[Article ID] 1003- 6326(2002)03- 0454- 04

Influence and prediction of hot deformation parameters on microstructure of Ti-15-3 alloy①

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[Abstract] The effect of hot processing parameters on the microstructure of Ti-15-3 alloy after solution treatment was studied by isothermal compression test and metallurgical analysis. Predicting models for the relations between equivalent grain size and recrystallized grain volume percent with strain, strain rate and temperature have been developed with an artificial neural network method. The coincidence of predicted results with measured ones shows that the neural network can predict the influence of hot deformation parameters on the microstructure of Ti-15-3 alloy after solution treatment successfully. These studies are significant for determining hot-forging processing parameters of Ti-15-3 alloy.

[Key words] Ti-15-3 alloy; artificial neural network; equivalent grain size; recrystallized grain volume percent
[CLC number] TG302 **[Document code]** A

1 INTRODUCTION

Ti-15-3 (Ti-15V-3Cr-3Sn-3Al) alloy is a new metastable β-type titanium characterized by improved high specific strength and cold formability. It has been used extensively in aerospace industry[1, 2].

In hot deformation and following solution treatment, microstructure evolution occurs and it has an important influence on mechanical properties of the product. In order to improve quality of products, it is necessary to understand relationship between thermomechanical parameters and microstructure of the material well[3~ 5].

Variation rule of the microstructure of Ti-15-3 alloy after hot deformation and solution treatment was investigated by isothermal compression test as well as metallurgical analysis. On the basis of the data obtained from these tests, predicting models for equivalent grain size and recrystallized grain volume percent have been established with an artificial neural network. These models lay scientific foundation for determining reasonable hot forming process and improving the forming quality.

2 EXPERIMENTAL

The chemical compositions of experimental Ti-15-3 alloy is listed in Table 1. The experimental material was machined to cylinder specimens with a diameter of 8 mm and a height of 12 mm. Isothermal constant-strain-rate compression tests were conducted on a Gleeble-1500 Thermal Simulator at strain rates of 0.01, 0.1 and 1 s^{-1} to the reduction of 40% and 60% in height at temperature varying from 750 ℃ to 900 ℃ with intervals of 50 ℃. Every deformed specimen was immediately cooled and then solution treated at 800 ℃ for 20 min and quenched in water. The deformed specimens were sectioned parallel to the compression axis and polished and etched for microstructure observation using an optical microscope.

Table 1 Chemical compositions of Ti-15-3 alloy (mass fraction, %)

V	Cr	Sn	Al	Fe
15.6	3.2	2.8	3.4	0.13
C	N	Si	O	Ti
0.03	0.02	0.07	0.13	74.62

The point counting method was employed to determine the microstructure parameters of Ti-15-3 alloy[6]. The equivalent grain size can be calculated as follows[7]:

$$d_e = \varphi_d(d_1\varphi_1 + d_2\varphi_2) \quad (1)$$

where $\varphi_1 + \varphi_2 = 1$, φ_1 and φ_2 are percents of coarse and fine grains respectively; φ_d is the distribution factor of fine grains, $\varphi_d = 0.5$; d_1 and d_2 are the mean diameters of the coarse and fine grains respectively.

3 EFFECT OF HOT DEFORMATION PARAMETERS ON MICROSTRUCTURE

3.1 Effect of deformation temperature

Fig. 1 illustrates the effect of temperature on the microstructure of Ti-15-3 alloy after solution treatment at a deformation of 40%. At a higher deformation temperature, grain growth takes place during deformation and the grain boundary area per unit volume is reduced. Otherwise, the deformation energy is

① [Received date] 2001- 07- 24; [Accepted date] 2001- 11- 19

reduced because of dynamic recovery. So in the microstructure after solution treatment, the equivalent grain size(d_e) increases and the recrystallized grain volume percent (δ) decreases with the increase of deformation temperature. When the strain rate is lower, recrystallization occurs in the deformed microstructure at a higher temperature. The higher the temperature, the larger the recrystallization degree. Therefore, in the solution treatment after hot deformation, two kinds of microstructure variation process may be found. Except some new grain nuclei form and grow in the deformed alloy (static recrystallization), the original recrystallized grain will grow continuously (metadynamic recrystallization). The later results in the recrystallization degree increasing and variation of the recrystallized grain volume percent with temperature is very weak.

