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ARTICLE

Modeling the High Temperature Deformation Constitutive Relationship of TC4-DT Alloy Based on Fuzzy-neural Network

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Abstract: By analyzing the high temperature TC4-DT titanium alloys' deformation temperature, strain rate and deformation degree with the parameters of the experimental data flow stress, an adaptive fuzzy-neural network model has been established to predict flow stress data to model the high temperature deformation constitutive relationship of TC4-DT titanium alloy. The experimental results were obtained at deformation temperature of 750~1150 ºC, strain rates of 0.001~ 10 s^{-1}, and height reduction of 50%. The network integrates the fuzzy inference system with a back-propagation (BP) learning algorithm of neural network. Results show that the predicated values are in satisfactory agreement with the experimental results and the maximum relative error is less than 6%. It proves that the fuzzy-neural network is a very effective and practical method to achieve more optimized TC4 - DT titanium alloy constitutive relation model and optimize deformation process parameters.

Key words: TC4-DT alloy; fuzzy-neural network; constitutive relationship

The Ti-6Al-4V alloy is the most applicable among titanium alloys due to its excellent mechanical properties[1-3], but it can't satisfy certain special requirements, especially in the aviation industry. From 1960 s, the Ti-6Al-4V ELI alloy[4-6] was developed according to this demand. The typical property of Ti-6Al-4V ELI alloy is due to its lower impurities content than common Ti-6Al-4V alloy. Recently, a kind of $\alpha+\beta$ titanium alloy named TC4-DT has been developed in China, which is similar to Ti-6Al-4V ELI alloy.

Due to its excellent mechanical properties, TC4-DT alloy is ranked among the most important advanced materials for a variety of technological applications. The thermal deformation process of TC4-DT alloy is very complex and can be affected by many factors, such as deformation temperature, deformation rate, and deformation degree. In previous scientific literatures, most researches were focused on establishing TC4-DT alloy's rheological stress model[2-3]. Establishing its rheological stress model through a function model constitutive relation is very difficult to accurately reflect the deformation parameters on the influence law of flow stress. The artificial neural network (ANN) is a kind of modeling of biological neural network of intelligent information processing system; through the approximate any repeated nonlinear system, it realizes the system modeling, estimation, forecasting, diagnosis and adaptive control, which is able to describe the complex process parameter function better. For example, Zhang Xingquan established congruent Ti-17 alloy constitutive relation of the artificial neural network model, based on the deformation process and performance data between the artificial neural network training, getting[7] a knowledge based on constitutive relationship model. Xiong Aiming et al[8] established the microstructure evolution of TC6 titanium alloy during high temperature deformation using a fuzzy neural network prediction model. They found that the calculation results have good agreement with experimental results.

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In this paper, the hot deforming behavior of TC4-DT alloy was studied by a fuzzy-neural network model. And then the high temperature deformation constitutive relationship of TC4-DT titanium alloy was established.

1 Materials and Experimental Procedure

All the TC4-DT samples were cut from the same ingot produced by Northwest Institute for Nonferrous Metal Research, P. R. China.

The samples were forged and then heat-treated below the β transus prior to hot compressing. The uniaxial hot compression was carried out by a computer controlled servo-hydraulic facility under constant temperature and strain rate conditions. The samples were machined to cylinders with 12.0 mm in height and 8.0 mm in diameter. Samples were compressed to the same true strain of about 50%, involving five constant strain rates, including 0.001, 0.01, 0.1, 1.0, and 10 s^{-1} and eight temperatures, including 750, 800, 850, 900, 950, 1050, 1100, and 1150 ℃. After hot compression, the samples were quenched directly in water.

2 Modeling of Constitutive Relationships

The purpose of applying the fuzzy-neural network to establish a constitutive relationship is to develop a representation of the deformation behavior. The proposed fuzzy-neural network can be constructed automatically by learning from training examples. The structure used in this research is based on the theory developed by Takagi and Sugeno[9-11]. The network consists of a number of interconnected nodes, and each node is characterized by a node function with fixed or adjustable parameters. In this model, nodes of the same layer have similar Gaussian functions. Therefore, the activation function in the output layer of the model obeys a linear function. The output signals from the nodes of the previous layer will be accepted as the input signals in the current layer. After manipulation by the node function in the current layer, the output will be served as input signals for the subsequent layer. Fig.1 shows the architecture of the six layers fuzzy-neural network model.

Based on the fuzzy-neural network model, it is desirable to predict the flow stress of TC4-DT alloy, furthermore, to establish constitutive relationships. For this purpose, parameter prediction is the determination of aimed values response to evident input values of the constituted model as shown in Fig.1. Three input variables of the network are deformation temperature, strain and strain rate, while one output denoted as σ is the flow stress during high temperature deformation. The three middle layers have the same number which consists with the number of fuzzy rules. When the desired input-output data is given to the FNN, the data is selected to train the FNN model. A BP algorithm

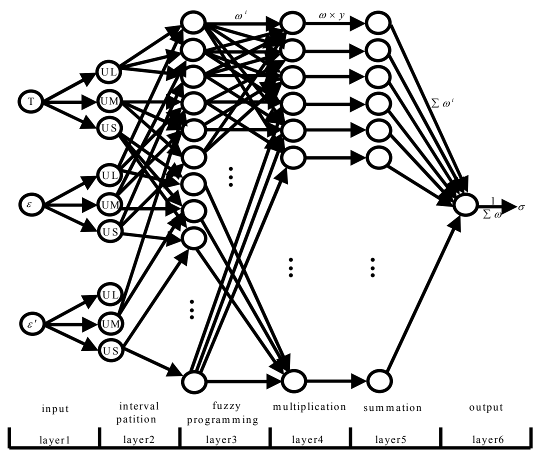

Fig.1 Architecture of the fuzzy-neural network model

using a gradient search technique is used to adjust the weights and thresholds until the mean squared error between the experimental results and the predicted results is minimized to the predefined convergence limit. And the mean squared error between the measured value and the predicted is computed.

This normalization procedure is crucial for rule combination. So as to run the fuzzy-neural network model, the Gaussian membership functions are constructed with three input variables, one output variable and the fuzzy subset of process parameters with "Large (L)", "Medium (M)", and "Small (S)" in the high temperature deformation.

3 Result and Discussion

Fig.2 shows the typical stress-strain curves of TC4-DT alloy deformed at 750 °C and 0.1 s^{-1}. Similar to TC4 alloy, the TC4-DT alloy is significantly sensitive to the deformation temperature and strain rate. At 750 °C, there is a distinct peak in the flow stress in the early stages of deformation followed by steady state at higher strains. The peak stress increases with strain rate and decreases with temperature. Flow softening phenomenon could be observed at all temperatures used in this study. When deformed below the phase transition temperature, 950 °C, the flow stress decreases rapidly after a peak. While deformed above phase transition temperature, the flow stress decreases more slowly after the peak stress. The flow stress curves show the dynamic response curve characteristics[12].

Fig.3 exhibits the variation of flow stress with inverse of deformation temperature in two microstructural regions. The different slopes obtained in different sides of the β transus indicate that the temperature sensitivity of flow