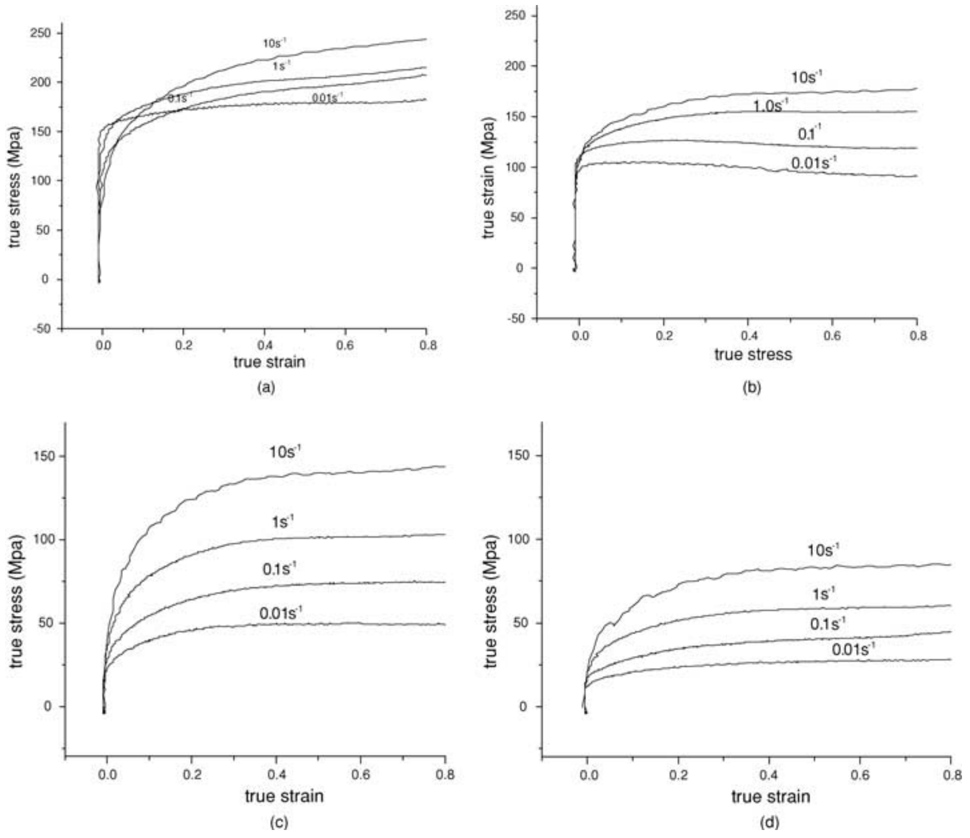


Figure 1 True stress-true strain curves during hot compression at various strain rates and temperatures of 550°C (a), 700°C (b), 800°C (c), 900°C (d) for pure α-Fe.

