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Hot deformation behavior and processing maps of AISI 420 martensitic stainless steel

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ABSTRACT

The hot deformation behavior of AISI 420 martensitic stainless steel is investigated though isothermal compression tests using a Gleeble-1500D thermal-mechanical simulator in a temperature range of 1123–1423 K and strain rate of 0.01–10 s^{-1}. The hot deformation apparent activation energy is calculated about 363 kJ/mol. Processing maps are conducted on the basis of the experimental data and the dynamic materials model (DMM) to reveal the hot workability. When the strain is no less than 0.5, the optimum hot working condition corresponds to the deformation temperature range of 1280–1360 K and strain rate range of 0.01–0.05 s^{-1} with a peak power dissipation efficiency of about 0.43 at strain rate of 0.01s^{-1} and temperature of 1323 K. Two instability regions are detected from the processing maps and should be avoided during hot working.

1. Introduction

Stainless steel has many desirable characteristics, which can be exploited in a wide range of construction applications. It is corrosion-resistant and long-lasting. The annual consumption of stainless steel has increased at a compound growth rate of 5% over the last 20 years, surpassing the growth rate of other materials. The rate of growth of stainless steel used in construction has been even faster, not least due to rapid development in China [1]. Martensitic stainless steels are usually used for manufacturing components with excellent mechanical properties and moderate corrosion resistance such as turbine blades, steam generators, pressure vessels and medical treatments. They can work under high temperature and erosion medium [2]. In the past, researches about AISI 420 martensitic stainless steel mainly focus on the corrosion resistance [4–7]. Little work has been done on the hot deformation behavior of this material. In order to improve the properties of stainless steel, the hot working parameters should be designed carefully. The understanding of hot deformation behavior of steel is therefore required.

The processing map (PM) technology based on the dynamic materials model (DDM) has been accepted as a powerful approach to evaluate the deformation mechanisms and optimize the process parameters of materials because of its characteristics of convenience and accuracy. It has been used in a wide range of materials including aluminum alloy [8], titanium [9–12], magnesium [13,14], aluminum [15–17], Ni-based alloy [18–23] and steels [24,25]. Recently, many researchers have attempted to reveal the hot deformation behavior of stainless steel using the processing map approach based on the hot compression test data. Murty et al. [26] found that the instability condition based on the Ziegler's continuum principles applied to large plastic flow for AISI 304 stainless steel was more appropriate for delineating the regions of unstable metal flow. Tan et al. [27] suggested that large-strain deformation should be carried out at the strain rate above 0.5 s^{-1} at 1100 $^{\circ}$ in the hot working of Super304H austenitic heat-resistant stainless steel. Momeni et al. [28] developed the processing map for AISI 410 martensitic stainless steel and suggested that the safe region for hot deformation was temperature range of 1000-1125° and strain rate of 0.001–10 s^{-1}. Li et al. [29] suggested that the small strain and multi-stage deformation should be carried out for large deformation of 1Cr11Ni2W2MoV martensitic heat-resistant stainless steel at the deformation temperatures ranging from 1310 K to 1383 K and the strain rates ranging from 0.001 s^{-1} to 10 s^{-1}. Zou et al. [30] investigated the hot workability of 00Cr13Ni5M02 supermartensitic stainless steel and suggested that large strain deformation should be carried out in the temperature range 1140–1200 $^{\circ}$ and strain rate range 0.1–50 s^{-1}. Chen et al. [31] developed the processing map for a wrought 2205 duplex stainless steel and found the optimum hot working domain is in the range of temperatures from 1373 K to 1473 K at strain rate of 0.01 s^{-1}. Han et al. [32] developed the processing map for 20Cr-25Ni superaustenitic stainless steel

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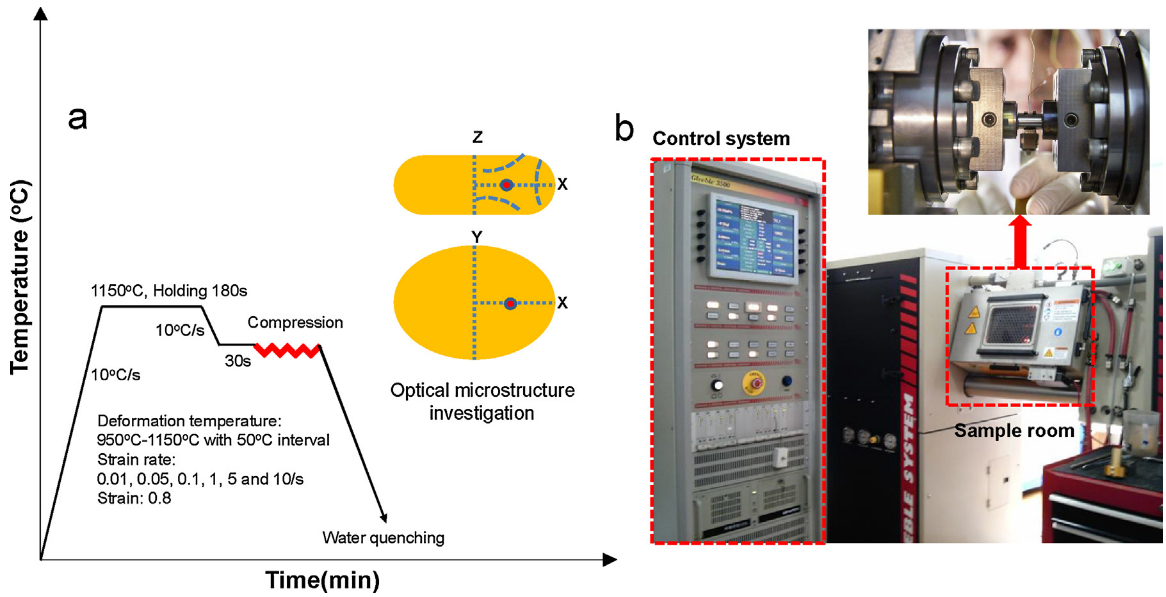

