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Recrystallization Texture Characteristic and Drawability of a Warm Rolled and Cold Rolled Interstitial-Free Steel

Z. Wang, P. Zhang, Y. Guo, X. Liu, and G. Wang

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The recrystallization textures and drawability in an interstitial-free (IF) steel were investigated as a function of cold rolling reduction. The hot bands for further cold rolling were obtained by lubricated hot rolling in the ferrite region. The orientation distribution function (ODF) was applied to analyze recrystallization textures. Texture analysis showed that hot bands rolled in the ferrite region had strong {111}//ND texture component. The {111}//ND recrystallization texture of the cold rolled steel with 73% reduction displayed the highest intensity, but weakened as more cold work was introduced. The highest *r*-value was obtained at a cold reduction of 73% when the hot band was previously rolled in the ferrite region.

Keywords cold rolling, ferrite rolling, interstitial-free steel, plastic anisotropy, texture

1. Introduction

Interstitial-free (IF) steels are widely used for the production of deep drawing steel sheets because they possess good formability and nonaging features (Ref 1). The drawability of the cold rolled steel sheet is influenced greatly by the microstructure and process conditions of the hot rolled steel. When finish rolled under the Ar_3 point, the aluminum killed low-carbon steel and IF steel show much lower *r*-values (plastic anisotropy value) compared with the case of hot rolling in the austenite region. Therefore, it is necessary to hot roll in the austenite region to obtain a high *r*-value (Ref 2, 3). However, for IF steel to be used, an improvement in the reheating temperature is needed (above 1250 °C) due to the high phase transformation temperature (between 870 and 890 °C), which leads to more energy consumption and bad surface quality. It has been reported (Ref 4-9) that warm rolling (i.e., hot rolling in the ferrite region) can lead to intense <111>//ND (where ND denotes the normal direction) hot band texture and is beneficial for the development of <111>//ND texture during subsequent cold rolling and annealing.

To develop an optimal cold rolling process to further improve drawability, the present work has investigated the effect of cold rolling reductions on the recrystallization textures and drawability of a Ti stabilized IF steel with strong <111>//ND texture subjected to ferrite hot rolling with lubrication, and the results have been explained by the mechanism of texture forming.

Zhaodong Wang, Yanhui Guo, Xianghua Liu, and **Guodong Wang,** The State Key Lab of Rolling & Automation, Northeastern University, Shenyang 110004, China; and **Peng Zhang,** The State Key Lab of Rolling & Automation, Northeastern University, Shenyang 110004, China and Benxi Iron and Steel Corp, Benxi 117000, China. Contact e-mail: zhdwang@mail.neu.edu.cn.

2. Experimental Procedure

The material used in this study contains 0.0029% C, <0.03% Si, 0.14% Mn, 0.009% P, 0.052% S, 0.037% Al, 0.0024% N, 0.054% Ti, and <0.01% Nb and was obtained from the head end of a transfer bar of a commercially produced titanium-stabilized IF strip. According to the requirement of hot rolling and cold rolling reductions, the original ingots were machined to slabs with four different thicknesses (i.e., 12, 18, 24, and 36 mm, respectively). The whole experimental procedure consisted of a hot rolling, cold rolling, and annealing process, as shown in Fig. 1. Hot rolling was performed on a pilot mill with $\Phi = 340$ mm, using Quaker HB-18-KT (Quaker Chemical Corp., Conshohocken, PA) as the lubricating oil. Samples were slowly reheated to 1100 °C and held for 2 h, then air cooled to 920 °C. The material was rolled in a single pass at a 33.3% reduction, air cooled to 820 °C, and finally rolled in two passes with a finish rolling temperature of 700 °C and a total reduction of 75%. After that, hot bands with thicknesses of 2, 3, 4, and 6 mm were cooled to 600 °C. They were put into a furnace and slowly cooled to simulate the cooling process after coiling. After pickling, such hot bands were cold rolled to the average thickness of 0.8 mm with reductions of 60, 73, 80, and 87%, respectively. Afterwards, samples with dimensions of 70 × 220 mm were annealed using a CCT-AWY continuous annealing apparatus, simulating a continuous annealing process line (CAPL), with the highest annealing temperatures equal to 820 °C (CAPL-1) and 840 °C (CAPL-2).

