Microtexture Evolutions in 304L and 316L Stainless Steels during Rolling at 200°C and Annealing

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Abstract. The deformation and annealed microtextures were studied in 304L and 316L stainless steels subjected to plate rolling at temperature of 200°C followed by annealing at 700°C for 30–480 min. The evolution of the microstructure and microtexture during rolling at 200°C is associated with the development of deformation twinning and micro-shear banding. Note that martensitic transformation took place in 304L steel during rolling, resulting in martensite fraction about 0.25 after 95% rolling reduction, whereas it hardly developed in 316L steel. The rolled austenite microtexture consisted of mainly Brass, Goss and S components, while the strain-induced martensite exhibited a strong $\{112\}\langle 110\rangle$ texture component along with maximums of intensity along γ-fiber. The subsequent annealing was accompanied by the austenite reversal and grain growth during continuous recrystallization, which developed faster in 304L. The textural changes were qualitatively the same in the both steels and depended on the annealing time.

INTRODUCTION

The great attention was paid to the structure-property relationship in stainless steels subjected to rolling at low temperatures followed by annealing [1–5]. On the other hand, such an important property as regularities of texture evolution in meta-stable austenitic stainless steels during the thermo-mechanical treatment, which is accompanied by direct and inverse phase transformations, has not been studied in sufficient detail. The cold deformation textures and martensite fraction in stainless steels are affected by stacking fault energy (SFE), but SFE itself depends on the temperature of deformation [6]. The cold rolled texture in stainless steels has been studied in detail in many studies [6–8], in contrast to the texture evolutions during deformation at temperatures just above room temperature. The annealing texture after austenite reversal is affected by martensite-austenite orientation relationship, whereas continuous recrystallization in ultrafine grained austenite leads to a gradual weakening of the cold rolled textures [3], although the influence of austenite stability on the annealing texture has not been clarified. The aim of the present study, therefore, is to report our current results about the texture evolutions in widely used stainless steels with different austenite stability during rolling at 200°C and annealing.

EXPERIMENTAL

304L and 316L austenitic stainless steels with the chemical compositions shown in Table 1 were investigated. The ingots of studied steels were forged at 1100°C to blanks with thickness of 30 mm and width of 30 mm. The obtained blanks were plate rolled at 200°C to rolling reductions of 65, 85 and 95% that corresponds to final thicknesses of 11, 4 and 1.5 mm, respectively. The samples rolled with 95% rolling reduction were annealed at 700°C for 30, 60, 120 and 480 min in a muffle furnace, Nabertherm LT5, with subsequent water quenching. The microstructural and textural studies after rolling and annealing were carried out on a scanning electron microscope, Nova Nanosem 450, using electron backscatter diffraction (EBSD) method.

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TABLE 1. Chemical compositions of the steels

Element, wt %	Cr	Ni	Mn	Mo	Si	P	S	C	Fe
304L	18.2	8.8	1.7	0.5	0.4	0.05	0.04	0.05	Bal.
316L	17.3	10.7	1.7	2	0.4	0.04	0.05	0.04	Bal.

Orientation distribution functions (ODFs) were received using software of TSL OIM Analysis 6.2. A volume fraction of the texture components was calculated assuming a spread of 15° from the respective ideal orientation.

RESULTS AND DISCUSSION

Typical microstructures developed in studied stainless steels after rolling at temperature of 200°C with 95% thickness reduction and annealing for 30–480 min at 700°C are shown in Fig. 1. The structural changes during rolling at 200°C have been considered in detail in previous study [9] and can be briefly summarized here as follows. The rolling at 200°C is accompanied by a strain-induced martensitic transformation in studied steels, which depends on the austenite stability. The strain-induced martensite comprises about 3% in 316L steel and 25% in 304L steel after rolling to total reduction of 95%. The deformation twinning readily develops at small to moderate strains and, then, tends to exhaust at large strains. The microshear bands develop at moderate strains and persist at large strains. Therefore, the final rolled structure consists of wavy flattened grains/subgrains alternating with nanosized grains. The average transverse grain size was about 150 nm in both steels after rolling at 200°C with 95% reduction.

