Flow stresses and activation energy of BRCMO tool steel

Krivulje tečenja in aktivacijska energija za orodno jeklo BRCMO

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Received: March 16, 2010 **Accepted:** May 20, 2010

Abstract: Flow stresses and activation energy of BRCMO high-speed steel has been investigated. Hot compression tests in the temperature range of 900–1050 °C at strain rates of 0.001–10 s^{-1} and true strain of 0–0.9 were applied on Gleeble 1500D thermo-mechanical simulator. For entire hot working range the constants of the hyperbolic sine function and activation energy were calculated. The value of activation energy is 607 kJ mol^{-1}. The microstructures of the samples after deformation were analysed by means of light microscopy.

Izvleček: Preiskovali smo krivulje tečenja in izračunavali aktivacijsko energijo hitroreznega jekla BRCMO. Na termo-mehanskem simulatorju Gleeble 1500D smo izvedli tlačne preizkuse do stopnje deformacije 0,9 v temperaturnem območju 900–1050 °C in v območju hitrosti deformacije 0,001–10 s^{-1}. Za celotno temperaturno območje smo izračunali konstante hiperbolične funkcije in aktivacijsko energijo, ki je 606 kJ mol^{-1}. Mikrostrukture preoblikovanih vzorcev smo analizirali s svetlobno mikroskopijo.

Key words: high-speed tool steel, flow curves, activation energy
Ključne besede: hitrorezna jekla, krivulje tečenja, aktivacijska energija

Original scientific paper

Introduction

For modern industrial mass production, machining is one of the most important shaping and forming processes. Almost all tools employed for this purpose are made from high speed steels, or HSS. The term `high speed steel' was derived from the fact that high-speed steel is capable of cutting metal at a much higher rate than carbon tool steel. It retains its hardness even when the point of the tool is heated to a low red temperature. HSS is a type of steel that is used in high speed applications, such as manufacturing of taps, dies, twist drills, reamers, saw blades and other cutting tools. HSS steel contains many alloying elements. Alloying elements are added to HSS to improve hardenability, control grain growth, improve strength, hardness and wear resistance. [1, 2, 3, 4] Main alloying elements are chromium, tungsten, molybdenum, vanadium and cobalt. When steels contain a combination of more than 7 % of molybdenum, tungsten and vanadium, and more than 0.60 % carbon, they are referred to as high speed steels or HSS. Carbon forms carbides, which increases wear resistance and it is responsible for the basic matrix hardness. Chromium promotes deep hardening and produces readily soluble carbides. Molybdenum in tool steels increases their hardness and wear resistance. Molybdenum also acts in conjunction with elements like chromium to produce substantial volumes of extremely hard and abrasion resistant carbides. Cobalt improves red hardness and peovides retention of hardness for the matrix. Depending on the steel composition several types of carbides are precipitated in HSS: mainly MC, M_2C and M_6C. A distinguishing feature of HSS is the uniform distribution and small size of the primary carbides. The primary carbides and their distribution have a major influence on the wear resistance and toughness of the material.

In the present paper the flow curves and activation energy for deformation of the BRMCO HSS were examined with respect to the dependence on temperature and strain rate.

Material and methods

A BRCMO type high-speed tool steel with the following chemical composition: C 0.91 %, Cr 4.15 %, Mo 4.7 %, W 6.3 %, V 2.1 %, Co 4.75 %, and Fe balance was used as samples for hot compression tests on Gleeble 1500D thermal-mechanical simulator. The initial cylindrical specimen was 10 mm in diameter and 15 mm in height and was machined from the rolled bar. The heat treatment condition for hot compression test is shown in Figure 1. Specimens were heated (cf. Figure 1) with rate of 3 °C s^{-1} (1) then held on soaking temperature 1160 °C for 10 min (2). After that they were cooled with rate of 2 °C s^{-1} on deformation temperature (3), held for 10 min at deformation temperature (4) and then deformed with prescribed strain rate (5) followed by water quenching (6) to retain the recrystallized microstructures. For reduction of friction between specimens and the tool anvil Ni-based lubricant, carbon and tantalum foils were used. The hot temperature compression tests were performed at six different temperatures: 900 °C, 950 °C, 1000 °C, 1050 C, 1100 °C and 1150 °C and five different strain rates: 0.001 s^{-1}, 0.01 s^{-1}, 0.1 s^{-1}, 1 s^{-1} and 10 s^{-1}. The maximum strain for all tests was 0.9. The temperature of the test specimen was measured by means of the thermocouple at the centre of the specimen.

