

EVOLUTION OF GOSS ORIENTATION DURING RAPID HEATING FOR PRIMARY RECRYSTALLIZATION IN GRAIN-ORIENTED ELECTRICAL STEEL

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Introduction

Magnetic properties are important for the grain-oriented electrical steel used as the core material of transformers. Studies have been carried out to reduce the core loss and increase the magnetic flux density and permeability by controlling the microstructure and texture via the addition of alloying elements as well as through process control and heat treatment[1-2]. To improve the properties of grain-oriented electrical steel, currently technically feasible $\{110\} \langle 001 \rangle$ Goss orientation is have a decided advantage. Thus, it is essential for grain-oriented electrical steel to have a Goss orientation with a fairly high degree of integration. Generally, this is achieved using advanced texture-control technology involving the addition of alloying elements as well as processing and heat treatment. This study aims to contribute to the manufacture of grain-oriented electrical steels with an ideal Goss texture by examining changes in the Goss orientation and microstructure during the development of the texture in processes from the rapid heating for primary recrystallization. We used EBSD (Electron Backscatter Diffraction) to investigate the size and distribution of Goss-oriented grains.

Experimental

The material used in this investigation was Fe-3.1%Si grain-oriented electrical steel with the chemical composition 0.002% C, 0.1% Mn, and 0.025% P. The start sheet was cold rolled to 0.3 mm in thickness. To study the effect of the heating rate on the primary recrystallization behavior, cold-rolled samples were heated at a rapid rate of 150°C/s (normal heating rate is 20°C/s). Samples were extracted at different holding times and estimated fractions of recrystallization. Orientation distribution function (ODF) was calculated with $\{110\}$, $\{200\}$, $\{211\}$ pole figures measured by X-ray diffraction using Co K α radiation. To measure the recrystalli-

zation phenomenon the EBSD scans were performed in FE-SEM (Hitachi S-4300SE) with EBSD. Microstructural data were evaluated using the OIM (Orientation Image Mapping) software package. The step sizes were 0.5 μm , 0.05 μm depending on magnification. Different colors used for different crystal orientations.

Results and discussion

Figure 1 indicates the texture of the layers of the cold-rolled sheet. Strong α -fiber texture and weak γ -fiber texture are developed in every layer. The maximum orientation density becomes stronger closer to the surface, and the $\{111\} \langle 110 \rangle$ component is more strongly developed than the $\{111\} \langle 112 \rangle$ component in the γ -fiber texture.

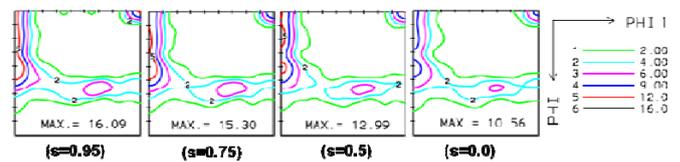


Figure 1: Texture across thickness ($\phi_2 = 45^\circ$ section) of cold-rolled grain-oriented electrical steel.

Figure 2 shows an OIM of the cold-rolled sheet obtained by EBSD with a step size of 0.05 μm . The wide grains mostly have α -fiber orientation, and the narrow and elongated grains mostly have γ -fiber orientation. The Goss-oriented grains, which will be able to operate as a seed for the secondary recrystallization, are mostly formed as small grains in strongly deformed micro or shear bands. The fraction of Goss-oriented grains is 0.7% at the $s=0.95\sim 0.75$ layer, 0.6% at the $s=0.75\sim 0.5$ layer, 0.2% at the $s=0.5\sim 0.25$ layer, and 1.2% at the $s=0.25\sim 0.0$ layer ($s=0.95$ is surface layer, $s=0.5$ is 1/4 layer, and $s=0.0$ is middle layer).

Figure 3 show the X-ray texture of the sample with 97% recrystallization. The α -fiber is almost disappeared and the $\{111\} \langle 112 \rangle$ component in γ -fiber has

strong developed. This indicates that the recrystallization was almost completed.

Distribution, size and fraction of Goss component after primary recrystallization were analyzed by the OIM. Figure 4 show microstructure evolution extracted at different fraction of recrystallization. Orientation mapping obtained by EBSD with a step size of $0.5 \mu\text{m}$. At 97% recrystallization the wide, narrow and elongated grains were still remained. The recrystallization rate was slow because of the low strain of those grains.