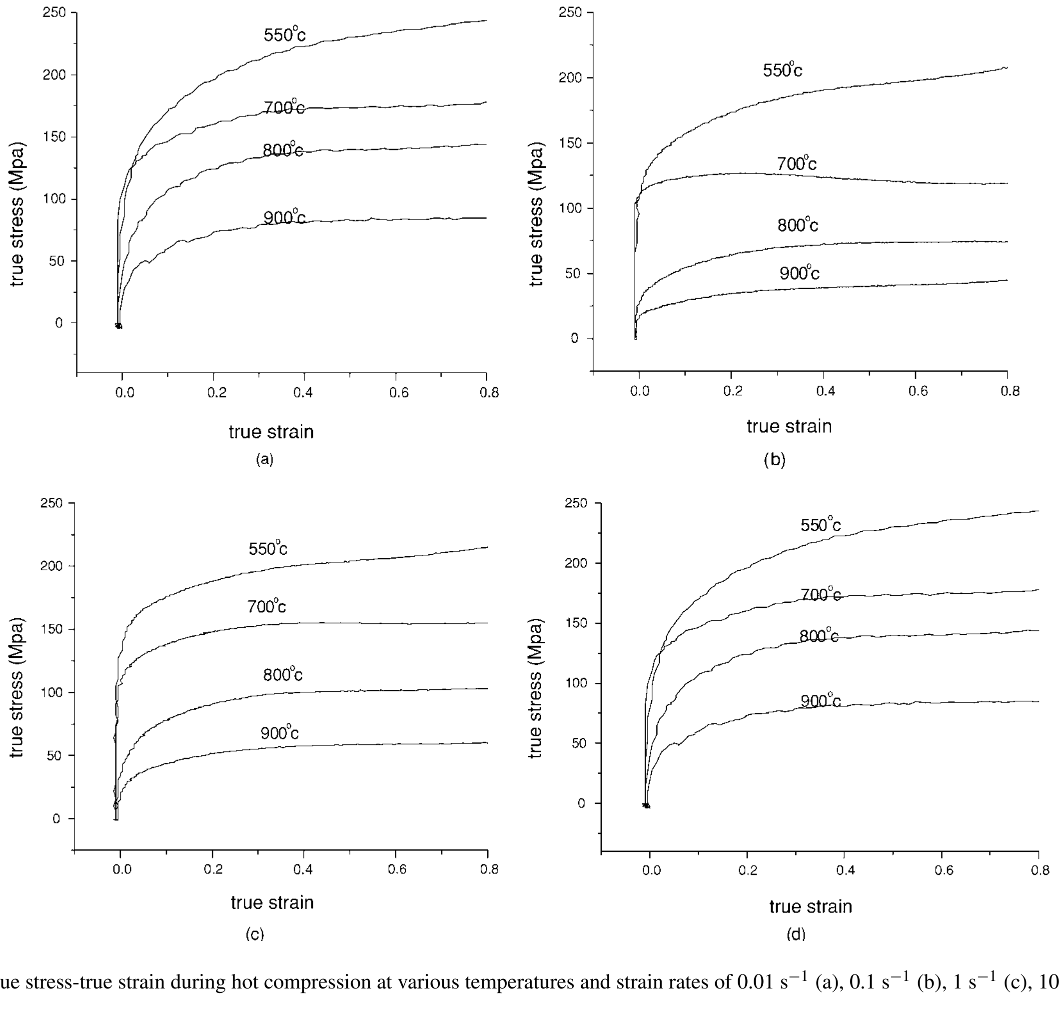


Figure 2 True stress-true strain during hot compression at various temperatures and strain rates of 0.01 s^{-1} (a), 0.1 s^{-1} (b), 1 s^{-1} (c), 10 s^{-1} (d) for pure iron.

