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Strain hardening behavior of a TRIP/TWIP steel with 18.8% Mn

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ABSTRACT

Tensile tests were carried out to study the strain hardening behavior of a TRIP/TWIP steel with 18.8% manganese. The results indicated that the true stress–strain curve can be divided into 4 stages in tension testing. Material is in an elastic region when the true strain is below 0.06. In the initial stage of the plastic deformation ($\varepsilon = 0.06$–0.14), ε-martensite was preliminarily formed, and that austenite transformed to α-martensite through the ε-martensite formation. When the true strain was between 0.14 and 0.35, the stacking fault energies were elevated by the increase of strain energy, deformation twinning occurred instead of the ε-martensite formation. The second derivative of the stress–strain curve satisfied the condition $d^2\sigma/d\varepsilon^2 > 0$. Twinning induced plasticity dominated this stage. In the last plastic deformation stage ($\varepsilon = 0.35$–0.45), $\gamma \rightarrow \alpha$ transformation occurred at the crossing of twins, and α-martensite grew along the thickness of the twinned regions.

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1. Introduction

Material researchers are currently paying much attention to the novel structural materials which can be used in transportation systems, mechanical engineering construction and architecture structures. Ultra-high manganese steels exhibit high strength and ductility, excellent formability, superior fracture toughness and reduced specific weight and therefore attention has been devoted to these steels [1–6]. These newly developed steels with high manganese are called TRIP (Transformation Induced Plasticity) or TWIP (Twinning Induced Plasticity) steels.

Fe–Mn(–C) alloys have relatively low stacking fault energies [7,8]. The additions of Al and Si elements to the Fe–Mn alloys affect their stacking fault energies and phase stability, and give rise to various properties in Fe–Mn alloys such as strain hardening associated with deformation twinning, strain-induced γ(f.c.c.) → ε(h.c.p.) and γ(f.c.c.) → α(b.c.t.) martensitic transformations [9–13]. The results of some research has indicated that the alloy mainly reveals the TRIP effect when the manganese content is lower than 15%, while TWIP effect is dominant when manganese content is higher than 25%. And when manganese content is between 15% and 25%, the TRIP and TWIP effects coexist. In TRIP/TWIP steels, the mechanisms responsible for strain hardening rate have been under discussion. Olson and Mottis [7] have shown the mechanism of strain-induced martensitic nucleation. Barbier et al. [14] suggested mechanical twinning is the dominant mechanism to increase the strain hardening rate. But only a few studies are related to microstructural evolution and mechanisms where TRIP and TWIP effects coexist during the deformation. Also, the sequence of these two mechanisms during the deformation requires detailed clarification.

The aim of this research is to investigate the deformation mechanisms of high manganese TRIP/TWIP steels with 18.8% Mn. In the present work, the tensile tests were carried out with different amounts of strain and microstructural features with true stress–strain curve were correlated‘. Based on the experimental results, the governing mechanisms for deformation and work hardening of high manganese TRIP/TWIP steel are discussed.

2. Experimental procedure

The steel was melted in a 50 kg vacuum induction furnace, and the billet size was about ϕ12 cm × 45 cm. Chemical analysis was conducted by chemical gauging and the error range was about 0.05. The chemical composition (mass percent, %) is shown in Table 1.

The ingot was first forged to 40 mm in thickness. After soaking at 1150 °C for 2 h, the billets were hot rolled to a plate with a thickness of 3.5 mm with reduction ratio of about 91%. The specimens were cut from the hot rolled plate and heated to 1100 °C for 1 h, then followed by water quenching. All the tensile tests were performed in a CMT5105 electron tensile test machine controlled by computer. The tensile testing was carried out at a constant strain rate of $10^{-3}\ s^{-1}$ at room temperature. One tensile test was conducted up to

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Table 1
Chemical composition of the tested steel (mass, %).

Mn	Al	Si	C	Fe
18.8	2.9	2.9	0.04	Balance

rupture and then other tensile samples were uniformly deformed to true strained of 0.03, 0.06, 0.14, 0.19, 0.24, 0.29, 0.35 and 0.45, respectively, in order to study the deformation mechanisms. The microstructures of these specimens prior to and after deformation were observed under an OLYMPUS GX51 optical microscope and Philips EM400T. D/Max-Ra X-ray diffractometer was used to identify the phase structure.

3. Experimental results

3.1. Tensile test

3.1.1. Mechanical behavior

The true stress–strain curve of the steel shows that the 18.8% Mn TRIP/TWIP steel possesses good mechanical properties, exhibiting high true stress (1300 MPa) and large true strain (0.45) with relatively low yield strength and continuous yielding (Fig. 1). It can be seen that the curve is readily divided into four stages according to the characteristic of the curve.

The relationship between the volume fraction of phases and true strain is shown in Fig. 2. The first stage is elastic deformation. The volume fractions of each phase are invariant. However, in stage II, the volume fraction of austenite decreases rapidly with true strain increasing in the initial period of plastic deformation (<0.14), whereas the trend of α-martensite is opposite. When the true strain level increases from 0.14 to 0.35 (stage III), no phase change was observed. In the last stage, the volume fraction of austenite decreases slowly with increasingdeformation, but that of the martensite is the opposite. Up to failure, the volume fraction of retained austenite is below 20%. In addition, the ε-martensite volume fraction increases rapidly in the beginning of plastic deformation, and then it remains nearly constant.