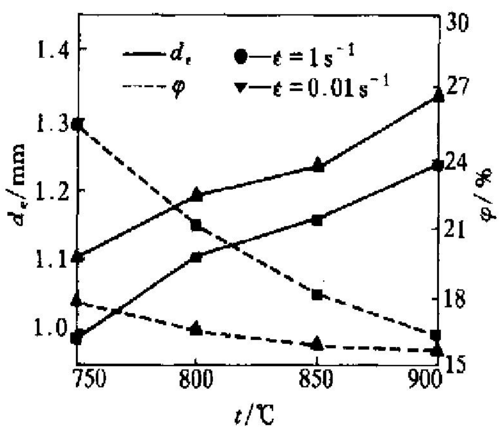

Fig. 1 Influence of deformation temperature on microstructure after solution treatment

3.2 Effect of deformation degree

The effect of deformation degree on the microstructure of Ti-15-3 alloy after solution treatment at a strain rate of 0.01 s^{-1} is shown as Fig. 2. It can be seen that the higher the strain, the more the recrystallized grain volume percent and the finer the grains. At a higher deformation degree, the dislocation density in the deformed microstructure increases and deformation energy stored in the deformed alloy increases too. Moreover, finer grains

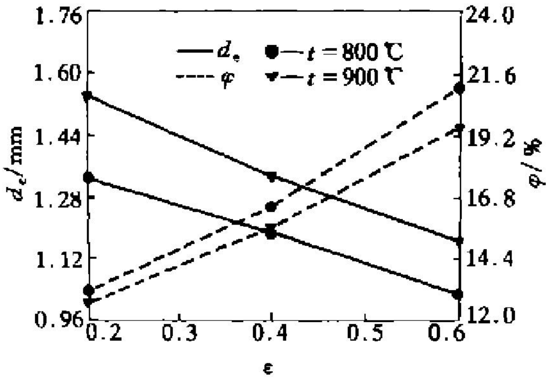

Fig. 2 Influence of deformation degree on microstructure after solution treatment

are obtained at a higher deformation degree and the grain boundary area per unit volume increases. Hence, the recrystallized grains nucleate more easily during the following solution. Otherwise, at a higher temperature and a lower strain rate, recrystallization degree in the deformed alloy increases with strain. So in the following solution treatment, static and metadynamic recrystallization occur and the recrystallized grain volume percent increases greatly.

3.3 Effect of strain rate

The effect of strain rate on the microstructure of Ti-15-3 alloy after solution treatment at a deformation of 40% is shown in Fig. 3. Just as the effect of deformation degree, the recrystallization degree increases and the equivalent grain size decreases with increase of strain rate after solution treatment. With the increase of strain rate, dynamic recovery rate decreases and dislocation generation rate increases. So the dislocation density and nucleation sites increase in the deformed microstructure. A faster deformation rate results in more deformation energy being stored in the deformed alloy and the recrystallized grains grow more easily during the following solution treatment[8]. Therefore, the recrystallization degree increases and the grain size decreases.

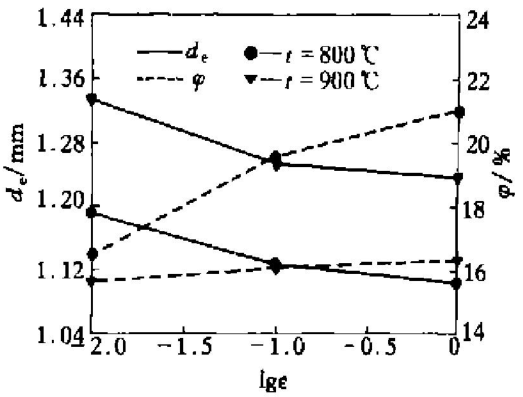

Fig. 3 Influence of strain rate on microstructure after solution treatment

When the strain rate is lower, recovery proceeds adequately or the recrystallization occurs during deformation. There is not sufficient deformation energy for static recrystallization to proceed during the following solution treatment and the recrystallization degree is small. But, at a higher temperature, recrystallization appears in the deformed alloy and the recrystallized grain will grow continuously during solution treatment. So the recrystallization percent increases and its variation with strain rate is very weak.