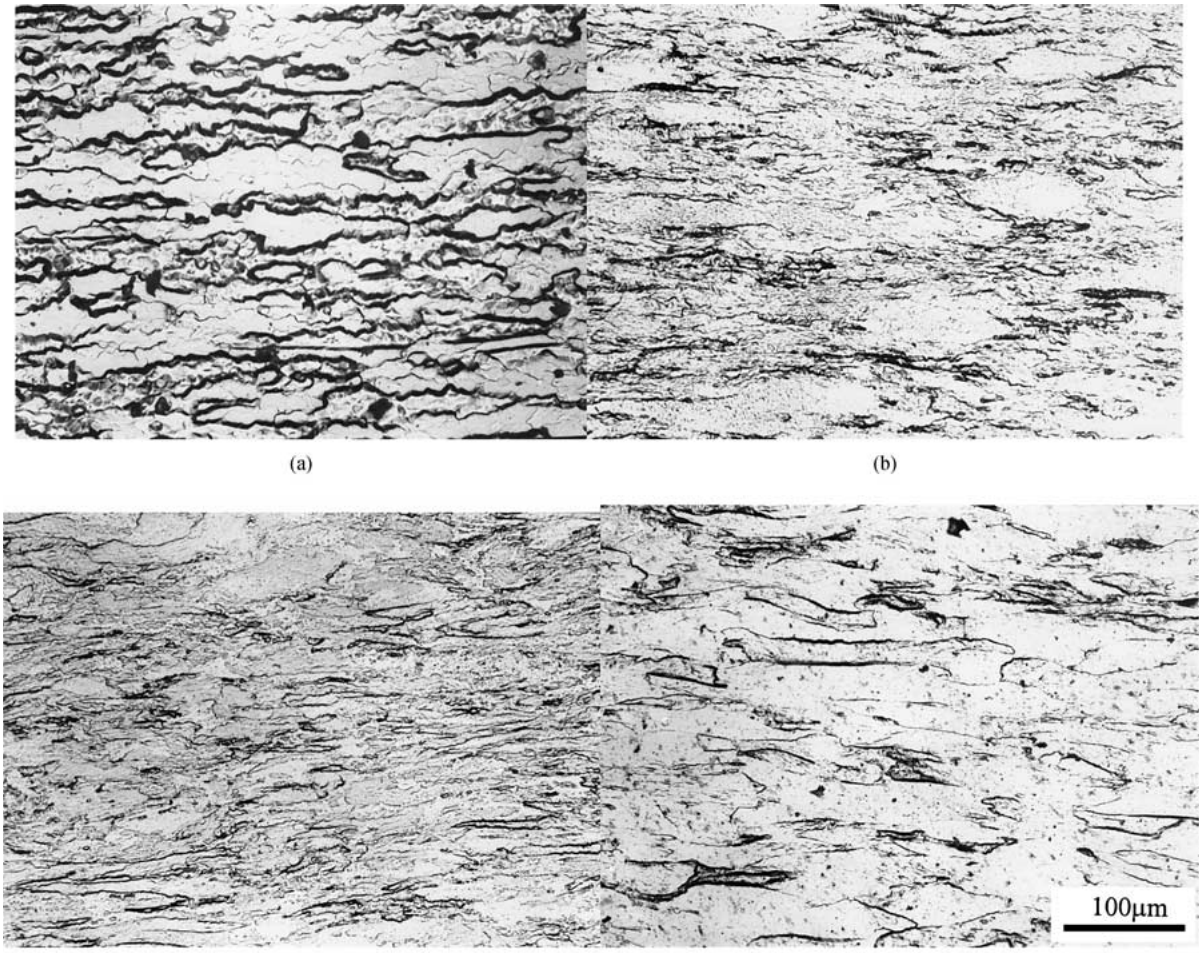

(a) (b) (c) (d)

Figure 3 Microstructures of the specimens compressed at 700°C (a) 0.001 s^{-1}, (b) 0.1 s^{-1}, (c) 1 s^{-1}, (d) 10 s^{-1}.

The deformation temperatures have a great effect on the true stress-true strain curves (Fig. 2). With the increase of deformation temperature, the peak stress values decrease. At higher deformation temperatures, i.e., 800°C and 900°C, the curves are nearly flat although a slight decrease after the peak in stress can be observed, which is very similar to that reported in DRX of stainless steel [2, 5]. As was pointed out by Tsuji *et al.* [1, 6], we also cannot decide about the occurrence of dynamic recrystallization only from true stress-true strain curves.

3.2. Deformed microstructures

The microstructures for the specimens deformed at strain of about 0.8 at 700°C and various strain rates are shown Fig. 3. All observations were carried out at center of the specimens. The specimen deformed at 10 s^{-1} shows elongated grains (Fig. 3d), which indicate that only dynamic recovery occurred. In the cases of a strain rate of 0.001 s^{-1} to 1 s^{-1} DRX grains surrounded by clearer boundaries are observed near initial grain boundaries (Fig. 3a–c). Small DRX grains were also elongated, the sizes of them are rather inhomogeneous and they seem to have subgrain boundaries inside. The density of new dynamic grains increases with decreasing of strain rate. Fig. 4 shows the microstructures of the specimens deformed at strain rate of 0.01 s^{-1} at various deformation temperatures. In the case of 550°C the grains were elongated (Fig. 4a). At 700°C and 800°C partial dynamic recrystallization occurs (Fig. 4b and c). In the case of the specimens deformed at 900°C dynamic recovery occurs (Fig. 4d). Almost all of microstructural features in the present study are very similar to those reported by Lin *et al.* [7, 8].

