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The fuzzy neural network model of flow stress in the isothermal compression of 300M steel

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ABSTRACT

The isothermal compression of 300M steel is carried out on a Gleeble-3500 simulator at the deformation temperatures ranging from 1173 K to 1413 K, the strain rates ranging from 0.1 s^{-1} to 25.0 s^{-1} and a strain of 0.69. The experimental results show that the flow stress decreases with the increasing of deformation temperature, and increases with the increasing of strain rate. The fuzzy neural network method with a back-propagation learning algorithm and the regression method are adopted to model the flow stress in the isothermal compression of 300M steel respectively. All of the results have sufficiently indicated that the predicted accuracy of flow stress in the isothermal compression of 300M steel by using fuzzy neural network model is better that using the regression model, and the present approach is effective to predict the flow stress in the isothermal compression of 300M steel.

1. Introduction

In the forming of materials, the deformation behavior in high temperature deformation is complex. The constitutive equation is necessary to understand the deformation behavior and optimize the deformation process of metals and alloys as it describes the correlation of dynamic material properties with processing parameters such as strain, strain rate and deformation temperature. In the past years, there were consistent efforts to develop constitutive model [1–5]. Momeni et al. [1] analyzed the relationship between the flow stress and Zener–Hollomon parameter via the hyperbolic sine function in the whole range of deformation condition for AISI 410 martensitic stainless steel. Yuan and Liu [2] proposed that the peak flow stress could be effectively related to processing parameters using an Arrhenius-type hyperbolic-sine relationship. Niu et al. [3] established the constitutive equation of Ti600 alloy by using an Arrhenius-type hyperbolic-sine relationship. Wang et al. [4] also developed the constitutive equation of superalloy 718 by using an Arrhenius-type hyperbolic-sine equation.

Generally speaking, the process parameters present a non-linear relationship against flow stress. Therefore, the constitutive relationships using the regression method are not satisfactory. The artificial neural network method being different from the regression method is that the capability of self-organization or 'learning'. This approach is particularly suitable for treating complex and non-linear phenomena. The artificial neural network can be trained, but it is extremely difficult to apply a prior knowledge about the system under consideration and it is impossible to explain the neural system in a particular situation. In order to compensate for the drawbacks of ANN approach, the fuzzy systems are combined with the artificial neural networks [6]. The fuzzy neural network (FNN) has also been successfully applied to predict the deformation behavior of metals and alloys [7–12]. For instance, Kumar et al. [9] established a hybrid neural network model using recurrent self-organizing neural network to predict the flow stress for carbon steels. Luo et al. [10] established the flow stress model in the isothermal compression of Ti–6Al–4V alloy in terms of the fuzzy neural network with a back-propagation learning algorithm using strain, strain rate and deformation temperature as inputs. Chen et al. [11] established an adaptive fuzzy neural network model to characterize the microstructure evolution and constitutive relation in the superplastic deformation of 15 vol.% SiCp/LY12 aluminum composite.

The 300M steel as one of the ultrahigh strength steels has excellent properties such as high strength, good fracture toughness, excellent fatigue property and preferable stress corrosion resistance, and is widely used to manufacture the aircraft landing system. It is known that the deformation behavior of steel is sensitive to processing parameters in high temperature deformation. The investigation of the deformation behavior can be applied to improve the workability and optimize the process parameters. Nowadays, the deformation behavior of 300M steel has not been investigated and/or reported. In this paper, a FNN model with a back-propagation learning algorithm and regression model have been developed to model the flow stress considering processing parameters in the isothermal compression of 300M steel.

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Meanwhile, the predicted flow stress using the FNN model is compared with that using the regression method in the isothermal compression of 300M steel.

2. Experimental procedure and results

The chemical composition (wt.%) of as-received 300M steel with a diameter of 22.0 mm is shown in Table 1. The cylindrical compression specimens with a diameter of 8.0 mm and height of 12.0 mm were machined from the as-received 300M steel. The isothermal compression was conducted on a Gleeble-3500 simulator at the deformation temperatures of 1173 K, 1273 K, 1373 K and 1413 K, the strain rates of 0.1 s^{-1}, 1.0 s^{-1}, 10.0 s^{-1} and 25.0 s^{-1}, and a strain of 0.69. The specimens were heated to deformation temperature at a heating rate of 10 K/s and held for 5 min prior to compression to obtain a uniform temperature in the 300M steel specimens. The flow stress was recorded as a function of strain at each deformation temperature and strain rate in the isothermal compression of 300M steel.

