Materials Science & Engineering A 574 (2013) 1–8

Contents lists available at SciVerse ScienceDirect

Materials Science & Engineering A

journal homepage: www.elsevier.com/locate/msea

The modelling of dynamic recrystallization in the isothermal compression of 300M steel

Y.G. Liu, M.Q. Li *, J. Luo

School of Materials Science and Engineering, Northwestern Polytechnical University, Xi'an 710072, PR China

ARTICLE INFO

Article history:
Received 25 December 2012
Received in revised form
2 March 2013
Accepted 6 March 2013
Available online 14 March 2013

Keywords:
300M steel
Isothermal compression
Dynamic recrystallization
Austenite

ABSTRACT

The 300M steel was isothermally compressed on a Gleeble-3500 simulator at the deformation temperatures ranging from 1123 K to 1473 K, the strain rates ranging from 0.1 s^{-1} to 25.0 s^{-1} and the strains ranging from 0.36 to 1.2. The morphology of austenite grains in the isothermally compressed 300M steel was observed using an OLYMPUS PMG3 microscope. The experimental results of DRX behavior and microstructure observation showed that dynamic recrystallization occurred more easily at higher deformation temperature and lower strain rate. Based on the work hardening rate versus flow stress curves, the critical strain was identified to express the initiation of dynamic recrystallization. In order to determine the kinetics of dynamic recrystallization, the Avrami equation based on the flow stress–strain curves was established. The austenite grain size of complete dynamic recrystallization was a power law function of Zener–Hollomon parameter with an exponent of –0.22.

1. Introduction

The metals and alloys with low stacking fault energy will undergo work hardening (WH), dynamic recovery (DRV) and dynamic recrystallization (DRX) during hot working [1–3]. Especially, DRX is an important mechanism for the microstructure control [4,5]. Microstructure control is of considerable importance in the hot working of metals and alloys because of the desirable properties of products. Therefore, understanding of DRX behavior in the hot working of metals and alloys will be helpful to determine the optimal processing parameters.

DRX behavior in the hot working of metals and alloys has drawn the attention of many researchers for many years. Mirzadeh and Najafizadeh [6] determined the occurrence of DRX by using the natural logarithm of strain hardening rate versus strain curve, and the constitutive equations. Abbasi and Shokuhfar [7] estimated the occurrence of DRX by implementing a Zener–Hollomon type equation in the hot compression of 10Cr–10Ni–5Mo–2Cu high alloy steel at different deformation temperatures and strain rates. Momeni and Dehghani [8] developed the Avrami equation to estimate the kinetics of DRX in the hot compression of AISI 410 martensitic stainless steel at different deformation conditions. Fernández et al. [9] pointed out that the initial austenite grain size, the amount of microalloying elements in solid solution, and the deformation conditions affected the kinetics of DRX in the hot torsion of Nb and Nb–Ti microalloyed steels. Shaban and Eghbali [10] estimated the austenite grain size of complete DRX using a function of Zener–Hollomon (Z) parameter in the hot torsion of a low carbon Nb–Ti microalloyed steel.

The 300M steel as one of the ultrahigh strength steels has been modified by adding the alloying elements of silicon and vanadium in 4340 steel. The 300M steel has excellent properties such as high strength, good fracture toughness, excellent fatigue property and preferable stress corrosion resistance, and is widely used to manufacture the aircraft landing system. It is well known that the coarsing grains will have an adverse effect on the plasticity, toughness, especially fatigue properties of 300M steel [11]. In the past several decades, some researches on controlling coarsing grains have been carried out. Zhang et al. [12] proposed two heat treatment processes of 300M steel to eliminate coarsing grains as follows: (1) austenitising at the temperatures ranging from 1243 to 1253 K and air-cooling; (2) tempering at a temperature of 973 K for 60 min and air-cooling, then rapidly heating to 1203 K with holding time of 60 min, and finally air-cooling. Zhang et al. [13] investigated the effect of heating temperature and holding time on the morphology and grain size of austenite in the heating process of 300M steel. Liu et al. [14] investigated the hot deformation behavior in the isothermal compression of 300M steel and obtained a model for the flow stress based on the fuzzy neural network method. Luo et al. [15] investigated the effect of deformation temperature, strain rate and strain on the morphology and grain size of austenite in the isothermal compression of 300M steel. Though the coarsing grains can be eliminated by the heat treatment, it brings about high cost of the forgings. Though the hot

* Corresponding author. Tel.: +86 29 88460328; fax: +86 29 88492642.
E-mail address: honeymli@nwpu.edu.cn (M.Q. Li).

0921-5093/$ - see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.msea.2013.03.011

deformation behavior and microstructure of 300M steel has been investigated, the study on the kinetics of DRX and austenite grain size of complete DRX in the hot working of 300M steel has not been investigated in the open literatures.

In this study, the DRX behavior in the hot working of 300M steel was investigated by using the isothermal compression. The effect of deformation temperature, strain rate, and strain on the DRX behavior and microstructure was analyzed. The critical strain for initiation of DRX was calculated by the work hardening rate versus flow stress curves. The kinetics of DRX in the isothermal compression of 300M steel was determined to predict the softening behavior so as to optimize processing parameters and control coarsing grains.

