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Recrystallization and strain accumulation behaviors of high Nb-bearing line pipe steel in plate and strip rolling

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ABSTRACT

The recovery and recrystallization behaviors of high Mn-high Nb line pipe steel were investigated by means of thermal-simulation and plane strain tests, and the morphology of prior-austenite grains in different conditions was revealed by special etching method. Proposed rolling windows of static recrystallization (SRX) and non-recrystallization were determined for industrial plate rolling. Moreover, partial dynamic recrystallization (DRX) behavior of high Mn-high Nb steel was proved by multi-pass plane strain tests. The results of SRX indicate the existence of a deformation temperature range for grain refinement by complete SRX, in which grains nucleate homogeneously and the coarsening rate is slow because of intense solute dragging. In non-recrystallization temperature range, partial DRX may be triggered by overmuch strain accumulation in the case of improper process design, and then, mixed grains and the loss of final S_v level take place.

1. Introduction

High Mn-high Nb approach for X80 pipeline is being applied in large number of Chinese pipeline projects. The diameter of both spiral and UOE/JCOE pipe is 1219 mm with thickness of 18.4 mm and 22 mm, respectively [1]. In order to meet the requirement of high performance, various metallurgical phenomena of high Mn-high Nb pipeline steel need to be concerned during hot rolling and accelerated cooling. No matter which rolling process is employed, grain refinement and strain accumulation are the keys for good properties. In general, these are influenced by recovery of dislocation, static and dynamic recrystallization and precipitation behavior. However, how to refine austenite grain and accumulate strain effectively are still not so clear in the case of high Mn-high Nb approach. Many literatures [2] had mentioned that high Nb content can raise static recrystallization stop temperature (T_{nr}), so finish rolling can start at higher temperature. But for higher Mn–Nb system, the precipitation of Nb(C,N) is delayed compared with low Mn system [3] during the relaxation of deformed austenite, moreover, the dragging force (compared with pinning effect of precipitates) would not be strong enough to retard the recrystallization [3]. Therefore, non-recrystallization temperature range of high Mn-high Nb system should be reconsidered. Less precipitates result in more niobium in dissolution, thus it is possible to the existence of a new temperature region based on the new characteristics of high Mn-high Nb steel, in which nucleation of new recrystallized grain occurs as usual, but growth rate is slow because of much stronger dragging force. The other important point during hot rolling is strain accumulation or high S_v. For high Nb steel, the recovery between passes would be retarded due to drag effect of solute Nb, as a consequence, accumulated strain should be higher, and it would increase the possibility of DRX and meta-dynamic recrystallization (MDRX), especially in the finish rolling of hot strip mill. Therefore, in industrial production, actual static and dynamic recrystallization behaviors in different conditions should be considered as hot strip mill (HSM) and plate mill (PM), which have different metallurgical characteristics, respectively.

In this paper, important characteristics of SRX and partial DRX of high Mn-high Nb steel were determined. These results are useful to obtain homogeneous, fine grain structure and higher S_v level after hot rolling.

2. Experimental steels and procedure

Chemical compositions of experimental high Mn-high Nb steel are shown in Table 1. Three kinds of thermo-simulation processes were designed to investigate different recrystallization behaviors under various conditions, all tests were accomplished by Gleeble-1500, and cylinder specimens of Ø 8 mm × 10 mm were prepared prior to the experiments.

Stress relaxation method was employed to research on the precipitation and the softening behaviors, and its schematic processes

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Table 1
Chemical compositions of experimental steel.

	C	Si	Mn	Nb	Al	Ti	Cu + Cr	N (ppm)
wt%	0.04	0.22	1.75	0.1	0.03	0.015	0.48	≤40

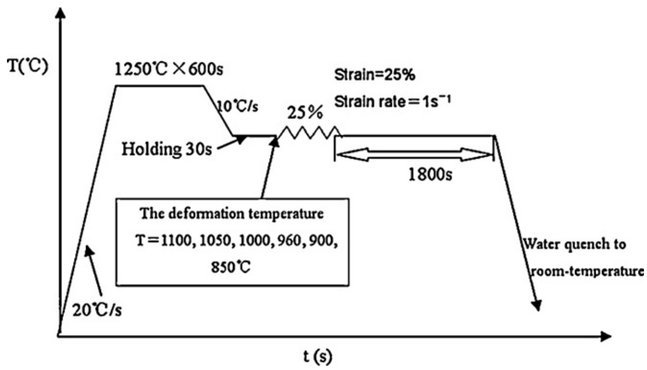

Fig. 1. Thermal-simulation processes of stress relaxation test.

are shown in Fig. 1. To dissolve 0.1 wt% Nb(C,N) and TiN as complete as possible [4,5], and also prevent too coarse austenite grain, the reheating temperature of 1250 °C was chosen for stress relaxation tests, in this case, the average size of austenite grain is about 125 μm prior to deformation [6]. The strain is constant during compression holding, and stress–time curve can reflect the softening and hardening behaviors of specimen.

