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Study of metadynamic recrystallization behaviors in a low alloy steel

Y.C. Lin*, Ming-Song Chen, Jue Zhong

Key Laboratory of Modern Complex Equipment Design and Extreme Manufacturing of the Ministry of Education, School of Mechanical and Electrical Engineering, Central South University, Changsha 410083, China

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ABSTRACT

The metadynamic recrystallization behaviors in deformed 42CrMo steel were investigated by isothermal interrupted hot compression tests on Gleeble-1500 thermo-mechanical simulator. Compression tests were performed using double hit schedules at temperatures of (850–1150) °C, strain rates of (0.01–1) s^{-1} and inter-stage delay time of (1–50) s. The kinetic equations have been proposed to predict the metadynamic recrystallization behaviors in hot compressed 42CrMo steel. Comparisons between the experimental and predicted results were carried out. Results show that the effects of deformation parameters, including strain rate and deformation temperature, on the softening behaviors in the two-pass hot deformed 42CrMo steel are significant. However, the deformation degree (beyond the peak strain) has little influence on the metadynamic recrystallization behaviors in 42CrMo steel. The predicted results well agree with the experimental ones, which indicate that the proposed kinetic equations can give a precise estimate of the softening behaviors and microstructural evolution for the hot deformed 42CrMo steel.

1. Introduction

The hot rolling and forging processes often consist of several successive deformation passes, including inter-pass periods between deformations. During the inter-pass periods, the metals and alloys will subjected to the dynamic recovery, static recrystallization (Fernández et al., 2000), and metadynamic recrystallization (Elwazri et al., 2004). Meanwhile, the materials are often subjected to complex time, strain, strain rate, and temperature histories in industrial forming processes. On the one hand, a given combination of thermo-mechanical parameters yields a particular metallurgical phenomenon (Lin et al., 2008a), including the microstructural evolution during the inter-pass periods; on the other hand, microstructural changes of the metal in turn affect the mechanical characteristics of the metal such as the flow stress, and hence influence the forming process (Cho et al., 2005). In order to achieve the desired mechanical properties of the product, understandings of microstructural changes and softening mechanisms taking place during the complex forming processes are vital for designers of metal forming processes (Rao et al., 1998). Elwazri et al. (2004) investigated the kinetics of metadynamic recrystallization in vanadium microalloyed high carbon steels. They found that there is a transition strain region between where both static and metadynamic recrystallization take place during the inter-pass time, and revealed that V and Si have a strong solute drag effect on the kinetics of metadynamic recrystallization. Kugler and Turk (2006) studied the influence of initial microstructure topology on the kinetics of static recrystallization using a cellular automata model. It was observed that more deformed microstructure accelerates the kinetics of recrystallization, increases the Avrami exponent

* *Corresponding author*. Tel.: +86 731 8877915.
E-mail address: yclin@mail.csu.edu.cn (Y.C. Lin).
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and influences the final mean grain size. Poliak and Jonas (2004) predicted the inter-pass softening from the strain hardening rate prior to unloading. Also, they eliminated the need to determine the retained strain to predict the softening kinetics in multi-hit deformation and simplified the extrapolation of laboratory data to the conditions of industrial processing. Toloui and Serajzadeh (2007) developed an integrated mathematical model to predict distributions of temperature, strain and strain rate during hot rolling as well as the subsequent microstructural changes after hot deformation. Through comparing the model predictions with the experimental results the performance of the model was proved for single stand hot rolling of AA5083 aluminum alloy. Zrnik et al. (2007) investigated the relationship of microstructure and mechanical properties of TRIP-aided steel processed by press forging. The complex relationship among the volume fraction of the retained austenite, the morphology and distribution of phases present in the microstructure, and mechanical properties of TRIP steel were revealed. Their findings suggested that the intercritical treatment conditions prior austenite transformation appeared to have decisive effect on steel refinement and forming of convenient multiphase structure, which should provide both, the high strength and sufficient ductility of bulky products.