The annealing behavior is characterized by the full austenite reversal followed by sluggish grain growth much similar to continuous post-dynamic recrystallization of severely strained metals and alloys. Therefore, the fine grained microstructures with an average grain size of about 1.5 and 0.9 μm evolve in 304L and 316L steels, respectively, even after annealing for 480 min.

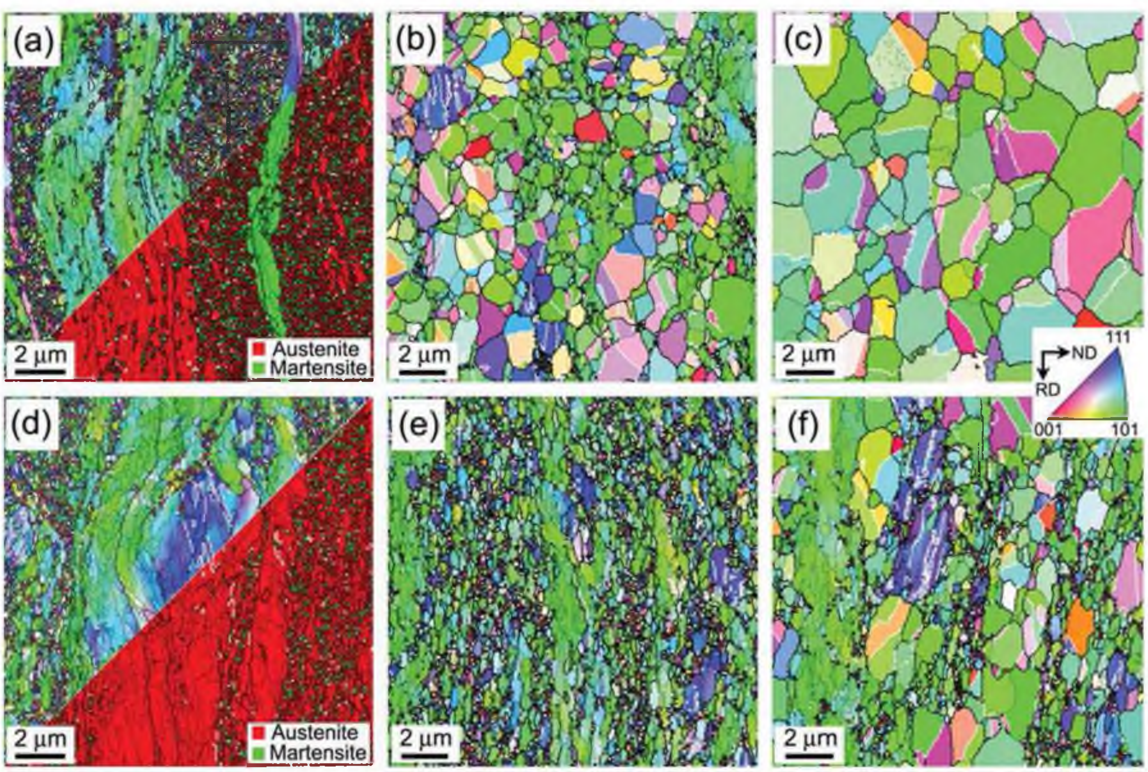

FIGURE 1. Deformation microstructures evolved in 304L (a–c) and 316L (d–f) steels by rolling at 200°C to total reduction of 95% (a, d) and annealing for 30 (b, e) or 480 min (c, f) at 700°C. Images represent the orientation map for normal direction (ND). Lower parts of the images in a and d represent the phase map. High-angle boundaries are indicated by thick black lines, low-angle boundaries—by thin black lines, twin boundaries—by white lines.

