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Static recrystallization behavior of 25CrMo4 mirror plate steel during two-pass hot deformation

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ABSTRACT

The static recrystallization behavior of 25CrMo4 mirror plate steel has been determined by hot compression testing on a Gleeble 1500 thermal mechanical simulation tester. Compression tests were performed using double hit schedules at temperatures of 950－1150 ℃, strain rates of 0.01－0.5 s^{-1}, and recrystallization time of 1－100 s. Results show that the kinetics of static recrystallization and the microstructural evolution were greatly influenced by the deformation parameters (deformation temperature, strain rate and pre-strain) and the initial austenite grain size. Based on the experimental results, the kinetics model of static recrystallization has been generated and the comparison between the experimental results and the predicted results has been carried out. It is shown that the predicted results were in good agreement with the experimental results.

1. Introduction

Industrial hot forming process consists of several successive deformations and inter-pass time between deformations. During the inter-pass time, the static recrystallization (SRX), which occurs when the strain in the last deformation pass is less than the critical strain of the dynamic recrystallization, is one of the most important metallurgical events governing the flow strength and the resulting microstructure[1-3]. It is essential to systematically investigate the behavior of the SRX for the process flow formulation and the control of the final grain size. As pointed out previously, the behavior of SRX is affected by the temperature, strain rate, pre-strain and the initial austenite grain size and the SRX behavior of a number of metals and alloys has been investigated[4-10]. Lin and Chen[4] studied the effects of forming temperature, strain rate, deformation degree, and initial austenite grain size on the microstructural evolution during static recrystallization in hot deformed 42CrMo steel and the kinetics model was determined based on the experimental results. Zahiri et al.[6] investigated the behavior of SRX in two interstitial free steels and pointed out that the strain rate had a strong effect on the time for strain independent softening. Furthermore, the results also revealed that SRX was delayed owing to the phosphorous and boron alloying elements.

The 25CrMo4 (Germany grade) steel discussed in this research is used in the production of mirror plate of large hydrogenerator for its good hardenability, weldability and cold plasticity. In the past years, many investigations have been implemented on the behavior of 25CrMo4. Khanafi-Benghalem et al.[11] studied the process of plastic deformation and the wear rate of 25CrMo4 in lubricated sliding against cemented tungsten carbide. Huo et al.[12] investigated the grain growth/refinement rule and damage features of 25CrMo4 in hot forming. Luo et al.[13] studied the high-temperature mechanical properties of 25CrMo4. No public research was found on the SRX behavior of 25CrMo4 steel during hot deformation.

In this research, the SRX behavior of 25CrMo4 steel during hot deformation has been investigated by double-hit compression tests on a Gleeble 1500 thermal mechanical simulation tester. The effects of temperature, strain rate, pre-strain and the initial austenite grain size on the kinetics of SRX and the microstructure were discussed. Additionally, the comparison between the experimental results and the predicted results was implemented.

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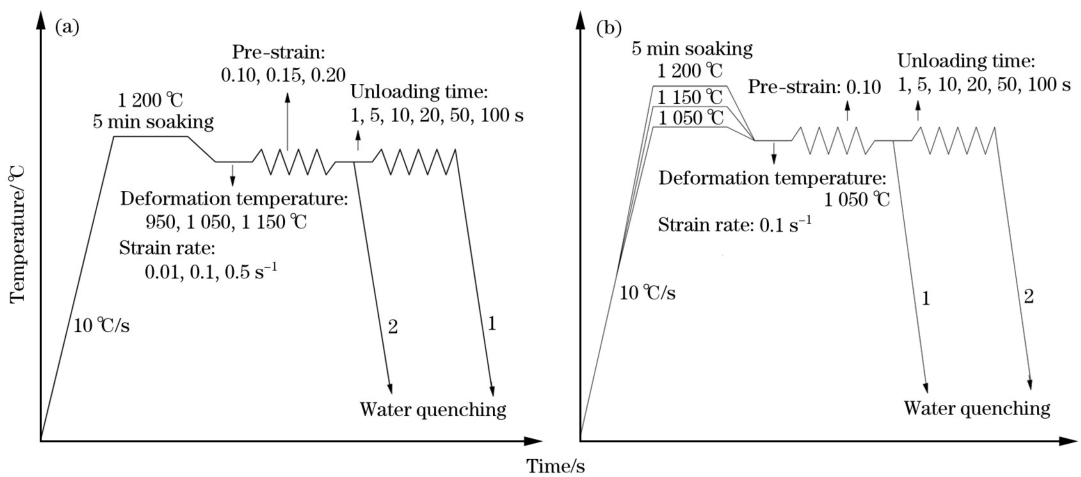
2. Experimental Material and Procedures