Tensile tests were performed according to JIS13A standards to measure the strength, ductility, *r*-value, and *n* value. For some selected samples, three incomplete pole figures ({110}, {200}, and {211}) were measured by x-ray diffraction (XRD). The corresponding orientation distribution functions (ODF) were then calculated using Roe's method (Ref 10).

3. Results

Figure 2 shows the effects of cold rolling reduction on the properties of the IF steel, hot rolled in the ferrite region under

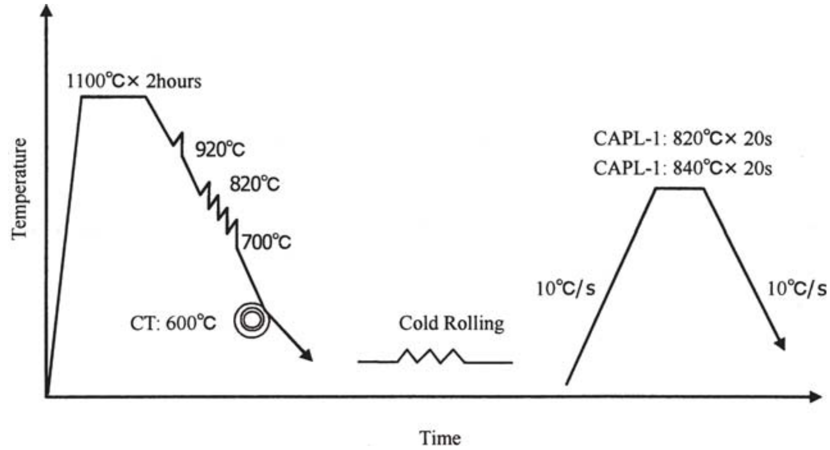

Fig 1 Schematic illustration of the experimental process

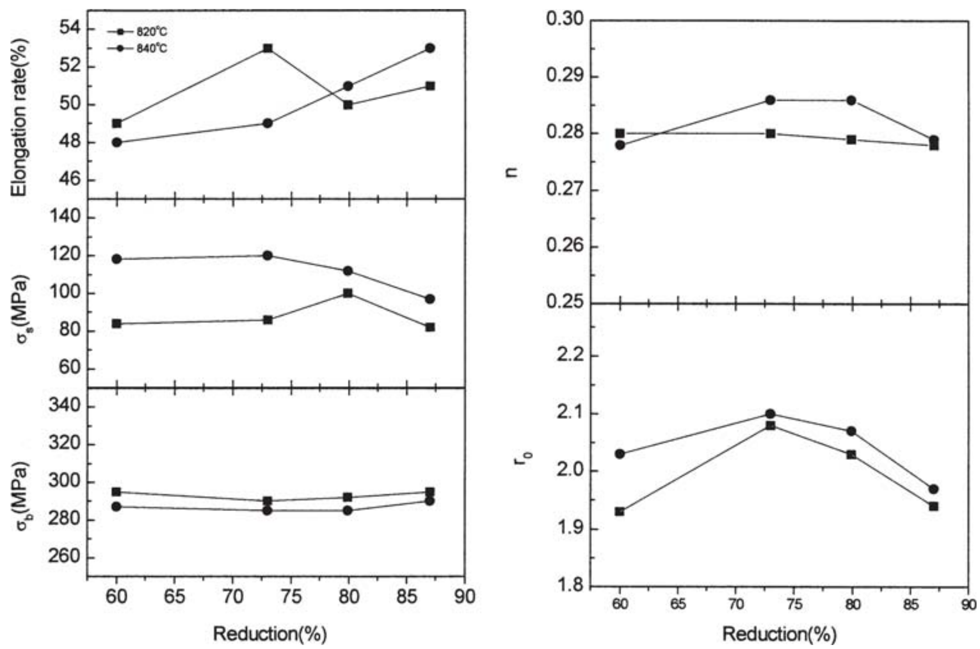

Fig 2 Effect of cold rolling reductions on properties of the tested steel in different continuous annealing conditions

