Study on hot deformation behavior of 70Cr3Mo back-up roll steel using processing map

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Abstract. The hot deformation behavior of 70Cr3Mo back-up roll steel was studied in the temperature range of 1173-1473K with the strain rates of 0.01-10s^{-1}, respectively. Based on the dynamic material model (DMM), processing maps of 70Cr3Mo steel at the strain of 0.1-0.7 were developed and investigated. The effects of deformation parameters on the hot working ability were analyzed. The optimal deformation conditions for hot working of 70Cr3Mo steel were obtained in the temperature range of 1150-1280K and strain rate range of 0.01-0.03s^{-1} with a peak efficiency power dissipation of about 42%.

Introduction

High-tech wide strip mill has introduced high speed, continuous and automatic rolling techniques to improve product quality and increase productivity in recent years. Back-up rolls are the main trait of hot and cold rolling mills which decrease unintended bending and support the work roll, enabling them to endure higher loads without failing [1-2]. Therefore the back-up roll should have good hardenability, high and uniform strength, sufficient thickness and high wear resistance of the function layer. Due to its good balance of strength, toughness and wear resistance, 70Cr3Mo steel is widely used to produce the forged cold back-up roll. Because of the complicated microstructure evolution during the multi-stage hot forging process of back-up roll, establishment of the hot working regime is difficult. Thus, further analysis should be carried out to optimize the hot working process. In recent years, processing maps have been widely used to characterize the workability, optimize the hot working process and control the microstructures of magnesium alloys [3], aluminum alloys [4], steel [5], titanium alloys [6], etc.

The objective of this paper is to characterize the hot compressive deformation behavior of 70Cr3Mo steel under wide range of the deformation temperature and strain rate. The main focus has been on the effects of strain on the efficiency of power dissipation and instability parameter. Based on the Dynamic Material Model (DMM), the processing maps of the studied steel were developed to optimize the hot working parameters. The optimum hot working parameters for 70Cr3Mo back-up roll steel were recommended.

Material and experimental procedure

In this investigation, the commercial 70Cr3Mo back-up roll steel was used, and its chemical composition (wt. %) is as follows: 0.69C-3.1Cr-0.50Si-0.60Mn-0.31Mo-0.07Ni-0.04Cu-0.013P-0.004S-(bal.)Fe. The hot compression tests were carried out on a Gleeble thermo-mechanical simulator. The specimens were heated to 1473 K at a heating rate of 10 Ks^{-1} and held for 3 min and then cooled to the test temperature at the cooling rate of 10 Ks^{-1}. Then, the specimens were held at the forming temperature for 30 seconds to get a uniform temperature distribution. The deformation temperature ranged from 1173 to 1473 k, while the strain rate from 0.01 to 10 s^{-1}.

Results and discussion

The processing map was developed by Prasad et al. on the basis of the dynamic material model (DMM) which considers the workpiece as a dissipater of power. The total dissipated power can be expressed as:

$$P = \sigma\dot{\varepsilon} = J + G = \int_0^{\sigma} \dot{\varepsilon}\, d\sigma + \int_0^{\dot{\varepsilon}} \sigma\, d\dot{\varepsilon} \tag{1}$$

Where P is the instantaneous power dissipated. G is the dissipater content, which represents the power dissipated by plastic work without changing the internal structure; and J is the dissipater co-content, which is related to the power dissipated by metallurgical processes, such as recovery, recrystallization, phase transformation and damage of the material. If the stress versus strain rate obeys a power law, for the given strain and deformation temperature, the flow stress can be expressed as [7]:

$$\sigma = K\dot{\varepsilon}^{m} \tag{2}$$

Where K is the material constant, m is the strain rate sensitivity and is defined as a power partitioning factor as follows:

$$m = \frac{dJ}{dG} = \frac{\dot{\varepsilon}\, d\sigma}{\sigma\, d\dot{\varepsilon}} = \frac{d\sigma}{\sigma}\left(\frac{d\dot{\varepsilon}}{\dot{\varepsilon}}\right)^{-1} = \frac{d\lg\sigma}{d\lg\dot{\varepsilon}} \tag{3}$$