42CrMo (American grade: AISI 4140) is one of the representative medium carbon and low alloy steel. Due to its good balance of strength, toughness and wear resistance, 42CrMo high-strength steel is widely used for many general purpose parts including automotive crankshaft, rams, spindles, etc. In the past, many investigations have been carried out on the behaviors of 42CrMo steel (Limodin and Verreman, 2006). Smoljan (2004) found that it is possible in effective way to improve a steel strength and toughness by the combined cyclic heat treatment consisted of temperature cycling followed by twice quenching. The increasing of both, yield strength and Charpy-V notch toughness are achieved due to structure refinement. Lin et al. (in press-a) developed an artificial neural network (ANN) model to predict the constitutive flow behaviors of 42CrMo steel during single-pass hot deformation. The flow stress constitutive equations, depicting the work hardening-dynamical recovery and dynamical recrystallization, were established (Lin et al., 2008b). A revised model describing the relationships of the flow stress, strain rate and temperature of 42CrMo steel at elevated temperatures is proposed by compensation of strain and strain rate (Lin et al., 2008c). Lin et al. (in press-b) carried out the numerical simulation for stress/strain distribution and microstructural evolution in 42CrMo steel during hot upsetting process. Despite large amount of efforts invested into the behaviors of 42CrMo steel, the kinetics of metadynamic recrystallization in the hot deformed 42CrMo steel still need further investigation.

In this study, the metadynamic recrystallization behaviors in 42CrMo steel were investigated by isothermal interrupted hot compression tests. The kinetics equations of metadynamic recrystallization in the hot deformed 42CrMo steel were developed to predict the softening behaviors induced by metadynamic recrystallization. Comparisons between the experimental and predicted results were carried out.

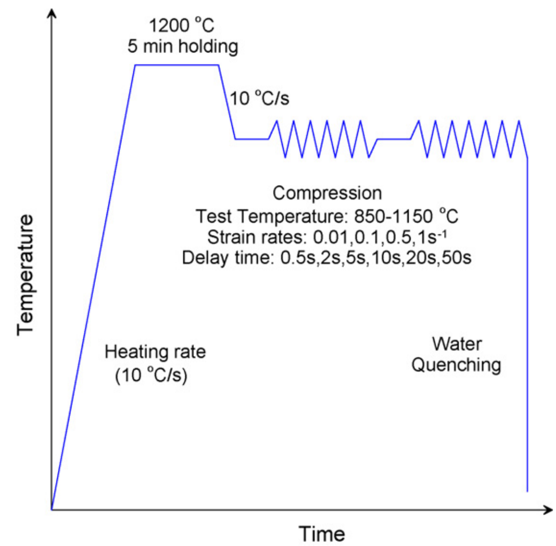

Fig. 1 – Experimental procedure for double hit hot compression tests.

2. Experiments

2.1. *Materials, specimens and experimental equipment*

A commercial 42CrMo high-strength steel of compositions (wt.%) 0.450C–0.280Si–0.960Cr–0.630Mn–0.190Mo–0.016P–0.012S–0.014Cu–(bal.)Fe was used in this investigation. Cylindrical specimens were machined with a diameter of 10 mm and a height of 12 mm. In order to minimize the frictions between the specimens and die during hot deformation, the flat ends of the specimen were recessed to a depth of 0.1 mm to entrap the lubricant of graphite mixed with machine oil. To study the progress of metadynamic recrystallization, two-pass hot compression tests were performed on a computer-controlled, servo-hydraulic Gleeble-1500 thermo-mechanical simulator. It can be programmed to simulate both thermal and mechanical industrial process variables for a wide range of hot-deformation conditions.

2.2. *Experimental procedure*

As shown in Fig. 1, the specimens were heated to 1200 °C at a heating rate of 10 °C/s and held for 5 min. Then, the specimens were cooled to the deformation temperature at 10 °C/s and held for 1 min to eliminate thermal gradients. Four different deformation temperatures (850 °C, 950 °C, 1050 °C and 1150 °C) and four different strain rates (0.01 s^{-1}, 0.1 s^{-1}, 0.5 s^{-1} and 1 s^{-1}) were used in two-pass hot compression tests. In order to investigate the effects of deformation degree on the softening behaviors, three different deformation degrees (a reduction of 30%, 40% and 50% in specimen height) were applied. Of course, it should be keep the first deformation was interrupted above the critical strain required for dynamic recrystallization in order to initiate the dynamic recrystallization. Then, the metadynamic recrystallization would occur in the unloading period (inter-pass). The critical strains had been reported elsewhere (Lin et al., 2008b,c). The deformation temperatures, strain rates