2. Experimentals

The chemical composition (wt%) of as-received 300M steel with a diameter of 22.0 mm is shown in Table 1. The as-received 300M steel is prepared for metallographic examination using standard procedures. Then, it is polished and etched in a detergent solution of saturated picric acid for about 30 min at room temperature. The morphology of austenite grains in the as-received 300M steel is illustrated in Fig. 1. It can be seen from Fig. 1 that the prior austenite grains of 300M steel are equiaxed with an average grain size of about 26.30 μm.

Table 1
The chemical composition of as-received 300M steel (wt%).

C	Si	Ni	Mn	Cr	Mo	V	Cu	S	P
0.39	1.61	1.82	0.69	0.91	0.42	0.07	0.06	0.0012	0.0089

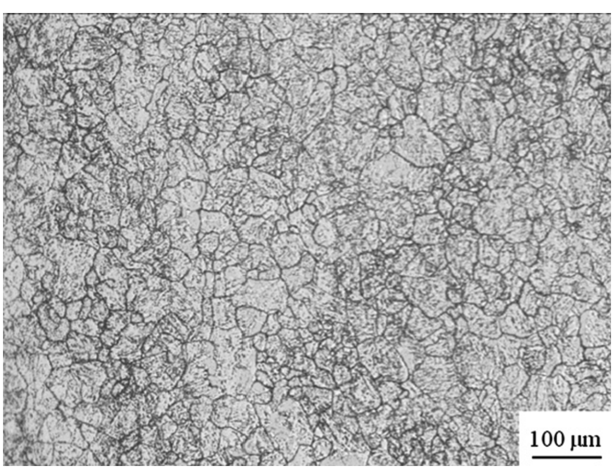

Fig. 1. The morphology of austenite grains in the as-received 300M steel.

The isothermal compression was conducted on a Gleeble-3500 simulator at the deformation temperatures of 1123 K, 1173 K, 1223 K, 1273 K, 1373 K, 1413 K, 1433 K and 1473 K, and strain rates of 0.1 s^{-1}, 1.0 s^{-1}, 10.0 s^{-1} and 25.0 s^{-1}, and strains of 0.36, 0.51, 0.69 and 0.92. The cylindrical compression specimens with a diameter of 8.0 mm and height of 12.0 mm were machined from the as-received 300M steel. The specimens were heated to the deformation temperature at a heating rate of 10 K/s and held for 5 min prior to compression so as to obtain a uniform temperature in the 300M steel specimens. Then, the 300M steel specimens were compressed at the selected constant temperature and rapidly quenched in water after isothermal compression.

In order to obtain the initial grain size, the specimens were heated to the same temperature at a heating rate of 10 K/s and held for 5 min. After heating, the 300M steel specimens were rapidly quenched in water.

The specimens of post isothermally compressed 300M steel were sectioned parallel to compression axis and prepared for metallographic examination using standard procedures. The sections were polished and etched in a detergent solution of saturated picric acid for about 30 min at room temperature. The morphology of austenite was observed by using an OLYMPUS PMG3 microscope. The grain size of austenite was measured using the linear intercept method by SISC IAS V8.0 image analysis software.

3. Results and discussion

3.1. Flow stress

The flow stress–strain curves at different deformation temperatures and strain rates in the isothermal compression of 300M steel are illustrated in Fig. 2. It can be seen from Fig. 2 that the shapes of the flow stress–strain curves is strongly dependent on the deformation conditions. Many investigations [16–18] have been indicated that the shapes of the flow stress–strain curves can be used to identify the phenomena of DRV and DRX. The schematic of typical flow stress–strain curves due to different softening mechanisms is shown in Fig. 3. The curve 'a' is corresponding to the softening mechanism of DRV, and the flow stress will achieve a saturation stress with the increasing of strain. If DRX occurs in the hot deformation, the flow stress–strain curves usually display a single peak followed by a steady state flow with the increasing of strain like the curve 'b'. Sometimes the flow stress–strain curves will display multi-peaks when discontinuous DRX occurs in the hot deformation. The shape of the flow stress–strain curves shown in Fig. 2 indicates that the 300M steel exhibits

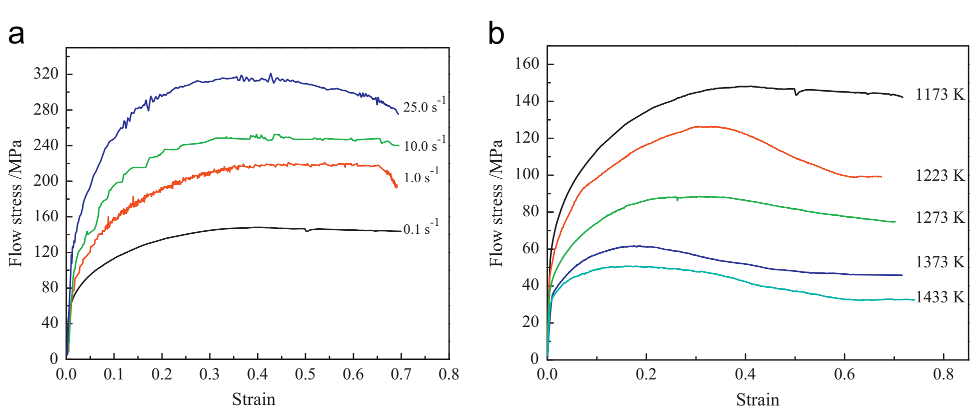

Fig. 2. The selected flow stress–strain curves in the isothermal compression of 300M steel (a) 1173 K and (b) 0.1 s^{-1}.