Assuming at a given strain and deformation temperature, the relationship between true stress and strain rate can be expressed through a cubic spline fit [8]:

$$\lg\sigma = a + b\lg\dot{\varepsilon} + b_1(\lg\dot{\varepsilon})^2 + b_2(\lg\dot{\varepsilon})^3 \tag{4}$$

Thus, the strain rate sensitivity (m) can be expressed as:

$$m = b + 2b_1\lg\dot{\varepsilon} + 3b_2(\lg\dot{\varepsilon})^2 \tag{5}$$

When m equals to 1.0 in Eq. (2), ideal power dissipation ($J_{\max}$) will occur and η is then calculated by Eq. (6):

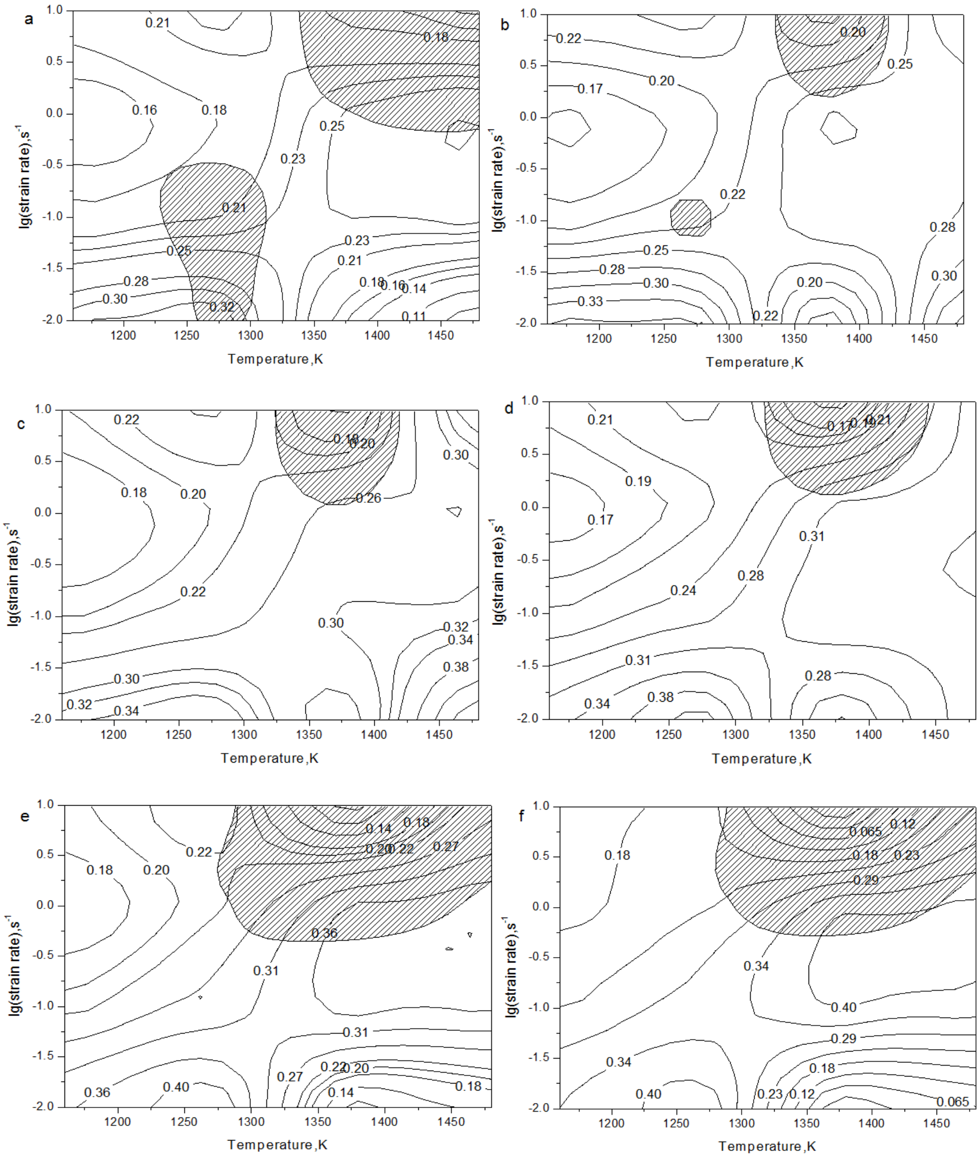
$$\eta = \frac{J}{J_{\max}} = \frac{J}{(\sigma\dot{\varepsilon}/2)} = \frac{2m}{1+m} \tag{6}$$

