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A simple constitutive model for predicting flow stress of medium carbon microalloyed steel during hot deformation

Zohreh Akbari [a], Hamed Mirzadeh [a,*], Jose-Maria Cabrera [b,c]

[a] School of Metallurgy and Materials Engineering, College of Engineering, University of Tehran, P.O. Box 11155-4563, Tehran, Iran
[b] Departamento de Ciencia de los Materiales e Ingeniería Metalúrgica, ETSEIB, Universitat Politècnica de Catalunya, Av. Diagonal 647, 08028 Barcelona, Spain
[c] Fundació CTM Centre Tecnologic, Pl. de la Ciencia, 08243 Manresa, Spain

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ABSTRACT

The constitutive behavior of a medium carbon microalloyed steel during hot working over a wide range of temperatures and strain rates was studied using the Johnson–Cook (JC) model, the Hollomon equation, and their modifications. The original JC model was not able to predict the softening part of the flow curves and the subsequent modifications of the JC model to account for the softening stage and the strain dependency of constants were not satisfactory owing to the uncoupled nature of the JC approach regarding strain rate and temperature. The coupled effect of these variables was considered in the form of Zener–Hollomon parameter (Z) and the constants of the Hollomon equation were related to Z. This modification was found to be useful for the hardening stage but the overall consistency between the experimental flow curves and the calculated ones was not good. Therefore, a simple constitutive model was proposed in the current work, in which by utilization of the peak stress and strain into the Hollomon equation, good prediction abilities were attained. Conclusively, the proposed model can be considered as an efficient one for modeling and prediction of hot deformation flow curves.

1. Introduction

Microalloyed or High Strength Low Alloy (HSLA) steels constitute an important category of steels estimated to be around 12% of total world steel production, which have been increasingly used in a variety of automotive components such as connecting rods, wheel hubs, suspension systems, crankshafts and driveline components [1–3].

Hot deformation is an important step in the production of microalloyed steels, which facilitates shaping, precipitation control, and grain refinement to achieve desired mechanical properties. Hot deformation in austenite recrystallization region refines coarse grains by repeated static recrystallization in the interpass times and also by dynamic recrystallization during deformation. Moreover, deformation in the non-recrystallization region increases ferrite nucleation sites through pancaking of austenite grains and creation of deformation bands. In this way, a fine microstructure will be produced after transformation [4,5].

In order to improve the properties, the parameters of the forming process must be controlled carefully. The understanding of the microstructural behavior of the steel under consideration is therefore required, together with the constitutive equations describing material flow [6–9].

Industrial hot deformation processing such as rolling for these steels is conducted in the temperature range of stability of austenite phase. Due to low stacking fault energy of austenite, the major restoration process during hot deformation is dynamic recrystallization (DRX) [10–14]. DRX is an important phenomenon for controlling microstructure and mechanical properties in hot working. The modeling of hot flow stress and the prediction of flow curves are important in metal-forming processes from the mechanical and metallurgical standpoints because this is an essential part of the numerical simulations in finite element codes. As a result, considerable researches have been focused on this subject in recent years [6,15–17].

The aim of this work is to introduce a simple but effective constitutive equation for modeling the flow curves during hot working of a medium carbon microalloyed steel.

2. Experimental materials and procedures

The chemical composition of the investigated steel is listed in Table 1. Cylindrical specimens with 11.4 mm in height and 7.6 mm in diameter were prepared from the microalloyed steel for the hot compression test, which carried out at deformation

* Corresponding author.
E-mail address: hmirzadeh@ut.ac.ir (H. Mirzadeh).

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Table 1
The chemical composition of the investigated steel.

Element	C	Mn	Si	P	S	V	Al	Ti	N
Wt.%	0.34	1.52	0.72	0.025	0.025	0.083	0.0145	0.018	0.0114

temperatures in the range of 900–1150 °C (1173–1423 K) and strain rates from 0.0001 to 3 s^{-1}. Previous to every compression tests, the samples were soaked at 1150 °C to put the microalloying elements into solution. The elastic region of flow curves was subtracted for subsequent flow stress analyses and modeling. More information about the hot deformation experiments on this material has been reported elsewhere [3,18] and are here revisited.