different continuous annealing conditions. It is clear that under the same annealing conditions, σ_s, σ_b, and n change little, but elongation increases with the amount of reduction. σ_s and σ_b obtained in the CAPL-1 process are higher, compared with the case of CAPL-2. However, the *r*-value in the CAPL-2 process is higher, and it improves with the increase in cold rolling reductions. The *r*-value reaches a maximum of 2.1 at the reduction of 73%, and decreases with further reductions.

The textures of samples after CAPL-2 annealing, represented by $\phi = 45°$ sections of ODFs, is shown in Fig. 3. It can be seen that the strongest components are all near <111>//ND axis but their intensities change with cold rolling reductions. Experiments show that the highest intensity of <111>//ND is obtained at 73% reduction.

4. Discussion

Cold rolling reduction is one of the most important factors that influence the deep drawability of IF steel. Generally speaking, IF steel is hot rolled in the austenite region and an 80 to 90% reduction is required to reach its highest *r*-value (Ref 11). However, as Fig. 2 shows, the highest *r*-value can be attained at a reduction of 73% in this work, and the *r*-value decreases when reductions reach 87%, which is consistent with other results (Ref 12).

The intensity changes of ε-fiber (<110>//TD), α-fiber (<110>//RD), and γ-fiber (<111>//ND) corresponding to Fig. 3 are shown in Fig. 4. In the ε-fiber, {554}<225> component is dominant. The {114}<221> and {113}<332> orientations also display high intensities. The {554}<225> component is intensified with the amount of cold rolling reduction and reaches a maximum of f(g) = 14 at the reduction of 73%, while {114}<221> and {113}<332>, which are the transition textures between {001} and {111}, become intense with increasing reductions, leading to the weakness in the {554}<225> component and poor drawability. In the α skeleton line, a weak peak near {114}-{113}<110> occurs only at the reduction of 60%, while only a strong peak including {111}-{223}<110> is

