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Composition and orientation effects on the final recrystallization texture of coarse-grained Nb-containing AISI 430 ferritic stainless steels

R.P. Siqueira[a], H.R.Z. Sandim[a,*], T.R. Oliveira[b], D. Raabe[c]

[a] Departamento de Engenharia de Materiais, Escola de Engenharia de Lorena, University of Sao Paulo, 12600-970, Lorena-SP, Brazil
[b] Centro de Pesquisa da ArcelorMittal Inox Brasil S.A., 35180-000, Timóteo-MG, Brazil
[c] Max-Planck Institut für Eisenforschung, D-40237, Düsseldorf, Germany

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Composition and orientation effects on the final recrystallization texture of three coarse-grained Nb-containing AISI 430 ferritic stainless steels (FSSs) were investigated. Hot-bands of steels containing distinct amounts of niobium, carbon and nitrogen were annealed at 1250 °C for 2 h to promote grain growth. In particular, the amounts of Nb in solid solution vary from one grade to another. For purposes of comparison, the texture evolution of a hot-band sheet annealed at 1030 °C for 1 min (finer grain structure) was also investigated. Subsequently, the four sheets were cold rolled up to 80% reduction and then annealed at 800 °C for 15 min. Texture was determined using X-ray diffraction and electron backscatter diffraction (EBSD). Noticeable differences regarding the final recrystallization texture and microstructure were observed in the four investigated grades. Results suggest that distinct nucleation mechanisms take place within these large grains leading to the development of different final recrystallization textures.

1. Introduction

Ferritic stainless steels (FSSs) have good corrosion resistance, particularly to chloride stress corrosion cracking, and appropriate formability during deep drawing [1–4]. In this paper, the texture evolution of AISI 430 FSSs containing 16% chromium and different amounts of niobium, carbon and nitrogen was investigated. Niobium improves mechanical properties such as creep and thermal fatigue resistances and it also avoids sensitization in the heat-affected zone of welded parts. Niobium plays two important roles in the microstructure of ferritic stainless steels. Niobium reacts with interstitials dissolved in the ferrite matrix leaving the steel free from interstitial C and N atoms. Precipitates such as Nb(C,N), Fe_2Nb and Fe_3Nb_3C were reported in Nb-containing FSSs depending on their composition [5,6]. Recent papers have also demonstrated that solid solution niobium, even in small amounts, is very effective to slow boundary migration during recrystallization and grain growth [7,8].

Alloyed ferritic steels (e.g. Fe–16 wt.% Cr and Fe–3 wt.% Si) and low-carbon ferritic steels reveal similarities in terms of the recrystallization texture evolution [9–13]. During typical industrial steel processing, bcc (body-centered cubic) steels are after initial hot rolling cold rolled up to approximately 80% thickness reduction and annealed subsequently to achieve primary static recrystallization [9–14]. The cold rolling textures of bcc steels can be described by a set of texture fibers such as the α-fiber collecting all grains with a ⟨1 1 0⟩ direction parallel to the rolling direction and the γ-fiber summarizing all crystals with a {1 1 1} plane parallel to the sheet surface [9–15]. The α-fiber texture strengthens during cold rolling leading to pronounced maxima at the {0 0 1}⟨1 1 0⟩, {1 1 2}⟨1 1 0⟩, and {1 1 1}⟨1 1 0⟩ texture components at strains of about 80% sheet thickness reduction [14]. After subsequent primary static recrystallization annealing, the orientation density of the α-fiber decays between {0 0 1}⟨1 1 0⟩ and {1 1 2}⟨1 1 0⟩ and the intensity of the γ-fiber texture increases leading to maxima around the {1 1 1}⟨1 1 2⟩ and {1 1 1}⟨1 1 0⟩ components (at sufficiently high preceding strains above 50%). Hence, in general {1 1 1}⟨*u v w*⟩ components characterize typical recrystallization textures observed in bcc metals [9–14]. A high and equally distributed intensity of the {1 1 1}⟨*u v w*⟩ texture and a topologically random arrangement of the γ-fiber crystallites is usually pursued to enhance formability under stretching and drawing constraints [4].

