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The influence of thermomechanical parameters in ferrite grain refinement in a low carbon Nb-microalloyed steel

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Abstract

The ferrite grain refinement in a low carbon Nb-microalloyed steel is investigated in the present work using hot compression experiments for various deformation temperatures. The results indicate that very fine ferrite grains of about 2–4 μm can be obtained by deformation at 760–850 °C, due to the occurrence of strain-induced transformation (SIT) of austenite to ferrite.

Keywords: Thermomechanical processing; Grain refining; Ultrafine grained microstructure; Low carbon microalloyed steel; Strain-induced transformation

1. Introduction

The attainment of ultrafine ferrite grain structures in low carbon, low alloy steels is of current interest because of the desire to improve yield strength and toughness. There are several thermomechanical controlled processing (TMCP) routes to a fine ferrite grain microstructure. Controlled rolling is one of the most important operations for producing low-cost, high strength steels with yield strength as high as 600 MPa [1]. Using commercial controlled rolling, a limiting ferrite grain size of around 5 μm appears to exist. In recent years, several groups have reported achieving ferrite grain size below the nominal 5 μm limit of controlled rolling of steels, using laboratory scale TMCP methods for low carbon microalloyed and plain carbon steels [2–4]. There are potentially three mechanisms to produce ultrafine ferrite grain size: (i) strain-induced transformation, (ii) transformation from dynamically recrystallized austenite, and (iii) dynamic recrystallization of ferrite [5,6]. Very fine ferrite grain sizes have been achieved via strain-induced transformation in plain carbon steels, as confirmed by optical microstructural observations [7–9]. However, there is very little information concerning ferrite grain refinement by the strain-induced transformation (SIT) mechanism in the case of microalloyed steels. Furthermore, it is well known that hot deformation has an important effect not only on the microstructural changes but also on the hot flow stress–strain curves. Therefore, in addition to optical microstructural observation, hot flow stress–strain curves can be used as more evidence for determining if SIT has occurred during the deformation.

In the present work, isothermal single pass hot compression tests were conducted on a low carbon Nb-microalloyed steel to study the effects of deformation temperature and strain on ferrite grain refinement. In particular, attention has been paid to studying ferrite grain refinement through SIT. The physical processes that occur during deformation are studied by optical metallography and analyzing the true stress–true strain hot flow curves.

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2. Experimental procedure

The material used in the experimental work was a low carbon Nb-microalloyed steel with the chemical composition shown in Table 1. The steel was prepared as a 35 kg ingot in an induction furnace operating under argon atmosphere, and then refined by electro-slag remelting in a laboratory unit. The ingot was reheated to 1250 °C for 1 h and hot rolled in six passes to 25 mm thick plate. Differential scanning calorimetry was used to measure the critical transformation temperatures. The Ar_1 and Ar_3 temperatures were thus found to be 750 and 830 °C, respectively. Cylindrical compression samples were machined out from hot rolled plate. The deformation tests were carried out according to the schedule in Fig. 1. The samples were 18 mm in length and 12 mm in diameter, with the axis aligned in the rolling direction of the plate. Care was exercised to minimize friction between the test dies and the sample surface by machining flat-bottomed grooves on the end faces of samples. Graphite powders and thin pieces of mica sheet were used as lubricants in compression, resulting in fairly uniform deformation with negligibly small barreling.

Table 1
Chemical composition of steel (wt.%)

C	Si	Mn	P	S	Nb	Al	N
0.035	0.14	0.93	0.008	0.016	0.02	0.01	0.0031

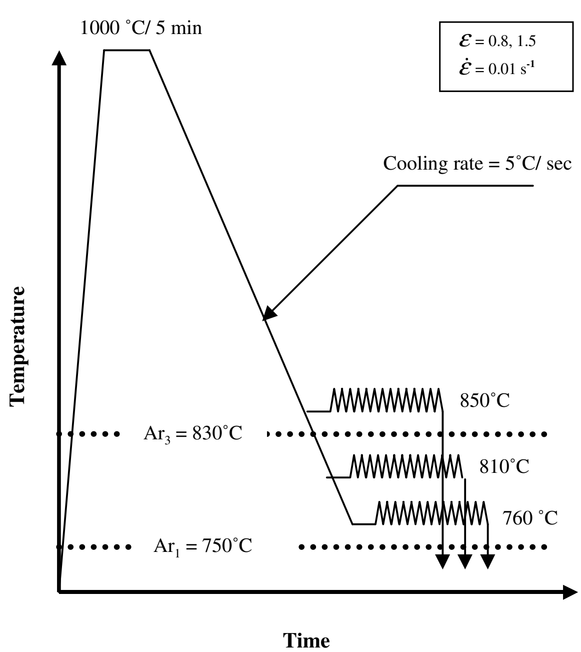

Fig. 1. Schematic representation of the thermomechanical processing conditions.

The uniaxial compression tests were performed on a servo-hydraulic 600 kN computerized Materials Testing System (MTS, Model 8500) equipped with a resistant furnace. Prior to deformation, the samples were solutionized at 1000 °C for 5 min. The solution temperature was selected according to the solubility product of Nb precipitates [10,11]. After solutionizing, the samples were cooled at a rate of 5 °C/s to different deformation temperatures (850, 810, and 760 °C), and held for 20 s to homogenize the temperature throughout the samples. Then samples were isothermally deformed with single pass strains of 0.8 and 1.5 at a constant strain rate of $0.01\ s^{-1}$. All specimens were water quenched for 2 s after deformation. Optical microscopy was conducted on mid-plane sections containing the axis of compression, in order to study the microstructural changes.

3. Results and discussion

3.1. Stress–strain curves and related dynamic softening processes

Fig. 2 shows the stress–strain curves up to the strain of 1.5 for three different deformation temperatures, 760, 810, and 850 °C, at a constant strain rate of $0.01\ s^{-1}$. As can be seen in this figure, at 850 °C, just above Ar_3, the slope of the flow curve decreases gradually and then remains constant, indicating dynamic softening during deformation. This behaviour might be interpreted as indicating dynamic recrystallization (DRX) of austenite. However, the deformation temperature of 850 °C is below the non-recrystallization temperature for this steel [12,13], and therefore DRX of austenite is ruled out. The hot deformation process can in principle result in: (i) dynamic recrystallization, (ii) dynamic recovery, or (iii) strain-induced transformation of deformed austen-

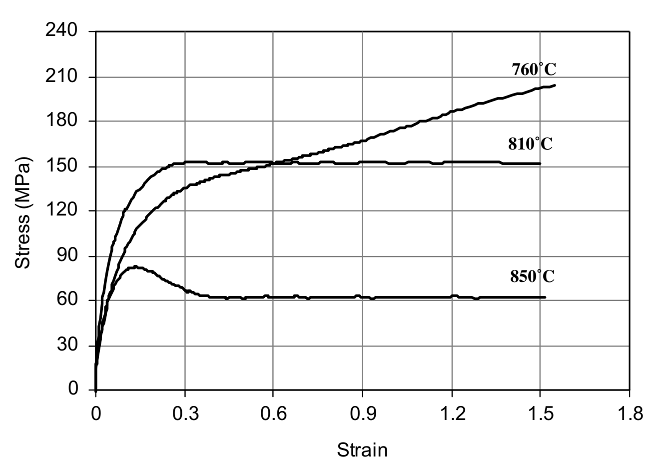

Fig. 2. Flow curves of low carbon Nb-microalloyed steel obtained under various deformation temperatures with a strain rate of $0.01\ s^{-1}$.