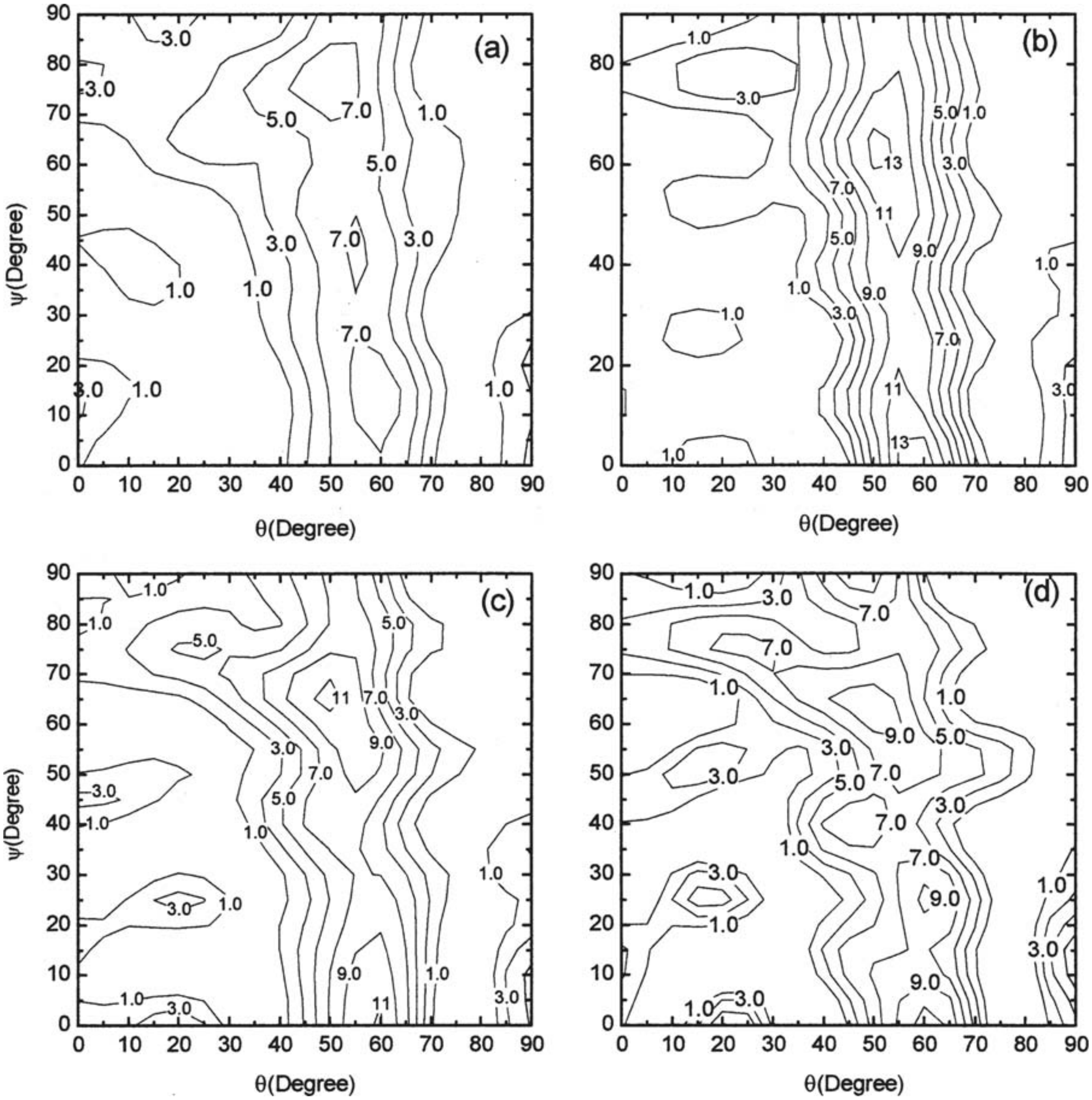

Fig 3 $\Phi = 45°$ sections ODFs in different cold rolling reduction and CAPL-2 (a) 60%, (b) 73%, (c) 80%, and (d) 87%

observed with other reductions. The {111}<110> orientation tends to rotate to {223}<110> with increasing reductions. In the γ skeleton line, the {111}<112> component with an orientation density of 6 is weaker than {111}<110> with an orientation density of 7 at 60% reduction. The shape of the γ skeleton line is constant as reductions vary from 73 to 87%, with {111}<112> stronger than {111}<110>. The intensity of {111}<112> and {111}<110> reach maximum values of 12 and 10, respectively, at 73% reduction. This indicates that {111}<112> is the most stable orientation.

Volume fraction changes of {111}, {112}, {110}, and {100} orientation grains calculated from the inverse pole figures are shown in Fig. 5. Obviously, <111>//ND orientation grains are predominant, whereas other orientation grains are less, and change little with reductions. The volume fraction of {111} orientation grains change significantly with reductions, and reach the minimum and the maximum at 68 and 73% reduction, respectively.

As shown in Fig. 6, hot band textures in this work comprise strong {111} texture, {001} texture, and relatively weak {110} texture due to hot rolling in the unrecrystallized ferrite region with good lubrication, which was consistent with references (Ref 13, 14). According to texture inheritance, {111} texture and {001} texture are further improved during the cold rolling process. The {001} component deteriorates the deep drawability, and excessive reduction will lead to high intensity of {100}<110>, which hinders the rotation toward {111} texture (Ref 15). Thereby, {114}-{113}<110> components in the TD fiber are intensified, giving rise to poor drawability. On the other hand, with an increase in reductions, cold rolling textures will change as follows (Ref 15, 16): {110}<001> → {554}<225> → {111}<112> → {111}<110> → {223}<110>.

