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Characteristics of martensite transformed from deformed austenite with various states of ultrahigh strength 300 M steel

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ABSTRACT

300 M steel was isothermally compressed on a Gleeble 1500 simulator at a deformation temperature of 1173 K, a strain rate of 0.1 s^{-1} and strains ranging from 0.11 to 1.20. The morphologies and structure characteristics of martensite transformed from deformed austenite during water quenching were observed and analysed via scanning electron microscope and transmission electron microscope. Subsequently, effects of prior austenite state on martensitic transformation behavior of 300 M steel were analysed. The experimental results showed that predominant lath martensite and complemental twinned martensite and retained austenite coexisted in deformation-quenched 300 M steel at various strains. The volume fraction of lath martensite and packets of lath martensite decreased with the increasing of strain, and the length and width of the blocks in lath martensite concurrently decreased. Prior austenite with the state of severely work-hardening or just completed dynamic recrystallization would hamper the nucleation and subsequent growth of lath martensite. Additionally, as for austenite with the state of work-hardening, the morphologies and width of laths changed little with the increasing of strain, whereas dislocations in the interior of laths dramatically increased. However, as for austenite with the state of dynamic recrystallization and subsequent growth, the width of laths obviously increased with the increasing of austenite grain size.

1. Introduction

Beyond any doubt, the favourite phase transformation resulting in ultrahigh strength is martensitic transformation. There has been persistent interest as yet in investigating martensite and martensitic transformation of metallic materials. Extensive studies have been performed on martensitic transformation behaviors including the volume fraction, morphology and crystallography of martensite, the martensite start temperature (M_s) and so on during heat treatment of metallic materials [1–7]. Lee et al. [5] investigated the structure characteristics of martensite in Fe-1.0C-7Cr stainless steel subjected to subzero treatment and pointed out that thin-plate martensite could be transformed into lenticular martensite. Matsuda et al. [6] found that increasing carbon addition in Fe-C-Si-Mn steel could raise M_s during cooling and thus improve the volume fraction of transformed martensite. Hong et al. [7] developed a thermo-kinetic model considering driving force-dependent activation energy to describe the martensitic transformation behaviors upon continuous cooling in Fe-0.2C-1Mn-1Si alloy.

Nowadays, in order to obtain the desirable properties of metallic materials, hot deformation is not only a process to remodel the shape and size of the components, but also an important approach combined with heat treatment to control and improve the final microstructure [8, 9]. So far the effects of hot deformation of austenite on martensitic transformation behaviors in Fe alloys have attracted great attentions [10–19]. Maalekian et al. [14] investigated the hot plastic deformation and subsequent transformation of pearlitic carbon steel, and found that the deformation at the strains above 0.4 could significantly suppress martensitic transformation due to mechanical stabilization. Nikravesh et al. [15] indicated that the hot plastic deformation at a strain of 0.5 hindered the martensitic transformation and diminished M_s of 22MnB5 boron steel especially at lower cooling rates. However, Abbasi et al. [16] obtained a fully martensitic microstructure in quenched 22MnB5 boron steel with prior isothermal compression at a deformation temperature of 1173 K and a strain of 0.5. Wang et al. [17] suggested that martensitic transformation was most difficult in the dynamically recrystallized austenite grains of high manganese TRIP steel owing to the influence of high-density crystal defects and small grain size. Besides, martensitic transformation was the next most difficult in work-hardening austenite grains, particularly near the grain boundaries of prior austenite. In contrast, Xu and Huang [18] showed that work-hardening of austenite in Fe-32% Ni alloy in small strain range was beneficial for martensitic transformation due to the low dislocation density and little

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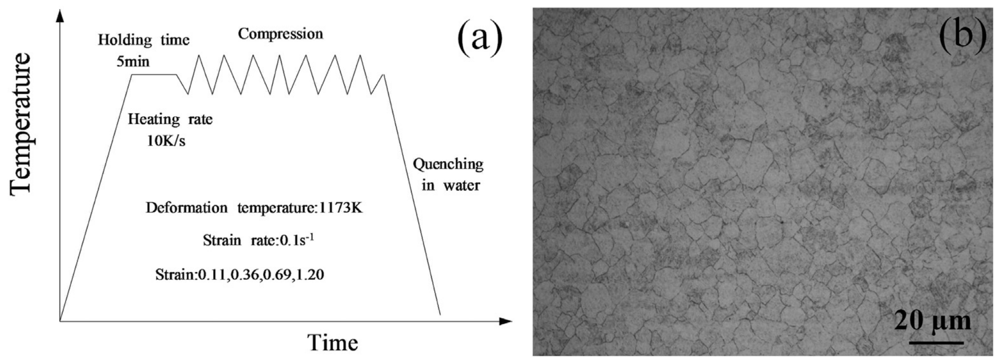

Fig. 1. Schematic diagram of isothermal compression test (a) and microstructure of 300 M steel prior to isothermal compression (b).