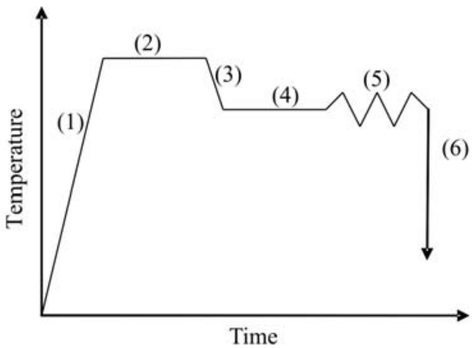


Figure 1. Heat treatment condition of compression test

The specimens were sectioned along the longitudinal compression axis and prepared for the light-optical microscopy. The microstructures in the centre of the section plane were examined using Zeiss Axio Imager A1m.

Results and discussion

The flow curves of BRCMO high-speed steel were evaluated in the temperature range of 900–1150 °C and in the strain rate range of 0.001–10 s^{-1}. The effect of temperature on the flow curves is shown in Figure 2. It shows that strain corresponding to the peak flow stress increases as the temperature decreases. The value of the peak strain is 0.11 for the 900 °C temperature. It decreases in the temperature range of 950–1150 °C and remains at constant value of 0.05. The increase of strain rate leads to the peak flow stress increase. The value of the peak strain at the 1100 °C is 0.45 for the strain rate 0.001, 0.21 for strain rates 1 and 0.1 and 0.05 for strain rates 0.01 and 0.001. The steady state flows are not fully reached at temperatures lower than 1000 °C.

The effect of the strain rate on the flow curves is shown in Figure 3. It can be seen that the peak flow stresses increase with the increasing strain rate. These curves are typical of a dynamic recrystallization (DRX) process. At the stress peak the strain hardening is balanced with softening and afterwards with the increase of strain the softening mechanism prevails over the work hardening. At higher temperatures (>1000 °C) a strain independent steady state stress is attained except for the higher strain rate (Figure 3).

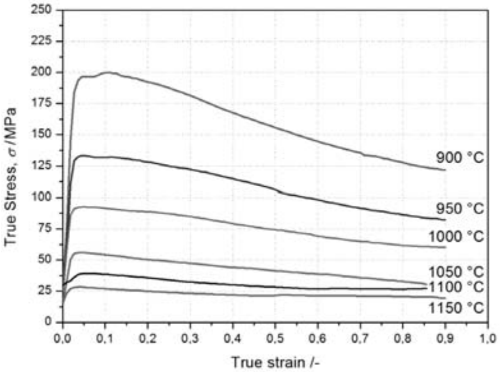


Figure 2. True stress / true strain curves of BRCMO at 0.001 s^{-1} strain rate

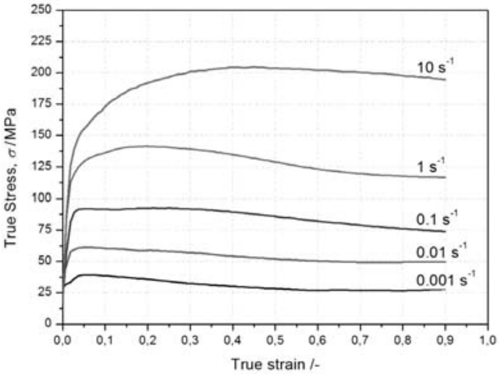


Figure 3. True stress / true strain curves of BRCMO at the temperature of 1100 °C