Secondly, Static recrystallization was studied further by conventional double compression [7,8]. As the actual reheating temperature in industrial plate rolling and strip rolling is around 1200 °C, so the specimens were reheated to 1200 °C, and cooled with cooling rate of 10 °C/s to different temperatures for double compression, in detail, interval times between passes at deformation temperature are shown in Table 2, 25% reduction and $1\,s^{-1}$ strain rate in each pass were adopted in this experiment, as shown in Fig. 2(a). The options of reheating temperature and reduction were based on industrial schedule of plate rolling, and to understand the recrystallization behavior under industrial rolling conditions. The average size of initial prior-austenite grain is about 100 μm [6] in the case of reheating temperature of 1200 °C. Moreover, covered area method (Fig. 2(b)) was applied to calculate isothermal softening fraction between pass-interval, instead of the discrepancy value of yield stress points. The softening fraction between passes can be determined by $X = (S_m - S_r)/(S_m - S_o)$, and the softening by recovery is estimated about 15%, so final fraction of recrystallization can be calculated by $R = (X - 15\%)/85\%$. Furthermore, to reveal the evolution of austenite grains in SRX and non-recrystallization region more clearly, other new thermo-simulated processes based on two-stage schedule of X80 plate actual rolling were adopted, as shown in Fig. 3, one pass with 25% reduction at 1070 °C was added in this test. The morphology of prior-austenite grains in the middle section of compressed cylinder at different temperatures was observed by optical microscope, after grinded, polished and specially etched. In addition, a new plane strain thermo-simulation machine in *University of Science and Technology Beijing* (USTB) was used to investigate strain

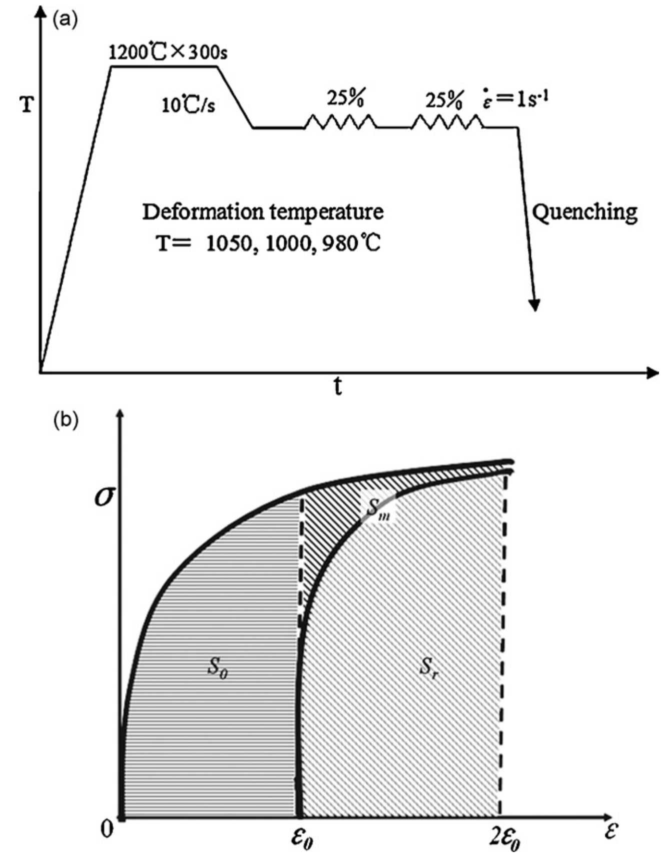

Fig. 2. Process of double compression tests (a) and schematic of covered area method for the calculation of recrystallization fraction (b).

accumulation of high Mn-high Nb steel, Fig. 4 shows the adoptive thermo-simulation processes, which are based on actual rolling of industrial X80 strip, therein, two finish rolling start temperatures were chosen, 940 °C and 910 °C, respectively, and the true stress–strain curves were recorded. In all experiments, optical microstructure and prior-austenite grain boundary were etched by different methods, the former was etched by 4% Nital, otherwise, to latter, a new thermal etching method was attempted to reveal the characteristic of austenite grain in low carbon high Nb pipeline steel, as shown in Table 3.

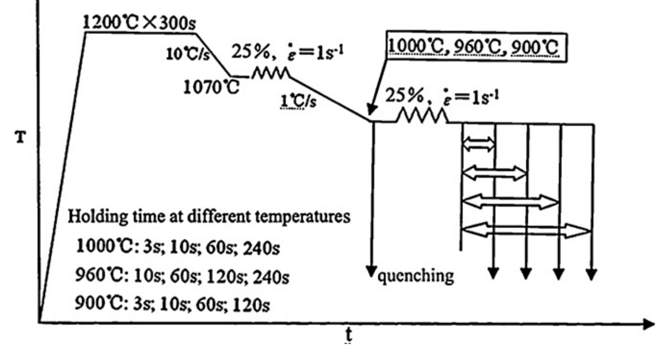

Fig. 3. Thermo-simulation processes for observing evolutions of austenite grains.

Table 2
Different interval times in the double compression test.

Temperature (°C)	Interval times (s)			
1050	1	10	40	
1000	10	40	100	500
980	10	40	100	500