The literature shows that the hot rolling in the ferritic region can enhance the deep drawability [16]. For high-alloyed steels such as FSSs, the formability is slightly lower than the one observed for low carbon steel sheets [17–20]. It was found that both, hot-band annealing or intermediate annealing during cold rolling can increase the γ-fiber texture after recrystallization annealing improving the overall forming properties under stretching and drawing loading conditions. In addition, previous studies suggest

* Corresponding author. Tel.: +55 12 3159 9916; fax: +55 12 3153 3006.
E-mail address: hsandim@demar.eel.usp.br (H.R.Z. Sandim).

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Table 1
Chemical composition of the Nb-containing ferritic stainless steels (in wt.%).

Steel type	Cr	Nb	C	N	Mn	Si	P
FSS-A	16.14	0.31	0.02	0.02	0.16	0.29	0.03
FSS-B	16.22	0.37	0.02	0.02	0.15	0.30	0.03
FSS-C	16.23	0.56	0.03	0.03	0.15	0.24	0.03
FSS-R	16.29	0.38	0.02	0.02	0.19	0.34	0.03

that the ridging phenomenon is minimized which is beneficial for further drawing operations, particularly for surface appearance and the forming limits [21–23]. Ridging which is sometimes also referred to as roping is a microstructural effect which manifests itself in the formation of a corrugated surface profile that maps the longitudinal alignment of grain clusters of different mechanical properties [12,24]. In bcc steels these are usually large $\{0\,0\,1\}\langle 1\,1\,0\rangle$ oriented grain clusters that are inherited form the hot band microstructure and in fcc (face-centered cubic) metals such as 6xxx Al alloys these are usually elongated near-$\{0\,0\,1\}\langle 1\,0\,0\rangle$-oriented grain clusters [24].

For grain-oriented silicon steels, after recrystallization, further high-temperature annealing is carried out in order to promote the formation of a sharp $\{0\,1\,1\}\langle 0\,0\,1\rangle$ Goss texture component through secondary recrystallization [25]. In this case, hot-band annealing can influence both the resulting primary and secondary recrystallization texture. The results show that the Goss texture increases after secondary recrystallization annealing [26].

In this paper, we investigate both composition and orientation effects in the final recrystallization annealing texture of three Nb-containing AISI 430 FSSs. Grades A, B, and C differ from each other with regard to the initial texture and to the amounts of Nb in solid solution (0.03, 0.09 and 0.14 wt.%, respectively). The final recrystallization texture and the microstructure vary significantly from one grade to another due to the coarse-grained microstructure obtained after hot-band annealing at 1250 °C for 2 h.

2. Experimental

The 4-mm thick Nb-containing FSS hot bands were supplied by ArcelorMittal Inox Brasil S.A. Hot bands of grades referred to as FSS-A, FSS-B, and FSS-C were annealed at 1250 °C for 2 h (high-temperature annealing) to obtain coarse-grained materials. The three steel grades differ mostly in the Nb and interstitial contents (0.31–0.56 wt.%. Nb), namely, steel FSS-A has 0.31 wt.% Nb, steel FSS-B has 0.37 wt.% Nb, and steel FSS-C has 0.56 wt.% Nb. The full chemical composition of these steels is shown in Table 1. For purposes of comparison, we have also investigated the annealing behavior of a hot band of a reference steel (FSS-R) annealed at 1030 °C for 1 min to promote static recrystallization. This reference steel was processed following industrial parameters. Two other important parameters to compare the different grades used in the present investigation are the ratio Nb/(C + N) and the amount of Nb in solid solution (Nb_{ss}). The latter is calculated using the simple expression $Nb_{ss} = Nb_t - 7(C+N)$, where Nb_t is the total amount of niobium and C + N the sum of the amounts of carbon and nitrogen, given in wt.% [1]. These parameters are displayed in Table 2. After hot rolling and hot band annealing all annealed hot bands, including FSS-R, were cold rolled up to 80% thickness reduction ($\varepsilon \approx 1.6$) and annealed at 800 °C for 15 min to promote final recrystallization. Grain size was determined using the linear intercept method. Fig. 1 summarizes the experimental procedure used in this work.

Table 2
Nb/(C + N) ratios and respective amounts of niobium in solid solution found in grades FSS-A, FSS-B, FSS-C and FSS-R.