To obtain uniform fine-grain microstructure in forging process it is required to decrease deformation temperature and increase deformation degree at an appropriate strain rate. Fig. 4 shows the microstructure after solution heat treatment of the specimens deformed at different deformation

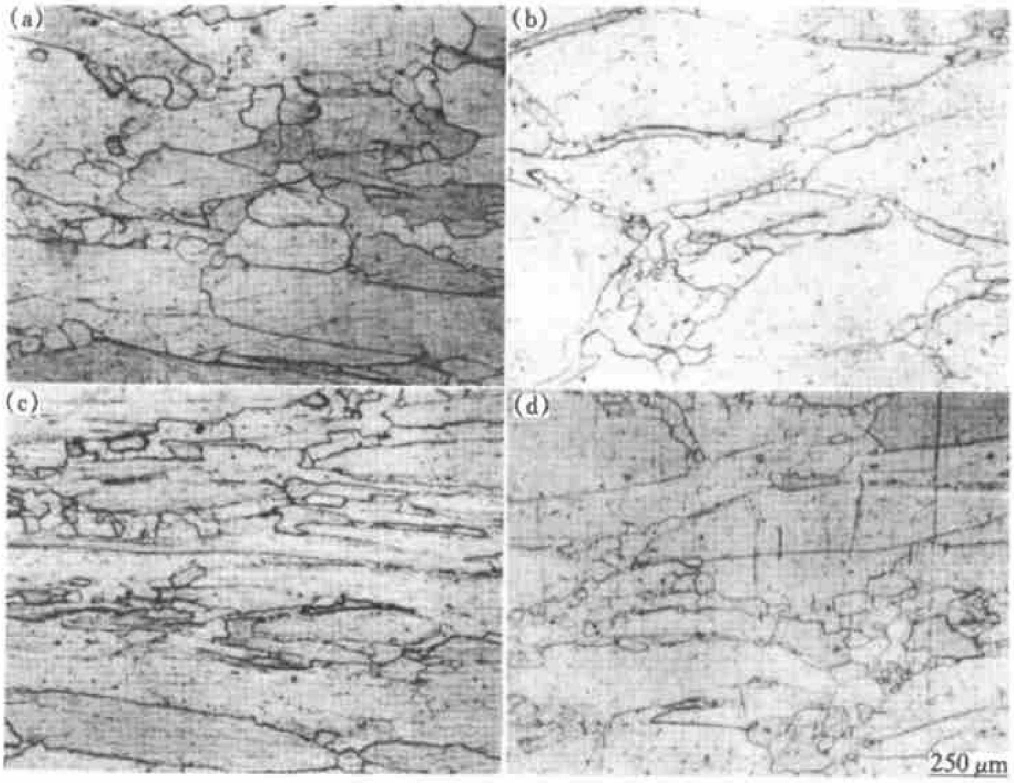

Fig. 4 Microstructures of specimens deformed at different parameters after solution treatment
(a) —t= 750 ℃, ε= 0.4, $\dot{\varepsilon}$= 0.01 s^{-1}; (b) —t= 800 ℃, ε= 0.4, $\dot{\varepsilon}$= 0.01 s^{-1};
(c) —t= 800 ℃, ε= 0.6, $\dot{\varepsilon}$= 0.01 s^{-1}; (d) —t= 800 ℃, ε= 0.4, $\dot{\varepsilon}$= 1 s^{-1}

conditions.

4 NEURAL NETWORK PREDICTION

Artificial neural network is an intelligent information-treatment system with the characteristics of adaptive learning and treating complex and non-linear relationships. Using a neural network, it is not necessary to postulate a mathematical model at first or identify its parameters. The relationship can be 'learned' by a neural network through adequate training from experimental data. It cannot only make decisions based on incomplete and disorderly information, but can also generalize rules from those cases on which it was trained and apply these rules to new stimuli[9~11].

In this paper, a three-layer neural network with a back-propagation learning rule is employed for acquiring models of the equivalent grain size and recrystallized grain volume percent of Ti-15-3 alloy. Temperature, effective strain and effective strain rate are used as the input vectors of the network. The outputs of the neural network are equivalent grain size and recrystallized grain volume percent respectively. The learning rate is 0.3 and the momentum parameter is 0.5.

Fig. 5 and Fig. 6 show the comparison of the predicted equivalent grain size and recrystallized grain volume percent acquired from the neural network with experimental results, respectively.