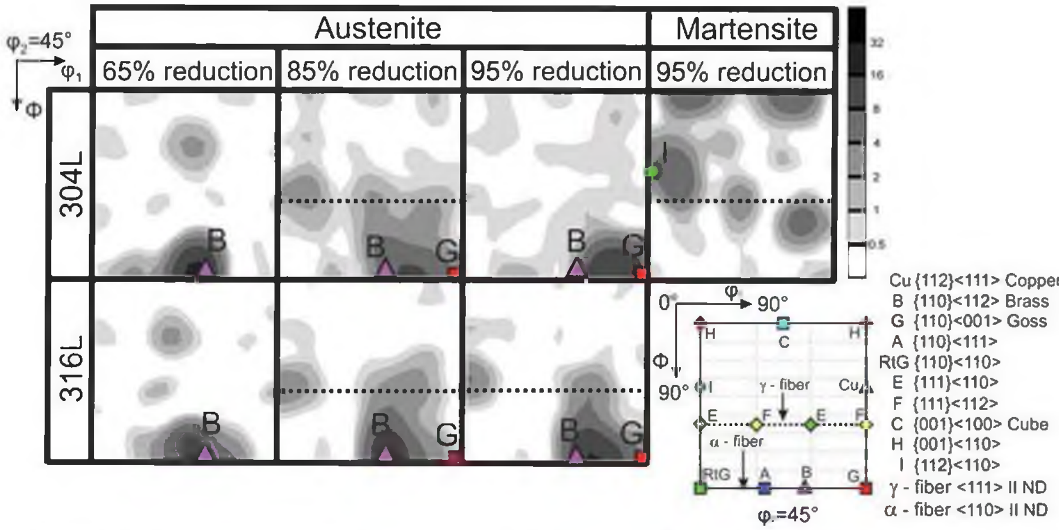

FIGURE 2. The sections of ODF at $\varphi_2 = 45°$ for studied stainless steels rolled at 200°C to total reductions of 65 to 95% and position of the main texture components in Euler space.

The strain-induced martensite completely transforms to austenite at 700°C. Comparing to 316L steel, 304L steel is characterized by faster continuous recrystallization and grain growth. The rather large recrystallized grains with a size above 1 μm appear in 304L steel after annealing for 30 min, whereas in 316L steel those evolve only after annealing for 480 min.

The rolled and annealing microtextures are shown in Figs. 2–4 as representative sections of ODF and fractions of main texture components. The strong Brass component develops in austenite of both steels during rolling at 200°C. The Brass component is typical of rolled (fcc) materials susceptible to deformation twinning [6–8]. The Brass component develops at small to moderate reductions faster in 304L steels than that in 316L steel (Fig. 2), that may be associated with lower SFE in 304L steel as compared to 316L one. The development of martensite in 304L at large reductions leads to a decrease in the number of grains with orientation of Brass component and its intensity drops. The intensity of Brass component gradually increases with increasing reduction in 316L steel, since the martensitic transformation hardly develops. In addition, an increase in reduction leads to a slight shift in the maximum of intensity from Brass component to Goss component in both steels. Besides the strong Brass and Goss components, the rolled austenite is characterized by remarkable S component (Fig. 3), which is typical for rolled texture of austenitic steels with low to medium SFE [8]. The γ-fiber with strong E and F components develops in austenite at moderate and large reductions, this fiber results from ultrafine crystallites evolved in micro-shear bands [8]. The martensite in 304L steel exhibits a strong {112}⟨110⟩ texture component, as well as the maximums of intensity along γ-fiber. Similar textures in cold rolled bcc metals have been commonly attributed to the operative slip systems, i.e., {110}⟨111⟩ [10].