Curves of strain hardening rate $d\sigma/d\varepsilon$ and work hardening coefficient ($H = (d\sigma/d\varepsilon)/\sigma$) are shown in Figs. 3 and 4, respectively. These curves were both obtained from the derivation of true σ–ε curve after smooth treatment using the origin software. As shown in Fig. 3, corresponding to different deformation stage in Fig. 1, the

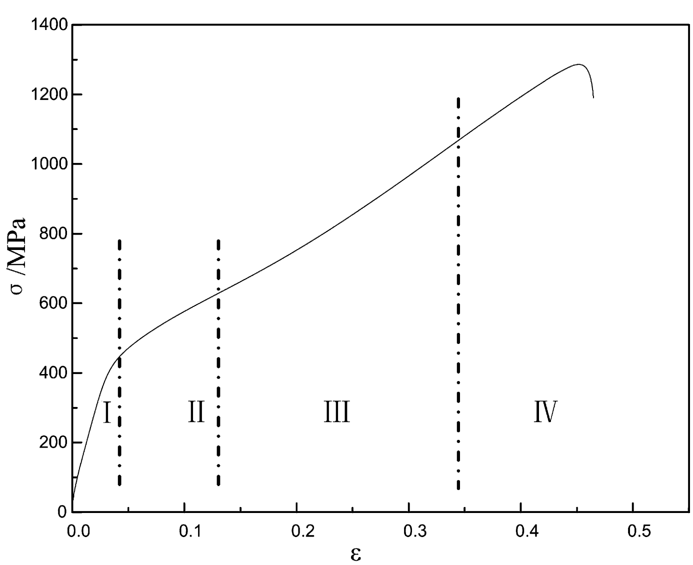

Fig. 1. True σ–ε curve of the experimental steel.

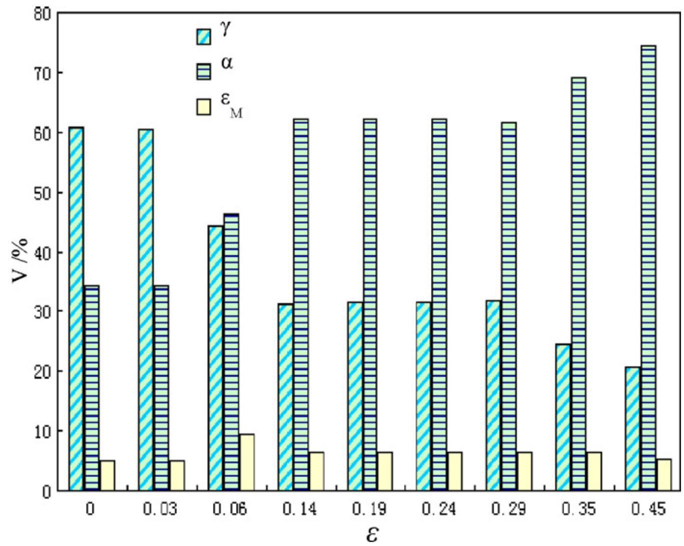

Fig. 2. Relation between volume fraction of phases and true strain.

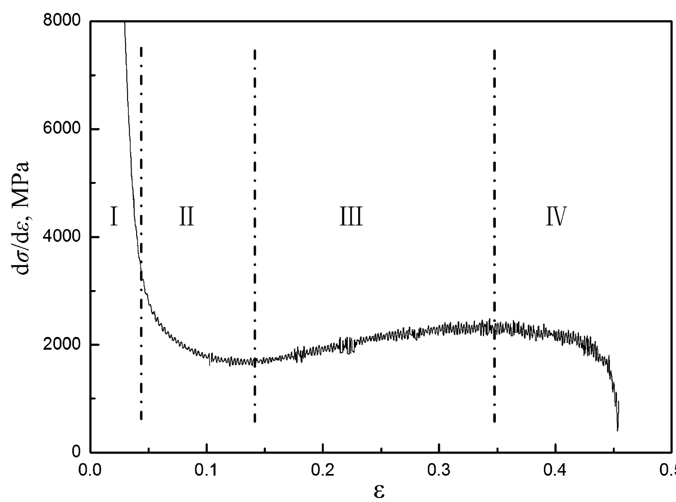

Fig. 3. Relation between strain hardening rate and true strain.

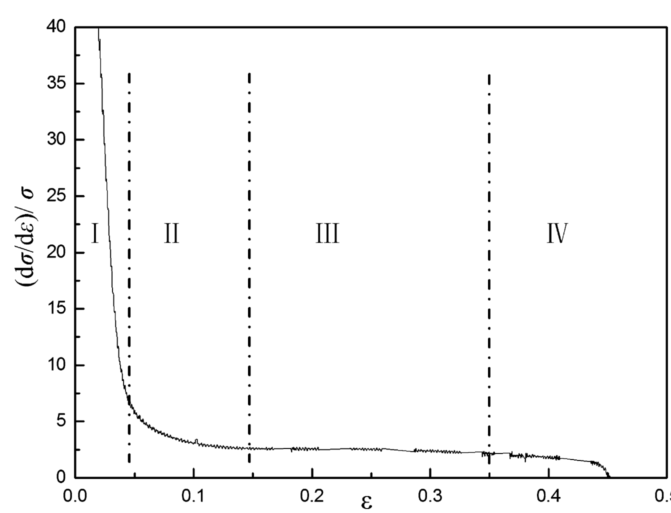

Fig. 4. Relation between H and true strain.

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