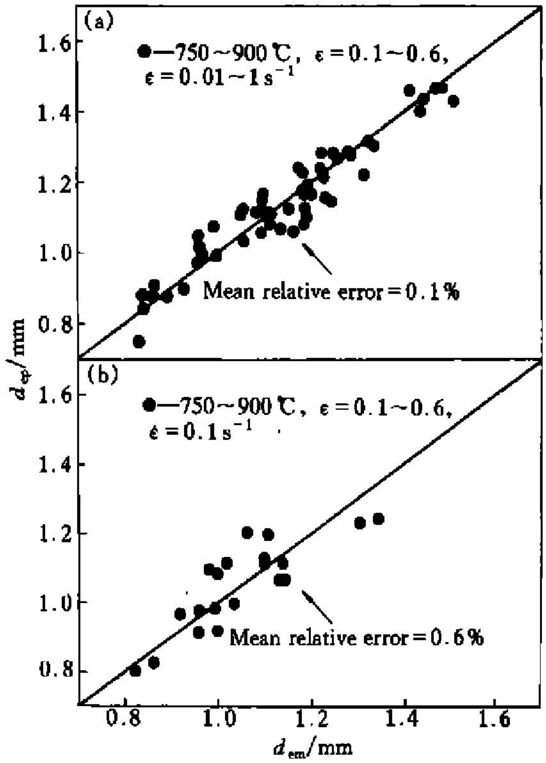

Fig. 5 Comparison between predicted (indicated by superscript p in d_{ep}) and measured (indicated by m in d_{em}) equivalent grain size
(a) —Sampled data; (b) —Non-sampled data

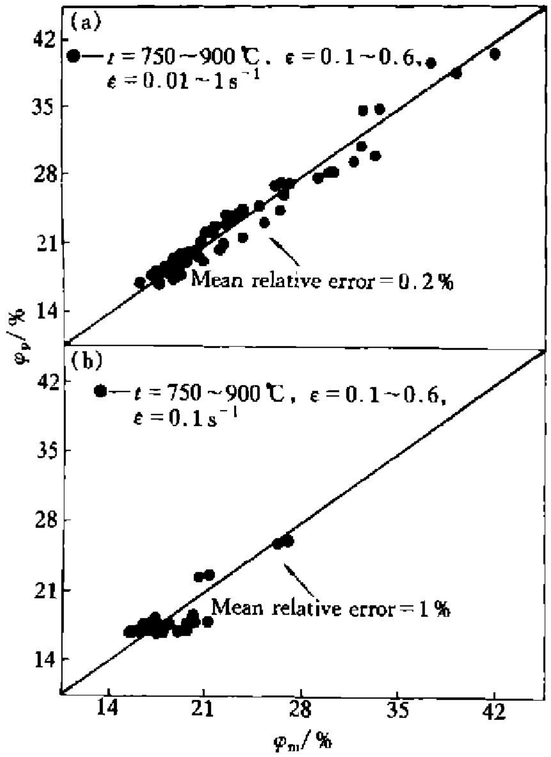

Fig. 6 Comparison between predicted and measured recrystallized grain volume percent, φ_p, φ_m

(a) —Sampled data; (b) —Non-sampled data

After training, the mean relative error between the expected equivalent grain size and actual ones of the neural network is within 0.1% for 84 sets sampled data and it is within 0.6% for 30 sets non-sampled data. For recrystallized grain volume percent, the mean relative errors are within 0.2% and 1% respectively. The agreement of predicted results with measured ones shows that the neural network is able to predict the variation of the microstructure of Ti-15-3 alloy with hot deformation parameters successfully.

5 CONCLUSIONS

1) Under the same conditions of cooling and heat treatment, the deformation temperature, deformation degree and strain rate have important effect on the microstructure of Ti-15-3 alloy after hot deformation and solution treatment. Equivalent grain size increases with deformation temperature and decreases with deformation degree and strain rate. Recrystallized grain volume percent decreases with deformation temperature (when the strain rate is lower, the variation is smaller) and increases with strain and strain rate (when the temperature is higher, the variation is smaller). To obtain uniform fine-grain microstructure in a forging, it is required to decrease temperature and increase deformation degree at a appropriate strain rate.

2) The predicting models for equivalent grain size and recrystallized grain volume percent have been established with an artificial neural network. The close agreement of predicted results with measured ones shows that the neural network is able to predict the variation of the microstructure of Ti-15-3 alloy with hot deformation parameters accurately.

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(Edited by HUANG Jin-song)