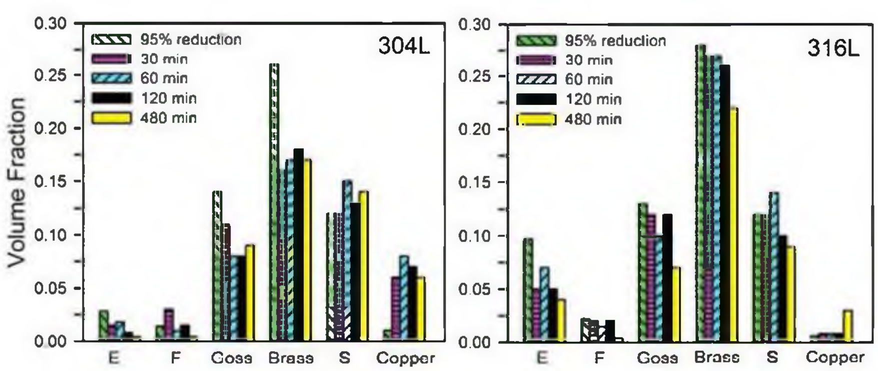

FIGURE 3. Fractions of texture components in studied stainless steels after rolling at 200°C with 95% thickness reduction and annealing for 30–480 min at 700°C.

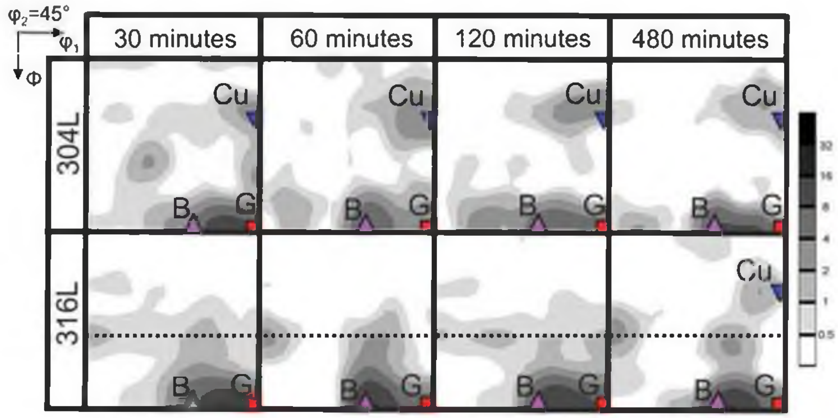

FIGURE 4. The sections of ODF at $\varphi_2 = 45°$ for studied stainless steels rolled at 200°C and annealed at 700°C.

The evolution of rolled microtexture during annealing at 700°C is characterized by gradual randomization of strong Brass and Goss components along the α-fiber and the formation of noticeable Copper component (Fig. 4). The rolled textures in 304L rapidly change during annealing for 30 min followed by texture invariant annealing. In contrast, the rolled textures in 316L steel significantly change only during annealing for 480 min that is due to higher stability to grain growth during recrystallization. The fraction of Brass component rapidly decreases in the 304L steel samples at early annealing for 30 min, whereas that in 316L steel remarkably decreases after long annealing for 480 min (Fig. 3). The fraction of other texture components slightly increases (Copper component) or insignificantly changes (Goss and S components) during annealing in both steels. The fraction of Copper component faster increases in 304L steel with an increase in the annealing time than in 316L steel (Fig. 3). Therefore, that the rolled texture developed in 316L steel is more stable during annealing than that in 304L steel.

CONCLUSION

The rolled and annealed microtextures were studied in 304L and 316L stainless steels. The microtexture evolutions in 304L and 316L steels during rolling at 200°C are characterized by the development of α-fiber ($\langle 110 \rangle \parallel$ ND) with strong Brass and Goss components. The formation of such textures is associated with the development of deformation twinning and micro-shear banding during rolling at 200°C. The 304L steel was characterized by faster kinetics of the microtexture evolution during rolling at 200°C than the 316L steel. The α-fiber is retained during annealing at 700°C for 480 min in both steels due to the absence of discontinuous recrystallization. The rolled microtexture in 316L steel was more stable during annealing than that in 304L steel.

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