Fig. 1. (a) Schematic representation of hot compression test and (b) Illustration of Gleeble 3500.

based on the dynamic materials model and the Murty's instability criterion and suggested that the optimum processing parameters should be chosen in the respective ranges of temperature and strain rate of 1025–1120° and 0.01–0.03 s^{-1}, or 1140–1200° and 0.08–1 s^{-1}.

In this paper, the hot deformation behavior of AISI 420 martensitic stainless steel was investigated by using the processing map approach based on the experimental results in combination with the microstructure analysis. The optimum hot working parameters for the present steel were proposed finally.

2. Experiment material and procedures

The chemical composition (wt.%) of AISI 420 martensitic stainless steel used in this investigation is as follows: 0.19C, 0.131Cr, 0.18Si, 0.16Mn, 0.02P, 0.004S and balance Fe. Cylindrical specimens for hot compression test with a diameter of 10 mm and a height of 15 mm were machined from the as-received hot forged bar. The specimens were heated to 1423 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 s to get a uniform temperature distribution. The isothermal compression tests were carried out on a Gleeble-3500D thermo-mechanical simulator in the temperature range of 1223–1423 K and strain rate range of 0.01–10 s^{-1}. The slices of graphite were used between the specimen and anvil to reduce the friction. All specimens were compressed to a true stain of 0.8 and then instantly quenched into cold water in order to preserve the hot deformation microstructure. Fig. 1 shows the experimental procedure. The quenched specimens were sliced along the axial section. The sections were polished and etched with 10% sulphuric acid aqueous solution and optical micrographs were recorded.

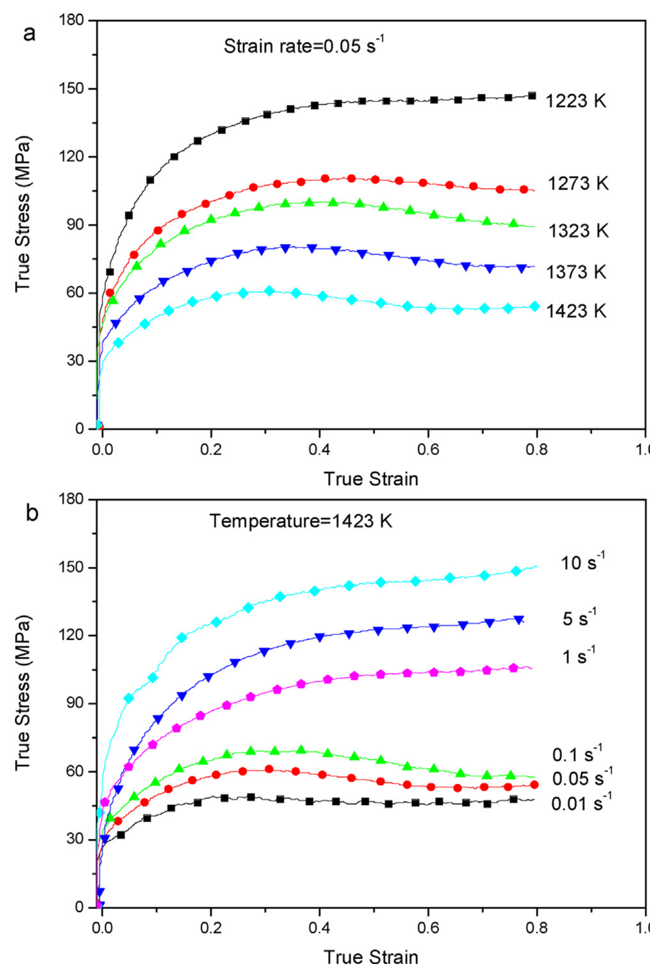

Fig. 2. Typical true stress-strain curves of AISI 420 martensitic stainless steel at deformation conditions: (a) 0.05 s^{-1} and (b) 1423 K.

3. Results and discussion

3.1. Hot deformation flow curves

Fig. 2 shows the representative true stress-strain curves of AISI 420 martensitic stainless steel under different deformation conditions. As seen from Fig. 2(a), at a strain rate of 0.01 s^{-1} under different deformation temperatures, the flow stress will decrease with the increase of deformation temperature. That is because that the increase of deformation temperature increases the rate of the vacancy diffusion, cross-slip of screw dislocations and climb of edge dislocations. At a given temperature of 1423 K under different strain