Grade	C + N (wt.%)	Nb/(C + N)	Nb_{ss} (wt.%)
FSS-A	0.04	7.75	0.03
FSS-B	0.04	9.25	0.09
FSS-C	0.06	9.33	0.14
FSS-R	0.04	9.5	0.10

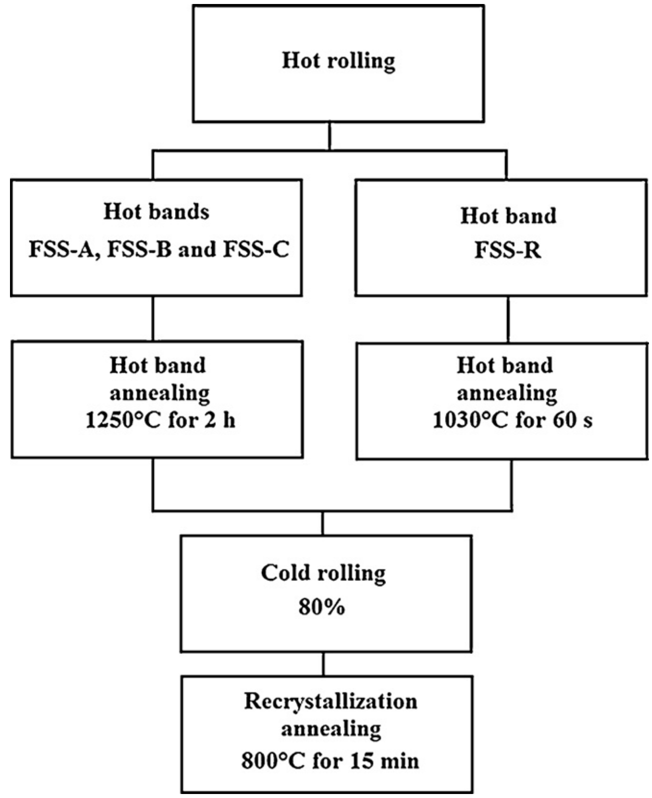

Fig. 1. Block diagram showing the thermomechanical processing used in this work. Ferritic stainless steels referred to FSS-A, B and C have coarse-grained structures. FSS-R has a finer grain structure.

Microstructural characterization was carried out in the rolling plane using a LEO 1450-VP SEM operated at 20 kV in the backscattered electrons mode (BSE). The EBSD scans were performed in a Philips XL-30 SEM operated at 20 kV with a LaB_6 filament. Microtexture data were evaluated using the EDAX-TSL software package. A map step size of 1 μm was used. The black and white lines mark high-angle (>15° misorientation) and low-angle boundaries (<15° misorientation), respectively, in all scans. The orientation distribution function (ODF) and pole figures (PF) were determined by the discrete-binning method from the EBSD data. The texture was evaluated by conventional X-ray texture analysis using a Philips X'Pert PRO MPD texture diffractometer with a Cu Kα radiation. The ODFs ($\varphi_2 = 0°$ and 45°) were calculated from three pole figures (2 0 0), (1 1 0), and (2 1 1) using the FHM software system [27]. The orientations are expressed in the Euler angles using the Bunge

Table 3
Main texture components for ferritic stainless steels after thermomechanical processing.

Miller indices $\{h\,k\,l\}\langle u\,v\,w\rangle$	Name	Symbol	Bunge notation (Φ, φ_1,φ_2)
$\{0\,0\,1\}\langle 0\,1\,1\rangle$	45°-rotated cube	H	(0°,45°,0°) or (0°,0°,45°)
$\{0\,0\,1\}\langle 0\,2\,1\rangle$	–	CH	(0°,26°,0°)
$\{0\,1\,1\}\langle 0\,0\,1\rangle$	Goss	G	(45°,0°,0°) or (90°,90°,45°)
$\{0\,1\,1\}\langle 2\,1\,1\rangle$	Brass	B	(45°,35°,0°)
$\{0\,2\,1\}\langle 0\,0\,1\rangle$	–	CG	(26°,0°,0°)
$\{4\,4\,11\}\langle 11\,11\,8\rangle$	Taylor	T	(27°,90°,45°)