3.3. Effect of Z parameter on dynamic recrystallization

The deformation conditions are usually expressed in terms of temperature compensated strain rate (Z):

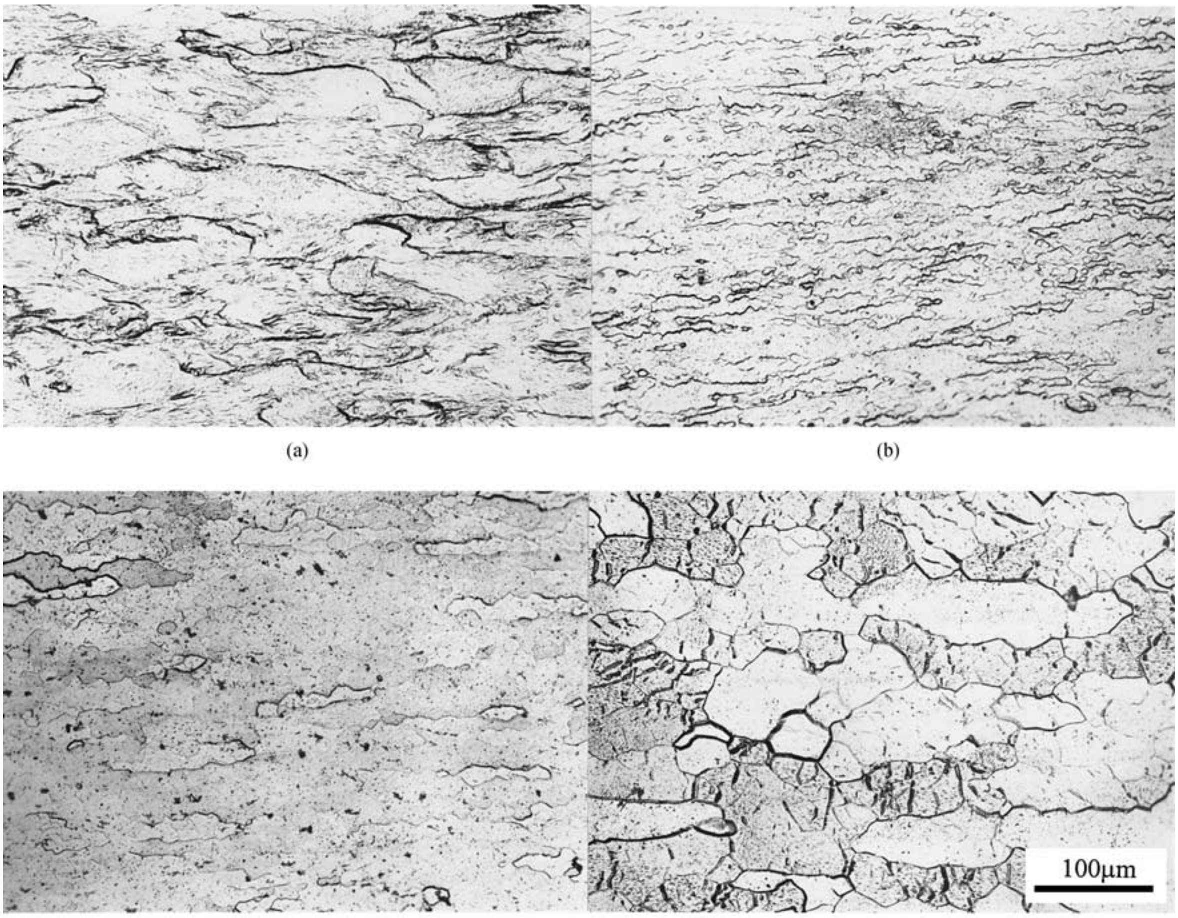
$$Z = \varepsilon' \exp(Q/RT) \tag{1}$$

Where Q is activation energy for deformation and R is the gas constant.

The relationship of temperature compensated strain rate (Z) and maximum or peak flow stress (i.e., the stress at a first peak, σ_p) is described by the following equation (3, 4, 9):

$$Z = A\sigma_p^n \tag{2}$$

Where A and n are the experimental constant.



(a) (b) (c) (d)

Figure 4 Microstructures of specimens compressed at 0.01 s^{-1} (a) 550°C, (b) 700°C, (c) 800°C, (d) 900°C.