3. Results and discussion

3.1. Flow curves

The obtained flow curves are shown in Fig. 1. These curves illustrate the conventional DRX behavior, showing a broad peak with subsequent flow softening. During initial stages of deformation,

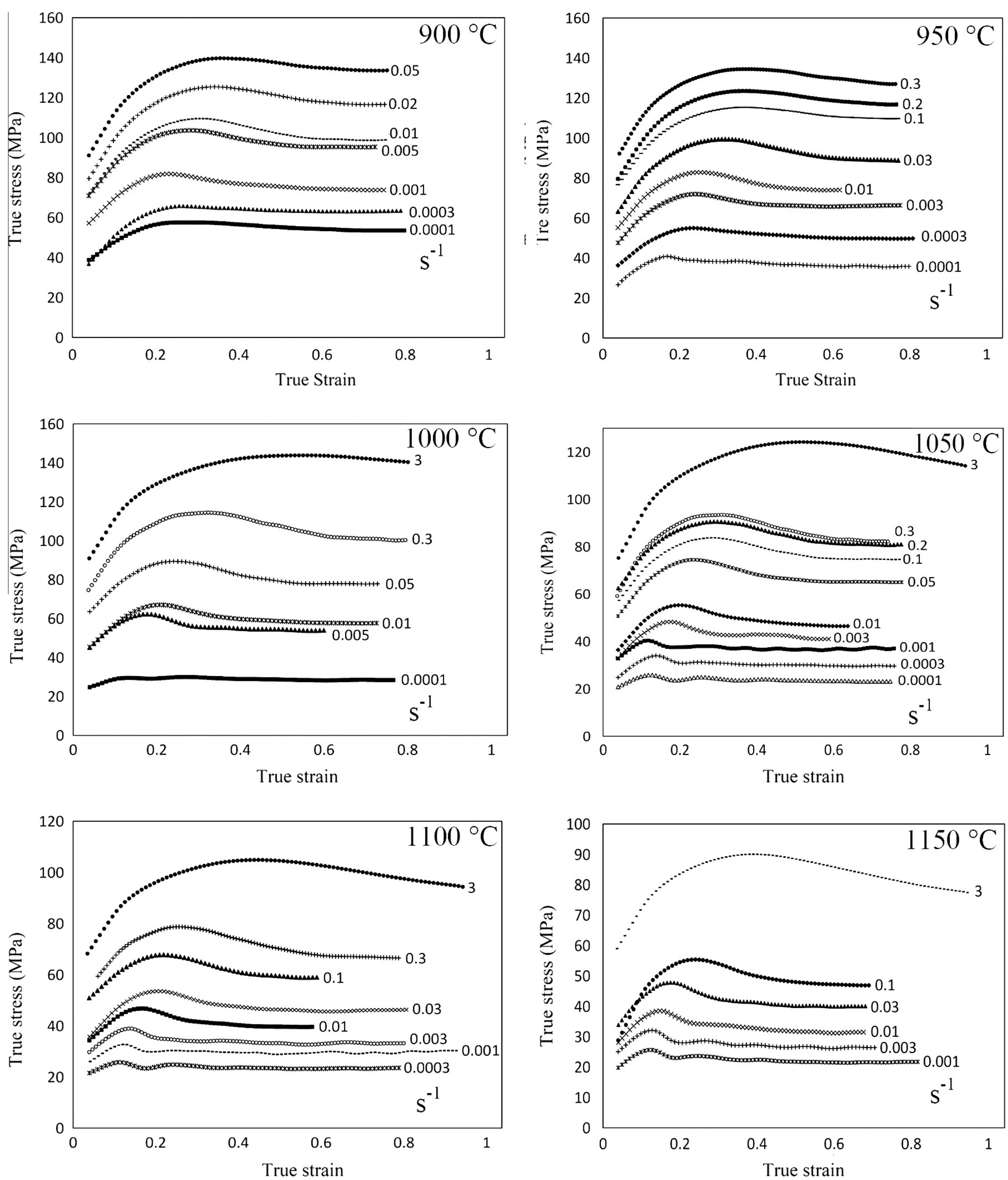

Fig. 1. The obtained flow curves.