The instability parameter ($\xi(\dot{\varepsilon})$) can be expressed as [9]:

$$x(\dot{\varepsilon}) = \frac{\partial \lg\left(m/(1+m)\right)}{\partial \lg \dot{\varepsilon}} + m < 0 \tag{7}$$

A negative value of $x(\dot{\varepsilon})$ indicates an unstable condition for plastic deformation.

The processing maps of 70Cr3Mo steel generated in the temperature range of 1173-1473K and strain rate range of 0.01-10s^{-1} at strains of 0.1, 0.2, 0.3, 0.4, 0.5, 0.6 and 0.7 developed using the flow stress data are shown in Fig. 1, in which the contours represent constant efficiencies of power dissipation (η) marked as percent and the shaded areas denote the unsafe domains which are not suitable for bulk metal processing and should be avoided.



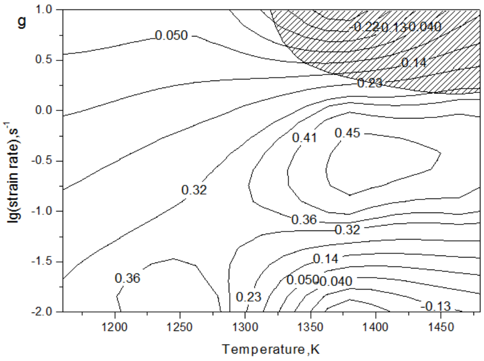


Fig. 1. Processing maps for 70Cr3Mo steel at strains of (a) 0.1, (b) 0.2, (c) 0.3, (d) 0.4, (e) 0.5, (f) 0.6 and (g) 0.7.

As can be seen from Fig. 1, it can be easily found that the features of power dissipation efficiency are fundamentally similar in the whole strain range indicating the effect of strain on the power dissipation efficiency is not significant and the same has been explained in other publications [10]. It also can be seen from Fig. 1(a) and (b), at low strains ($e \leq 0.2$), there are two instability regions. At the intermediate strain ($0.3 \leq e \leq 0.4$) as shown in Fig. 1(c) and (d), the instability region occurs in the temperature range of 1325-1425K and strain rate range of 1-10s^{-1}. At high strain ($0.5 \leq e \leq 0.6$) as shown in Fig. 1 (e) and (f), the instability region, occurring when the temperature is higher than 1275 K and strain rate is higher than 0.4s^{-1}, is relatively larger. At a true strain of 0.7, the power dissipation map exhibits two relatively high value domains as shown in Fig. 1(g). One domain occurs in the temperature range of 1210-1280 K and strain rate range of 0.01-0.03 s^{-1} with a peak power dissipation efficiency of 0.42 at strain rate of 0.01s^{-1} and temperature of 1273 K. The other domain occurs in the temperature range of 1300-1473 K and strain rate range of 0.05-1 s^{-1} with a peak power dissipation efficiency of 0.44 at strain rate of 0.1s^{-1} and temperature of 1373 K.

Conclusions

Based on the constructed processing maps, the hot deformation behaviors of 70Cr3Mo steel were studied. The optimal deformation conditions for hot working of 70Cr3Mo steel are in the temperature range of 1150-1280K and strain rate range of 0.01-0.03s^{-1} with a peak efficiency power dissipation of about 42%.

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