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Correlation between Primary and Secondary Recrystallization Texture Components in Low-temperature Reheated Grain-oriented Silicon Steel

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Abstract: Low-temperature slab-reheated grain-oriented silicon steel is characterized by a sharp {411}<148> primary recrystallization texture. To date, the influence of this texture on secondary recrystallization is not clear. Microtextures in primary and secondary recrystallized sheets of low-temperature reheated grain-oriented silicon steel were examined using electron backscatter diffraction. By comparing the textures and microstructures of specific primary recrystallized grains neighboring secondary grains with those of other primary grains, the influences of primary recrystallization textures and microstructures on the orientations of secondary grains were investigated. Results show that for low-temperature reheated grain-oriented silicon steel, the primary recrystallization sheet comprises {411}<148>, {111}<112>, and {001}<120> texture components. During secondary recrystallization, the {111}<112> primary recrystallized grains were easily consumed by abnormally grown Goss, deviated Goss, Brass, or {210}<001> grains; the {411}<148> primary recrystallized grains were more resistant to being swallowed; and the {001}<120> grains were the most resistant to being consumed. For a particular primary grain, the distribution of its surrounding grain boundaries determined how easily it is consumed during secondary recrystallization. Primary grains surrounded by 20°—45° grain boundaries were consumed much earlier than those having grain boundaries above 45°, which is in accordance with high-energy grain boundary theory. In addition, special Σ9 boundaries between {411}<148> and Goss grains move more slowly than Σ9 boundaries between {111}<112> and Goss grains, which is attributed to the different positions of <110> rotation axis with respect to the normals of grain boundaries.

Key words: grain-oriented silicon steel; secondary recrystallization; texture; low-temperature slab reheating

The most advanced low-temperature slab-reheating technology of grain-oriented silicon steel is characterized by low energy cost and high cold rolling reduction[1]. As is well known, the key requirement for obtaining superior magnetic properties and a sharp Goss texture is related to the secondary recrystallization behavior, which is significantly affected by the primary recrystallization texture[2-4]. In contrast to the strong {111}<112> primary recrystallization texture in Hi-B steel[5,6], major primary recrystallization texture components in low-temperature reheated silicon steel are strong {411}<148> and weak {111}<112>[7]. To date, most researchers believe that the {111}<112> texture is beneficial for the abnormal growth of Goss grains owing to its special grain boundaries, i. e. , Σ9 (39°<110>) or high-energy boundaries (20°—45°) with high migration rates. In materials exhibiting pinning by secondary-phase particles[8-10], these special boundaries will unpin first. Therefore, secondary recrystallization is induced by special grain boundaries between {111}<112> and Goss grains. In contrast, the effects of {411}<148> grains on secondary recrystallization behavior are not clear, especially in low-temperature reheated grain-oriented silicon steel.

Yoshitomi et al. [11] reported that both {411}<148> and {111}<112> grains have Σ9 misorientation relationships with {110}<001> grains. Both types of primary grains promote the abnormal growth of Goss grains; thus, sharp Goss textures can be obtained during secondary recrystallization. Kumano et al. [12] found that the {411}<148> primary recrystal-

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lization texture increased the frequency of Σ9 boundaries relative to Goss grains. Therefore, the final magnetic permeability was improved by strengthening the {411}<148> texture. Both studies focused on the Σ9 misorientation between {411}<148> grains and Goss grains but ignored the spatial distribution and evolution of Goss grains during deformation and recrystallization. Therefore, it was assumed that although {411}<148> and {111}<112> grains could be swallowed by Goss grains, resulting in sharp Goss textures in the final products, it could not be concluded that the grain boundaries between the Goss grains and the grains with the other two types of orientations migrate with the same rate during secondary recrystallization. In other words, it is not clear whether the effect of {411}<148> primary grains on secondary recrystallization is the same as that of {111}<112> primary grains.

Additionally, deviated Goss ({110}<227>), Brass ({110}<112>), and {210}<001> grains could show abnormal grain growth and compete with Goss grains. To obtain a more comprehensive understanding of the effects of primary recrystallization textures on secondary recrystallization behavior, observation and analysis of the effects of {111}<112>, {411}<148>, and {001}<120> primary recrystallization grains on the abnormal grain growth (AGG) behavior of Goss, deviated Goss, Brass, and {210}<001> grains are necessary. Accordingly, such an investigation is essential for obtaining superior magnetic properties in grain-oriented silicon steel.

1 Experimental

The initial material consisted of hot-rolled bands of 2.3 mm thick low-temperature slab-reheated grain-oriented silicon steel (C 0.052, Si 3.12, Mn 0.091, P 0.011, S 0.0072, Al_s 0.028, N 0.0086, Sn 0.052, Cu 0.02, Cr 0.02 and Fe balance, mass%). After being subjected to normalization at 950 ℃ for 2 min, the specimens were cold rolled to 0.23 mm with a reduction of 90% by a one-stage cold-rolling method. Afterwards, decarburization annealing at 850 ℃ for 3 min, 6 min, and 9 min respectively in a wet hydrogen atmosphere was carried out to obtain a primary recrystallized microstructure. All of the specimens were then nitrided at 750 ℃ in a NH_3-H_2-N_2 atmosphere to acquire about 2×10^{-4} mass% of nitride content. The secondary recrystallization annealing was carried out in a N_2-H_2 atmosphere with a heating rate of 15 ℃/h. In order to analyze the process of AGG, secondary recrystallization annealing was interrupted, and some specimens were extracted at 1050 ℃.

The primary recrystallization specimens were observed from the ND-RD (normal direction-rolling direction) section using a ZEISS Ultra 55 scanning electron microscope equipped with a Channel 5 electron backscatter diffraction (EBSD) system. The interrupted-annealing specimens were polished to the central layer. At least four large area views were measured by EBSD for each secondary recrystallized grain. The orientation distribution functions (ODFs) were calculated by summing Gaussian spreads method.

2 Results and Discussion

2.1 Primary recrystallization microstructure and texture

Fig. 1 shows the orientation image maps and ODFs of primary recrystallized specimens after annealing for 3 min, 6 min, and 9 min, respectively. The typical primary recrystallization texture components are {111}<112>, {411}<148>, and {100}<021>. With increasing annealing time, the intensity of the {411}<148> texture component continuously increased with the growth of the recrystallized grains. Fig. 2 shows the average diameters and area fractions of grains with different orientations. The average diameter of the {411}<148> grains is always larger than that of the {111}<112> grains. The {411}<148> grains are larger due to their higher growth rate during recrystallization. Although the area fraction of {111}<112> grains is higher than that of {411}<148> grains, it decreases as the area fraction of {411}<148> grains increases during grain growth. This phenomenon suggests that the strong {411}<148> texture results from the stronger ability of {411}<148> grains to grow normally, despite their nucleation ability being lower than that of {111}<112> grains during primary recrystallization.

Homma et al.[13] reported that {411}<148> grains nucleated at grain boundaries piled with irregular strain after heavy deformation in BCC steel. Such grains will grow quickly, relying on the fast migration of the large misorientation angles between {411}<148> nuclei and a strong α-fiber deformation matrix. Other researchers have stated that strong {411}<148> texture forms from deformation bands or shear bands of rotated cube grains[14]. In this study, the {411}<148> grains nucleated at an α-fiber deformation matrix. The final strong {411}<148> texture component resulted from the higher growing rate of {411}<148> grains. The higher