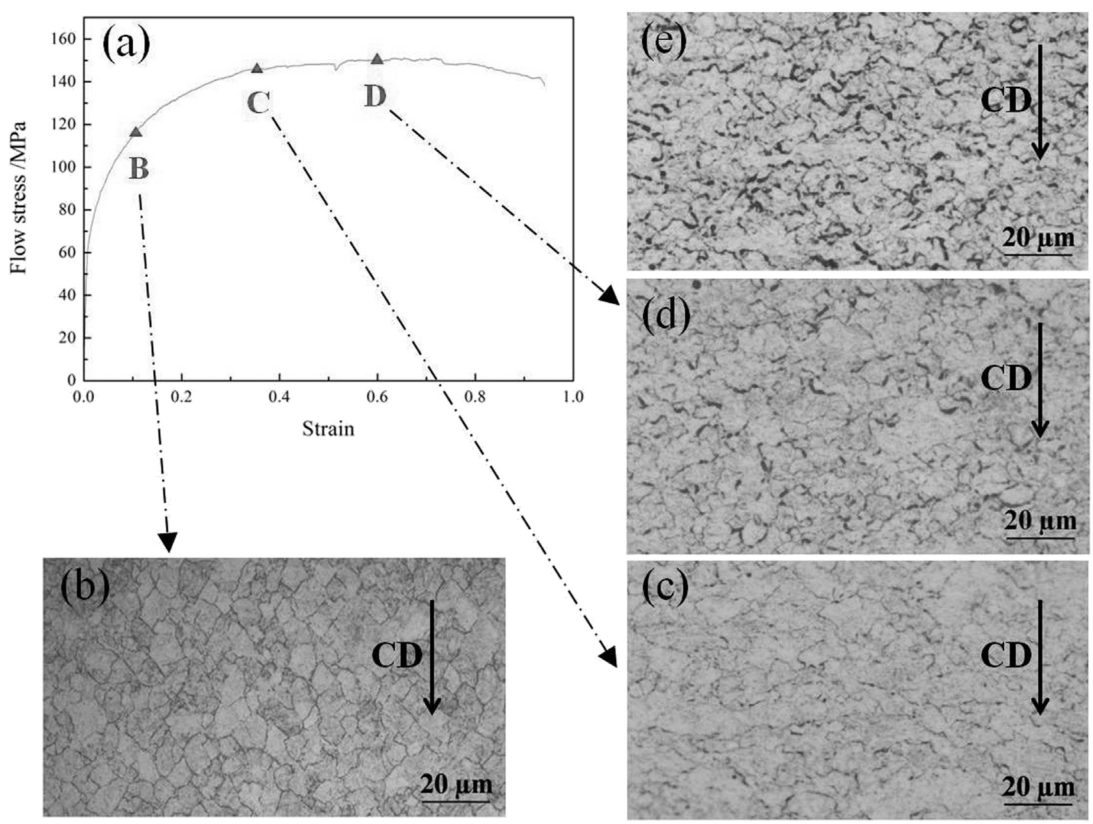

Fig. 2. Isothermal compression of 300 M steel: (a) flow stress-strain curve; the morphologies of deformed austenite at different strains of 0.11(b), 0.36 (c), 0.69 (d) and 1.20 (e).

lattice distortion. Wang et al. [19] indicated that increasing strain would enhance the stability of austenite in Mn-Cr gear steel, resulting in a gradual increase of martensite/austenite (M/A) constituent. In summary, it is widely believed that various austenite states can produce a variety of microstructures, which ultimately leads to different properties of steels. However, the effects of austenite state after the hot deformation on the martensitic transformation behaviors are complicated and different as for Fe alloys.

300 M steel as one of the ultrahigh strength steels has excellent properties including high strength, good fracture toughness, excellent fatigue property and preferable stress corrosion resistance, which is widely used in severe environment such as aircraft landing gear [20, 21]. As well known, austenite in deformed 300 M steel normally undergoes the whole process from work-hardening to completed dynamic recrystallization (DRX) with the increasing of the strain [20]. However, few efforts have been made to thoroughly understand the relationship between austenite states after hot deformation and martensitic transformation behaviors of 300 M steel [22].

It is the purpose of this investigation to present a systematical investigation on morphologies and structure characteristics of martensite in deformation-quenched 300 M steel at various strains via X-ray diffraction (XRD), scanning electron microscope (SEM) and transmission electron microscopy (TEM). In particular, the effects of austenite states including work-hardening, just completed DRX, slightly growing after DRX and coarsening after DRX on martensitic transformation behaviors were analysed in depth so as to efficiently control the martensite structure in deformation-quenched 300 M steel.

2. Experimental Procedure

300 M steel is a medium carbon steel and its chemical composition (wt%) is 0.39C, 1.61Si, 1.82Ni, 0.69Mn, 0.91Cr, 0.42Mo, 0.07V, 0.06Cu, 0.0012S, 0.0089P and Bal. Fe. The A_{c1} temperature and A_{c3} temperature of as-received 300 M steel are 1021 K and 1075 K,