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Improvement of strength and toughness for hot rolled low-carbon bainitic steel via grain refinement and crystallographic texture

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ABSTRACT

Low-carbon bainitic steel with effective grain size of ~2.0 μm and strong < 110 > //RD (rolling direction) transformation texture was obtained by adopting ultra fast cooling following non-recrystallization rolling. The steel exhibited higher tensile strength of ~840 MPa and lower ductile-to-brittle transition temperature of ~ −106 °C in comparison with the steel that had no distinct texture with effective grain size of ~4.5 μm. High intensity of {110} planes normal to the rolling direction were formed as a result of the strong {114}~{223} < 110 > transformation texture and effectively inhibited the main crack propagation by ductile fracture mechanism. The existing {100} planes parallel to the rolling plane led to the impact fracture delamination at −20~ −100 °C, which improved the low temperature toughness.

1. Introduction

The toughness of steels usually deteriorates with the increase in strength. Grain refinement has been used as a major approach to improve the steel toughness. The ductile-to-brittle transition temperature (DBTT) can be effectively lowered through grain refinement. However, many researches indicated that the excess grain refinement resulted in a significant reduction in upper shelf energy [1–4]. In addition, delamination or splitting caused by elongated structure is usually favorable for the low temperature toughness. Bourell et al. reported that warm-rolling produced cleavage delamination and thereby lowered the DBTT [5,6]. Meanwhile, they still found that delamination also lowered high-temperature toughness in the ductile mode.

Utilization of the combining effects of grain refinement and delamination is a new and potent approach to improve the strength and toughness of steels. Kimura et al. obtained a high strength and toughness steel with chemical composition of 0.4C–2Si–1Cr–1Mo (wt%), which was characterized by ultrafine elongated ferrite grain structure and strong < 110 > //RD deformation texture [1,7]. It was produced by warm caliber rolling of square/square type. *Inoue* et al. developed a high toughness steel with a more simple chemical composition using the similar process with caliber-rolling at 500 °C followed by water quenching [8]. However, it is difficult to apply this process in industrial rolling line, especially the hot strip rolling line. With the purpose of improving mechanical properties of hot rolled steels, especially toughness, the present work introduced a new approach to achieve grain refinement as well as the beneficial crystallographic texture, which was more suitable for industrial rolling production.

2. Experimental procedure

Chemical composition of the experimental low-carbon steel contains 0.055C–0.18Si–1.75Mn–0.35Cr–0.15Mo (wt%) and also a sum of 0.15 wt% Nb, V and Ti. The steel was austenitized at 1200 °C for 1.5 h and then hot rolled from 130 mm to 13 mm in a two-high 450 mm hot rolling mill equipped with ultra fast cooling (UFC) system (UFC system is located behind the rolling mill, which was developed by Northeastern University and has been industrially applied to many hot strip production lines in China). Controlled rolling was conducted with total reduction of 43% in 1200~1050 °C (austenite recrystallization region) and total reduction of 82% in 900~850 °C (non-recrystallization region). After hot rolling, the steel was cooled to 300~200 °C by UFC system with a cooling rate of ~65 °C/s. For convenience, this steel was designated as NR-UFC. For comparison, another steel was hot rolled only in austenite recrystallization region followed by cooling to 300~200 °C using laminar cooling (LC) system with a cooling rate of ~10 °C/s, and designated as R-LC.