The IF steel hot rolled in the ferrite region can achieve the strongest {111} texture, requiring less reduction than in traditional process. Textures will rotate to {223}<110> with further reduction, which deteriorates deep drawability. This is why the *r*-value first increases and then decreases with increasing reductions, as Fig. 3 shows.

Therefore, less reduction is needed to get good drawability

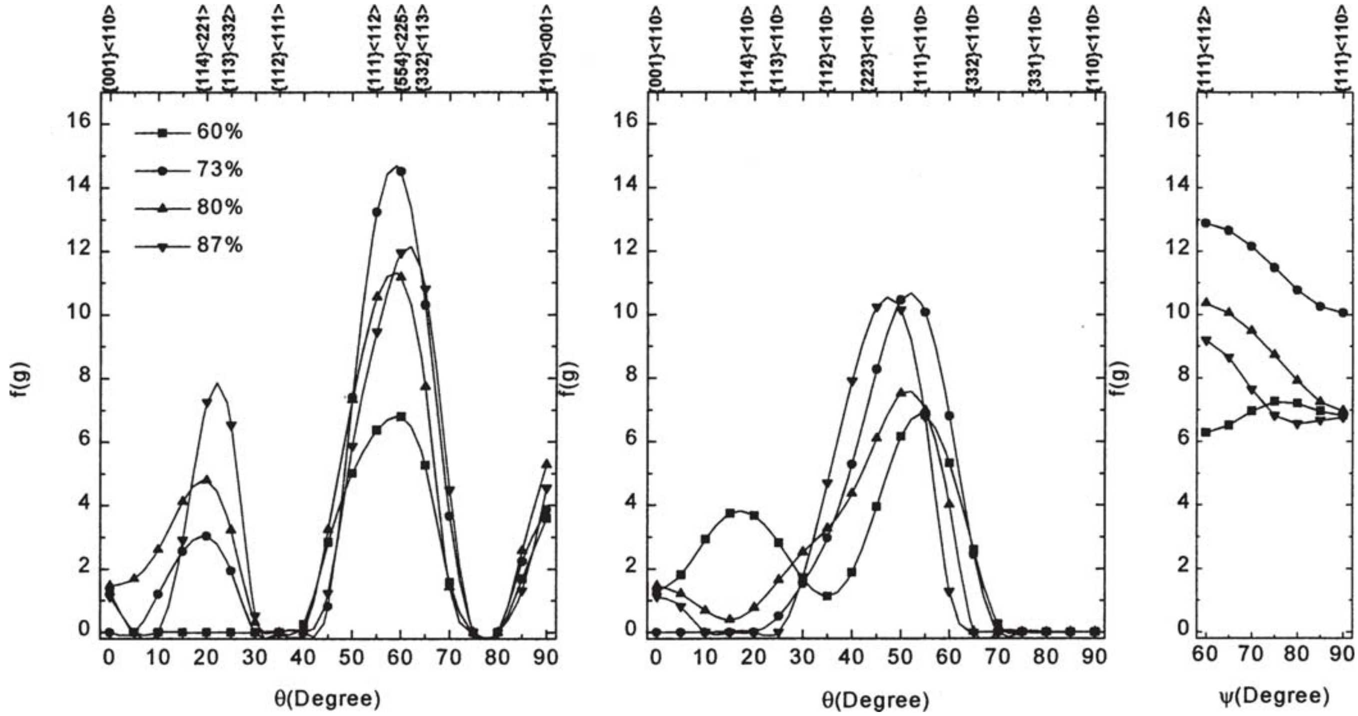

Fig 4 Effect of cold reduction on ε fiber, α fiber, and γ fiber of cold strip and CAPL-2