2.1. *Material and experimental schedules*

The 25CrMo4 steel used in this research was directly sampled from wrought billet of mirror plate with a composition of C 0.27, Si 0.3, Mn 0.7, Cr 1.0, Mo 0.2, P 0.02, S 0.02 and Fe for balance in wt.%. Compression specimens of 12 mm in length and 8 mm in diameter were machined. Double-hit compression tests were performed by using a Gleeble-1500 thermal mechanical simulation tester. In order to reduce frictional effects during compression and avoid the sticking problem in quenching, the Ta pieces with a thickness of 0.5 mm were positioned between the anvils and the specimens.

As shown in Fig. 1(a), the specimens were austenitized at 1200 ℃ for 5 min and then cooled to the test temperature at a strain rate of 10 ℃/s. After holding at the test temperature for 1 min, the first deformation was applied and interrupted at a strain below the critical strain for nucleation of dynamic recrystallization. After unloading, the specimen was held at the test temperature for 1 to 100 s to enable the occurrence of SRX. A second deformation was applied under the same deformation conditions as that in the first pass to measure the amount of softening, and then the specimen was quenched in water. Testing was conducted at temperatures of 950 to 1150 ℃, strain rates of 0.01 to 0.50 s^{-1} and pre-strains of 0.10, 0.15 and 0.20 (curve 1 in Fig. 1(a)). Additionally, the specimen was directly quenched in water after the SRX in the inter-pass time to investigate the microstructure (curve 2 in Fig. 1(a)).

In order to investigate the effect of the initial austenite grain size on the microstructural evolution during SRX, the specimens were heated to 1050, 1150 and 1200 ℃, respectively, and held for 5 min. Then, some specimens were directly quenched in water and the obtained initial grain sizes are 57.6, 141.3 and 266.1 μm, respectively. The other specimens were deformed at 1050 ℃ and 0.1 s^{-1} to a pre-strain of 0.1 followed by unloading time of 1, 5, 10, 20, 50 and 100 s to allow the occurrence of SRX. Then, some specimens were quenched in water to evaluate the microstructure (curve 1 in Fig. 1(b)) and others were further deformed to a strain of 0.2 (curve 2 in Fig. 1(b)) to investigate the softening fraction.



(a) Double-hit deformation under different deformation conditions; (b) Considering the effect of initial austenite grain size on the softening and microstructure.

Fig. 1. Schematic illustration of experimental procedures.

The deformed samples were sliced along the compression axis section. After mechanical polishing, the specimens were etched with a saturation picric for 7 min water bath heating at 70 ℃. Optical metallograph observation was carried out to reveal the microstructure of deformed specimens.

2.2. *Quantifying softening*

The interrupted method is based on the principle that the yield stress at high temperature is a sensitive measure of the structural change. The softening fraction resulting from the SRX is usually evaluated by the 0.2% offset yield stress method[3], the mean stress method[14] and strain recovery method[15]. In this study, the 0.2% offset yield strength was used to determine the softening fraction resulting from SRX. The softening fraction, X, is measured by:

$$X=\frac{\sigma_m-\sigma_2}{\sigma_m-\sigma_1} \quad (1)$$

where, σ_m is the flow stress at the interruption; and σ_1, σ_2 are the offset stresses (0.2%) due to the first hit and second hit, respectively.

3. Results and Discussion

3.1. *Flow curves*

Interrupted compression stress-strain curves var-