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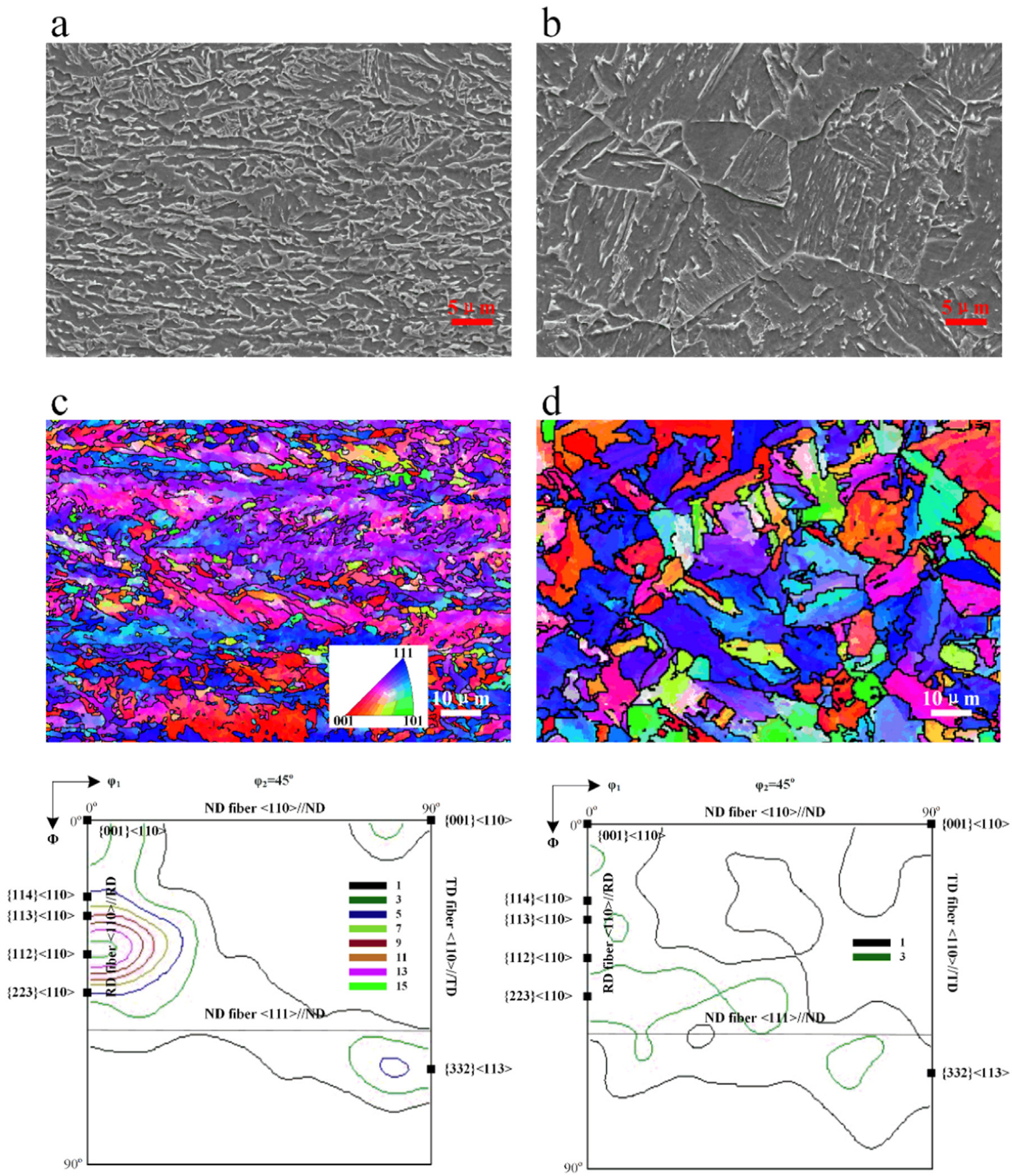

Fig. 1. Microstructure and texture of the steels: (a) and (b) SEM micrographs of NR-UFC and R-LC steels, respectively; and (c) and (d) EBSD results of NR-UFC and R-LC steels, respectively.

Table 1
Mechanical properties of NR-UFC and R-LC steels

Steel	Yield strength ($R_{P0.5}$)/MPa	Tensile strength/MPa	Uniform elongation/%	Total elongation/%	Strength-ductility balance/MPa%	Ductile-to-brittle transition temperature/°C
NR-UFC	670	841	7.6	22.5	18,900	−106
R-LC	637	766	6.3	21	16,086	−30

3. Results and discussion

The SEM micrograph and EBSD results of the NR-UFC steel are presented in Figs. 1(a) and (c). The microstructure consists of acicular ferrite and granular bainite with the effective grain size of ~2.0 μm measured by EBSD. The hot rolling in non-recrystallization region produces the deformed austenite with large amounts of grain boundaries and intragranular deformation bands, which means an increase in nucleation sites. The subsequent UFC provided significant driving force and promoted nucleation rate, thereby refining the grain size [9–11]. Fig. 1(c) shows that the NR-UFC steel has strong α-fiber (<110>//RD)