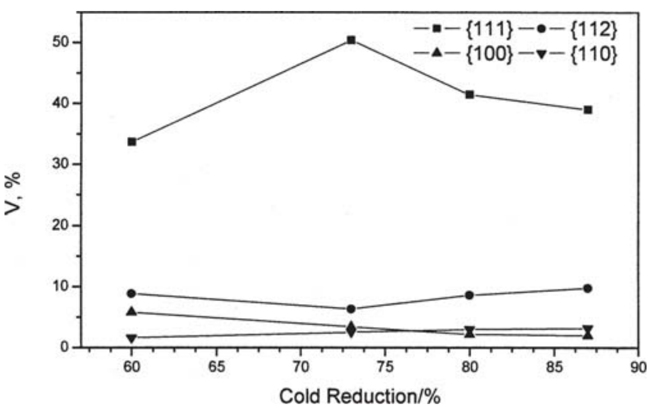

Fig 5 Volume fraction of orientated grains of specimens in different cold rolling conditions and CAPL-2

for IF steel hot rolled in the ferrite region with lubrication. In a traditional process, it is hard to satisfy the requirement of cold rolling reductions due to the constraints of pickling set to the thickness of hot bands and constraints of rolling force, which limits the thickness specifications of IF steel (Ref 4). Nevertheless, hot rolling in the ferrite region reduces the requirement of the thickness of hot bands, and thick cold rolled slabs can be produced. Furthermore, it helps to decrease the cold rolling load and improve productivity.

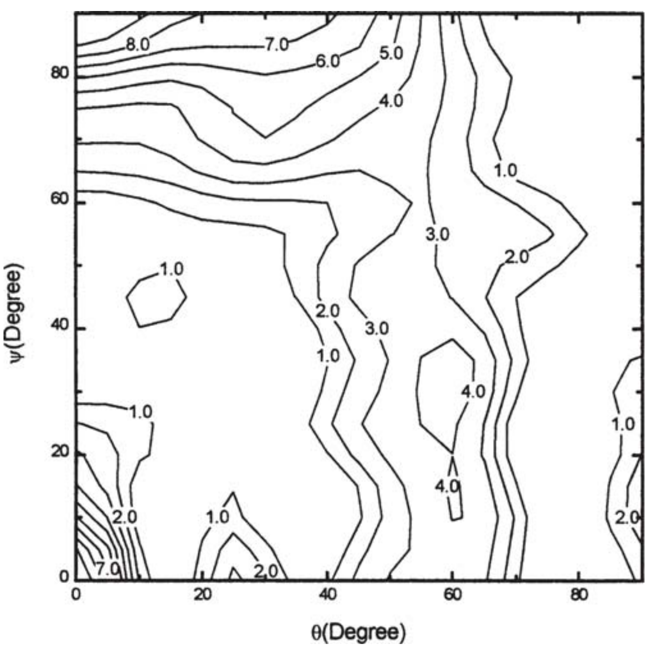

Fig 6 $\Phi = 45°$ sections of ODF of hot band in Ti-IF steel lubricated rolled in ferrite region

5. Conclusions

- Under continuous annealing conditions, the highest *r*-value was obtained at a cold reduction of 73% when the hot band was previously hot rolled in the unrecrystallized ferrite region. However, for the hot band rolled in the austenite region, 90% cold reduction was required to achieve the same *r*-value, and deep drawability improved with increasing annealing temperature.
- Strong <111>//ND components were formed in hot bands rolled in the ferrite region with lubrication, and the maximum was obtained at 73% cold reduction and subsequent annealing. Strong {100}<110 > components were developed along ε-fiber, textures rotated towards {223}<110 > in α-fiber and <111>//ND components became weaker

with further reduction, which is detrimental to deep drawability.

Acknowledgment

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