Journal of Materials Science & Technology xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Journal of Materials Science & Technology

journal homepage: www.jmst.org

Grain refinement of non-magnetic austenitic steels during asymmetrical hot rolling process

Changsheng Li*, Biao Ma, Yanlei Song, Jianjun Zheng, Jikai Wang

State Key Laboratory of Rolling and Automation, Northeastern University, Shenyang 110819, China

ARTICLE INFO

Article history:
Received 25 November 2016
Received in revised form 10 February 2017
Accepted 19 February 2017
Available online xxx

Keywords:
Austenitic steels
Microstructure
Recrystallization
Grain refining
Asymmetrical hot rolling

ABSTRACT

Asymmetrical hot rolling (ASHR) was proposed to acquire productive grain refinement for Fe-20Mn-4Al-0.3C and Fe-18Cr-18Mn-0.5N non-magnetic austenitic steels. The intensive additional shear deformation caused by ASHR promotes the nucleation of recrystallization and grain refining of steel plates. With the speed ratio of 1.2, the austenitic grains were refined to ~5 μm on the surface, the recrystallization fraction was enhanced to ~34.7%, and the thickness of fine-grained surface layer increases to ~450 μm for Fe-20Mn-4Al-0.3C steel. The Fe-18Cr-18Mn-0.5N steel also exhibited an effective surface grain refinement with an average size of ~3 μm, and the recrystallization fraction reached ~76.9% at the speed ratio of 1.15.

1. Introduction

Non-magnetic steel is a kind of functional steel materials with a face centered cubic structure, which has a stable single phase of austenite at ambient temperature and shows extremely low permeability. They are widely used in electric power, shipbuilding, transportation, construction industries and so on [1,2]. However, the conventionally hot rolled plates of non-magnetic steels usually have a relatively low yield strength because of coarse austenitic grains, which limits their industrial application. Therefore, the improvement of yield strength should be the subject of great significance in terms of non-magnetic austenitic steels.

Among a variety of strengthening mechanisms for metallic materials, the grain refinement is one of the most efficient methods, which hardly leads to the deterioration of plasticity in materials. At present, the main strategy for preparing ultra-fined metallic materials is by means of severe plastic deformation (SPD) imposed on bulk metals, including equal channel angular extrusion, high pressure torsion and asymmetrical rolling (ASR), etc. The ASR process is considered to be the most feasible candidate for the large-scaled steel sheet production among these SPD methods [3–7]. For the past three decades, a pronounced grain refinement caused by asymmetrical cold rolling and its subsequent annealing have been first achieved in pure aluminum, magnesium and aluminum alloys [8–10]. Nevertheless, the relevant research on asymmetrical hot rolling (ASHR) has not been extensively carried out especially for steel production.

Song et al. [11] investigated the difference in both texture and phase components for oriented silicon steel between symmetrically and asymmetrically rolling. Mapelli et al. [12] applied ASHR to a duplex phase stainless steel, and found that the application of ASHR was conducive to improving the formability and tensile elongation in this steel. Additionally, the effect of ASHR processing parameters, such as speed ratio, temperature and rolling reduction on microstructural refinement and rolling force was also examined for AISI304 steel by Liu et al. [13]. Another report by Chen et al. [14] suggested that the ASHR process could enhance the impact toughness of HSLA steel to a certain degree, by refining the ferritic grains at the plate center. Therefore, there is a need and possibility of exploring appropriate ASHR processing parameters to accomplish effective grain refinement in the hot rolled non-magnetic steels, and an improvement of mechanical properties is also expected. For this reason, the present study is primarily aimed at the achievement of grain refining for non-magnetic steels through the optimization of ASHR processing parameters, i.e. speed ratio, temperature and rolling reduction.

2. Experimental

The experimental steels for ASHR are Fe-20Mn-4Al-0.3C and Fe-18Mn-18Cr-0.5N austenitic steels. The chemical compositions are given in Table 1. The ingots weighting 150 kg were firstly melted

* Corresponding author.
E-mail address: lics@ral.neu.edu.cn (C. Li).