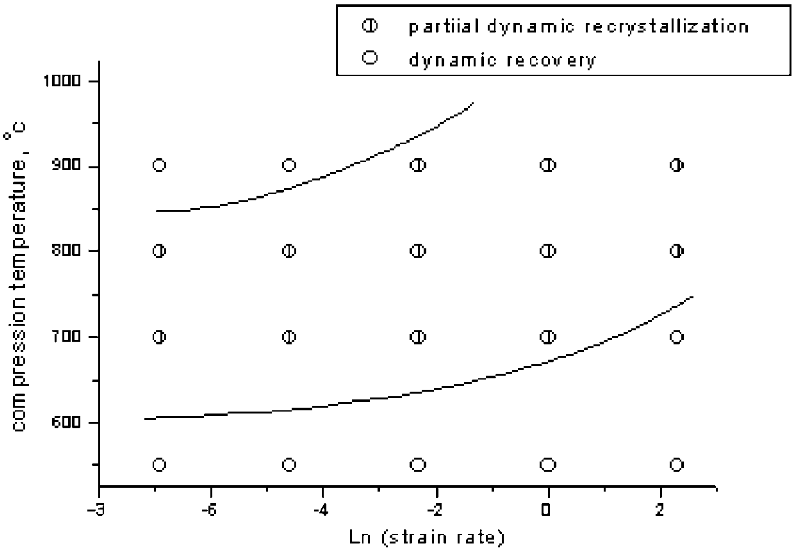


Figure 5 Dynamic recrystallization diagram.

From Equations 1 and 2 we can derive following equations.

$$\frac{\partial(\ln\sigma_p)}{\partial(\ln\varepsilon')}|_{1/T} = 1/n \tag{3}$$

$$\frac{\partial(\ln\sigma_p)}{\partial(1/T)}|_{\ln\varepsilon'} = Q/Rn \tag{4}$$

Combining the Equations 3 and 4, it is possible to calculate activation energy Q

$$Q = 290\ \text{kJ/mol}$$

The calculated value of Q and that reported in the previous papers [2, 3] are the same. The compensated strain rate (Z) at various compression states using Equation 1 and activation energy Q can be calculated.

In Fig. 5, it can be seen that dynamic recrystallization is accelerated with increasing compression temperature and decreasing strain rate. In the case of pure iron employed in this study, after a strain of about

0.8 partial dynamic recrystallization occurs during hot compression within a certain range of Z parameter, i.e., $25 < \ln Z < 37$.

Fig. 5 shows the dynamic recrystallization diagram, showing the dynamic recrystallization of hot compressed pure iron employed in the study.

4. Conclusions

The present study using high purity α-Fe confirmed that dynamic recrystallization can occur also in ferrite where it has been generally considered that recovery is only restoration process during hot deformation. Although the occurrence of dynamic recrystallization has been clarified by microstructural observations, true stress-true strain curves do not show an obvious drop of true stress, which has been typically reported in the case of DRX of austenite. After a strain of about 0.8 of pure iron partial dynamic recrystallization occurs during hot-compression with a certain range of Z parameter, i.e., $25 < \ln Z < 37$. Dynamic recrystallization is accelerated by increasing compression temperature and decreasing strain rate.

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References

1. N. TSUJI, Y. MATSUBARA and Y. SAITO, *Scripta Mater.* **37**(4) (1997) 477.
2. G. GLOVER and C. M. SELLARS, *Metall. Trans.* **3** (1972) 2271.
3. *Idem., ibid.* **4** (1973) 765.
4. J. P. LIN, T. Q. LEI and X. Y. AN, *Scripta Metallurgica.* **26** (1992) 1869.
5. A. BELYAKOV, H. MIURA and T. SAKAI, *Materials Science and Engineering* A **255** (1998) 139.
6. A. NAJIAFI-ZADEH, J. J. JONAS and S. YUE, *Metall. Trans.* A **23A** (1992) 2607.
7. J. P. LIN, X. Y. AN and T. Q. LEI, *J. Mater. Sci. Lett.* **12** (1993) 850.
8. X. Y. AN, J. P. LIN and T. Q. LEI, *Materials Chemistry and Physics* **20** (1988) 275.
9. *Idem., ibid.* **18** (1987) 255.

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