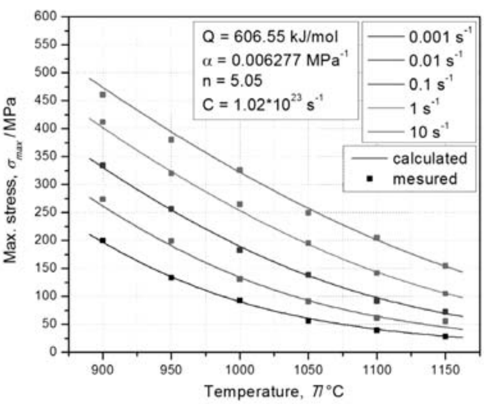


Figure 4. Dependence of the peak flow stress on temperature

With the Arrhenius equation the relationship between the strain rate, flow stress and temperature was described. Activation energy Q was determined with the following equation:

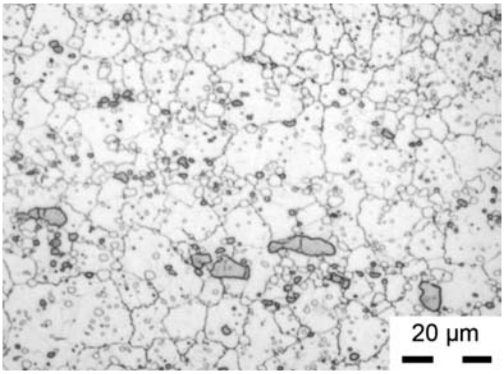
$$\dot{\varepsilon} = A[\sinh(\alpha\sigma)]^n \exp\left(-\frac{Q}{RT}\right)$$

where A, α are material constants, n is stress exponent $\dot{\varepsilon}$ is strain rate, σ is flow stress, T is the absolute temperature and R is the universal gas constant. The comparison between measured and calculated dependence of peak stresses on temperature for different strain rates is shown in Figure 4. A very good fit of data was obtained by taking α = 0.006 MPa^{-1} and n = 5. The value of the activation energy was 607 kJ mol^{-1}. This value for the activation energy was compared with other investigations as summarized in the Table 1.

The microstructures of BRCMO HSS before and after the hot compression test are shown in Figure 5. Fine precipitated carbide particles can be seen in the initial billet microstructure (Figure 5a). Carbides are mostly distributed within the grains. In micrograph (Figure 5b) of the hot deformed specimen at temperature 1000 °C and strain rate of 0.001 s^{-1} the amount and the shape of carbides hasn't changed.

Table 1. Values of the activation energy for hot working of tool steel

Steel	Q/kJ mol^{-1}	Temperature T/°C	Ref.
M32	607	900–1105	Current work
M2	610	900–1100	[5]
T1	654	<1000	[1]
	467	>1000	



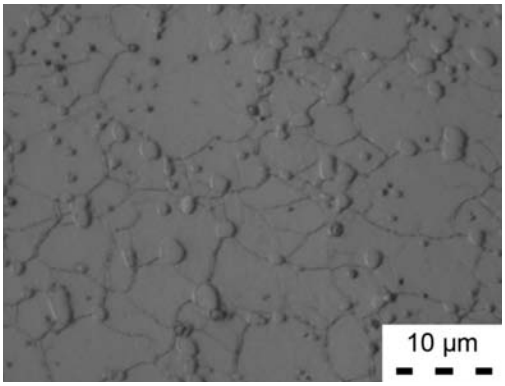


Figure 5. Light-optical micrographs of BRCMO at: (a) initial state, (b) 1000 °C, $\dot{\varepsilon} = 0.001$ s^{-1}

Conclusions

For hot compression test of BRCMO high-speed steel Gleeble 1500D thermo-mechanical simulator was applied. The true stress – true strain curves and activation energy has been determined in the temperature range of 900–1050 °C at strain rates of 0.001–10 s^{-1} and true strain of 0–0.9.

The presence of stress peaks in flow curves is an indication of the initiation of DRX. A strain independent steady state stress is attained at the temperatures above 1000 °C (Figure 2). The comparison between measured and calculated dependence of peak stresses on temperature for different strain rates shows good agreement.

The activation energy Q for deformation was evaluated by fitting the hyperbolic sine function to the stress corresponding to the peak. A value of 607 J mol^{-1} was obtained for this steel which is close to the value reported for other tool steels, Table 1.

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