http://dx.doi.org/10.1016/j.jmst.2017.06.002

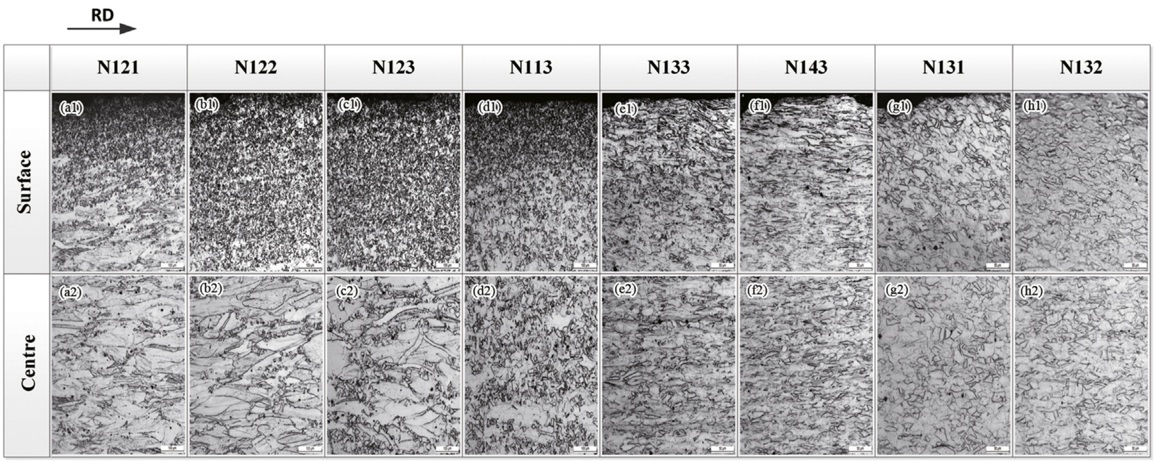

Fig. 1. Microstructures on the upper surface and at the center of N121, N122, N123, N113, N133, N143, N131 and N132 steel during ASHR process (RD: rolling direction, scale bars for a1-d1 and a2-d2 are 100 μm, scale bars for e1-h1 and e2-h2 are 50 μm).

Table 1
Chemical compositions of experimental steels.

	C	Si	Mn	P	S	Al	Cr	N	V	Fe
Fe-20Mn-4Al-0.3C	0.298	0.45	20.56	0.006	0.002	4.11	–	0.015	0.11	Bal.
Fe-18Mn-18Cr-0.5N	0.09	0.30	18.32	0.014	0.003	–	18.11	0.48	0.295	Bal.

in a vacuum induction furnace, and then forged into several billets with the dimensions of 100 mm × 40 mm × L mm. Conventional hot rolling was carried out on a Φ450 mm hot rolling mill in the laboratory. After homogenizing at 1200 °C for 2 h, the billets were rolled within rolling temperature range of 1050–920 °C. The final thickness after conventional hot rolling was 5.5 mm. These plates were then used for the raw materials of the subsequent ASHR experiment. Subjected to the reheating at a certain temperature, the plates were hot rolled on a ϕ400 mm ASHR mill with a thickness reduction of 20%–60% per pass, followed by water quenching. The detailed rolling process parameters for two experimental steels are listed in Table 2. In the table, γ, T_H, T_S, T_F, R_r correspond to the speed ratio between upper roll and lower roll, heating temperature, start rolling temperature, finish rolling temperature and thickness reduction ratio, respectively.

A two-dimensional rigid-plastic finite element method (FEM) was utilized to calculate the shear stress field in the deformation region of roll gap during ASHR process, according to the flow stress model for experimental steel regressed from the data of uniaxial compression on a thermo-mechanical simulator [15]. The microstructure of Fe-20Mn-4Al-0.3C steel on longitudinal section was etched by 5% Nital solution and observed on a LEICA DMIRM optical microscopy (OM). Microhardness distribution across the plate thickness was examined using a FUTURE-TECH FM-700 microhardness tester. The values at five various locations of the same depth were measured and averaged. The microstructure of Fe-18Mn-18Cr-0.5N steel was obtained by the electron backscattered diffraction (EBSD) scan.

Table 2
Rolling parameters of experimental steels.

Sample		γ	T_H (°C)	T_S (°C)	T_F (°C)	R_r (%)
Fe-20Mn-4Al-0.3C	N121	1.0	1100	1000	940	60
	N122	1.1	1100	1000	940	60
	N123	1.2	1100	1000	940	60
	N113	1.2	1100	1050	1010	60
	N131	1.2	970	930	830	20
	N132	1.2	970	930	830	40
	N133	1.2	970	930	830	60
	N141	1.0	970	860	750	60
	N142	1.1	970	860	750	60
	N143	1.2	970	860	750	60
Fe-18Mn-18Cr-0.5N	N213	1.15	970	860	750	50

3. Results and discussion

3.1. *Effect of ASHR processing parameters on microstructure*

The ASHR microstructures of Fe-20Mn-4Al-0.3C steel as a function of speed ratio are shown in Fig. 1. It is noteworthy that the grain size distribution along the thickness direction varies with the increasing speed ratio. With the speed ratio of 1.0 (N121), the average grain size is ∼8 μm on the upper surface, and the thickness of fine-grained layer is approximately ∼120 μm from the surface to the plate center. In the central layer, the area fraction of recrystallized region is only 5.8%, which exists mainly at the boundaries of elongated grains. As the speed ratio is enhanced to 1.1 (N122), the finer grains with an average size of 6 μm are observed in the surface layer, the thickness of fine-grained surface layer is about 350 μm, and the recrystallization fraction is 29.8%. With the speed ratio up to 1.2 (N123), the mean size of fine grain decreases to ∼5 μm, and the thickness of fine-grained surface layer increases to 450 μm. Meanwhile, the recrystallization fraction at the center of the plate increases to 34.7%. Under the asymmetrical rolling condition, the intensive deformation creates a large number of nucleation sites for metal recrystallization in surface layer, and the impingement between the massive growing nuclei restricts their further growth, thereby facilitating a refined grain size [16]. The schematic illustration of physical metallurgical variation during ASHR process for N123 steel is shown in Fig. 2.

The ASHR microstructures of N113, N123, N133 and N143 under various start rolling temperatures of 1050 °C, 1000 °C, 930 °C and 860 °C are shown in Fig. 1. It is well known that the recrystallization that takes place during hot deformation is temperature dependent. Thus, the complete recrystallization only occurs in the surface layers of N113 and N123 steel, at the start rolling temperature above 1000 °C. Below this temperature, partial recrystallization (N133)