The stress–strain curves in the isothermal compression of 300M steel at different strain rates are shown in Fig. 1. It can be seen from Fig. 1 that the flow stress in the isothermal compression of 300M steel is sensitive to deformation temperature, strain rate and strain. The flow stress increases quickly with the increasing of strain. The stress–strain curves show a peak flow stress at low strain rate and high deformation temperature, and near steady state flow at large strain. The stress–strain curves do not show a peak flow stress obviously at relatively high strain rate and/or low deformation temperature. In addition, it is also observed that the flow stress decreases markedly with the increasing of deformation temperature at certain strain rate, and increases gradually with the increasing of strain rate at certain deformation temperature.

Table 1
The chemical composition of as-received 300M steel (wt.%).

C	Si	Ni	Mn	Cr	Mo	V	Cu	S	P
0.39	1.61	1.82	0.69	0.91	0.42	0.07	0.06	0.0012	0.0089

3. Establishment of models

3.1. Fuzzy neural network model

Fuzzy neural network is an intelligent information–treatment system with adaptive learning capable of treating the complex and non-linear relationships. The structure schematic of fuzzy neural networks for predicting flow stress in the isothermal compression of 300M steel is shown in Fig. 2. There are six layers in the structure schematic of fuzzy neural networks. Layer 1 is called input variable layer. Each node in this layer only transport input values to the next layer. The number of fuzzy sets of each input variable and membership functions are designated in layer 2. Each node in layer 3 represents one fuzzy rule and the degrees of rules are calculated in this layer. Each node in layer 4 represents multiplication operation. Each node in layer 5 represents sum operation. Layer 6 is the output layer of fuzzy neural networks. $x_1, \cdots, x_n$ represent the inputs and Y is the output of network, US, UM and UL represent the membership functions, $p_0^i, \cdots, p_n^i$ are the weight coefficients of middle layer of neural network, S and P represent the sum and multiplication operations respectively, w^i is the weight value which denotes the degree of the rule, and y^i is the outputs of middle layer [8].

In order to establish the fuzzy neural network model for the flow stress in the isothermal compression of 300M steel, deformation temperature (T, K), strain rate ($\ln \dot{\varepsilon}$, s^{-1}) and strain (ε) are taken as the inputs of network, and the flow stress (σ, MPa) is taken as the output of network.

The activation function in output layer of FNN model is a linear function, while the activation function in hidden layer is selected to be a sigmoid function in the following form:

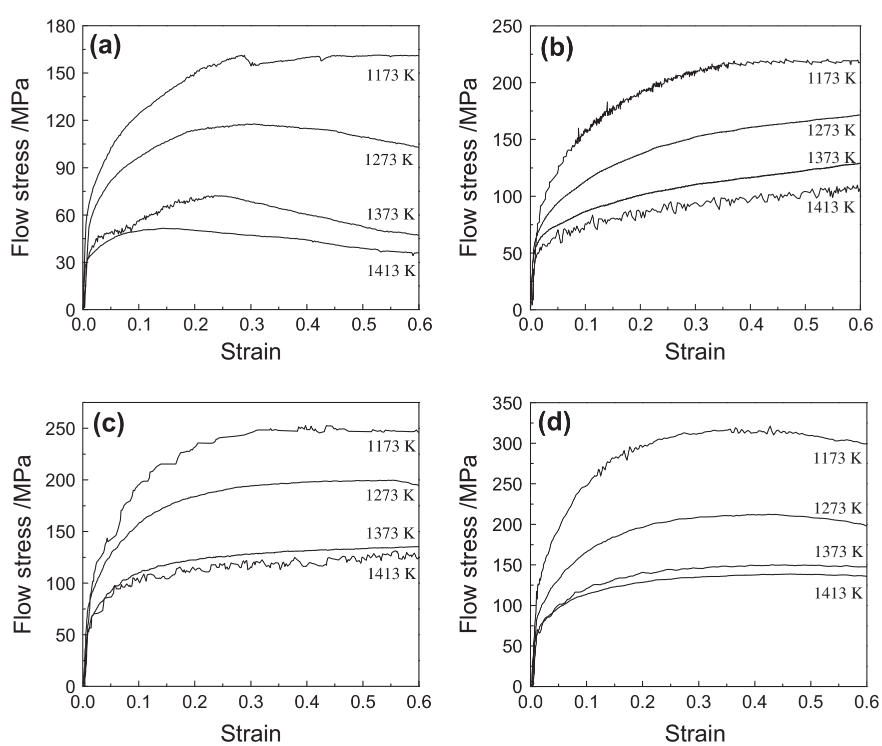

Fig. 1. The selected stress–strain curves in the isothermal compression of 300M steel at strain rates of: 0.1 s^{-1} (a), 1.0 s^{-1} (b), 10.0 s^{-1} (c) and 25.0 s^{-1} (d).