Figure 5 show average grain size and fraction of Goss oriented grain extracted at different volume fraction of recrystallization. The size of the Goss-oriented grains was about $1.06 \mu\text{m}$ at the beginning of the recrystallization, finally it reached about $2.56 \mu\text{m}$. The fraction of Goss oriented grain is increased from 0.33% to 2.5% with the volume fraction of recrystallization. And more Goss oriented grains are developed in the inside of the sheet.

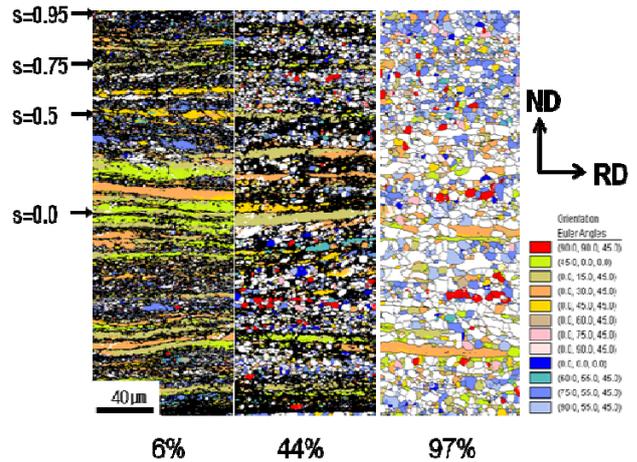


Figure 4: Evolution of microstructure during heating extracted at different fraction of recrystallization. Orientation mapping obtained by EBSD with a step size of $0.5 \mu\text{m}$.

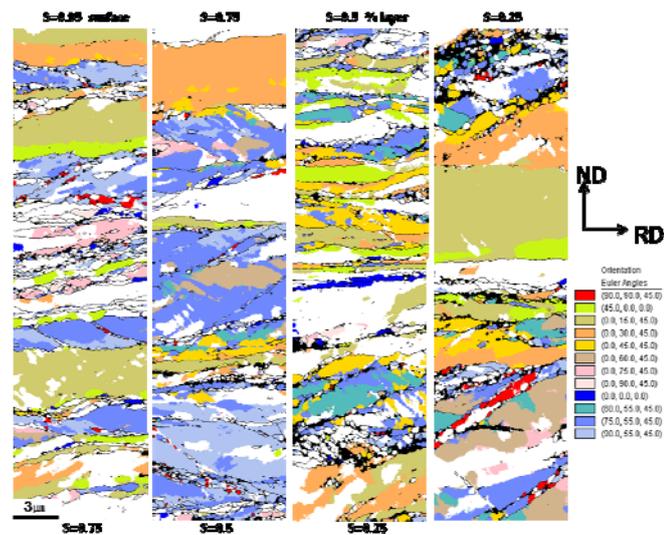


Figure 2: Orientation mapping of cold rolled sheet obtained by EBSD with a step size of $0.05 \mu\text{m}$ at near surface ($s=0.95\sim 0.5$) and middle layer ($s=0.5\sim 0.0$), ND-RD section. Colors indicate orientations as in legend.

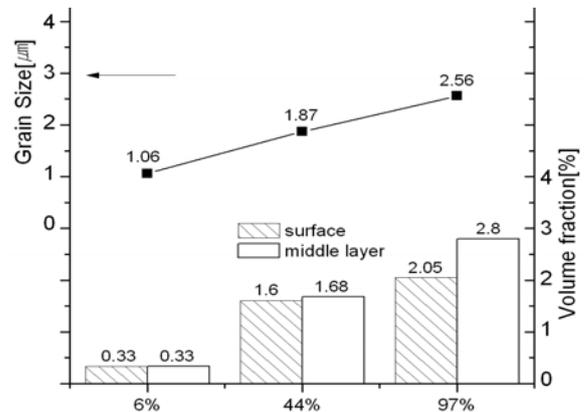


Figure 5: Average grain size and fraction of Goss oriented grain for the rapid heated sheet extracted at different volume fraction of recrystallization.

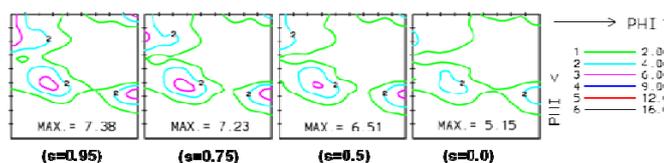


Figure 3: Texture across thickness of the rapid heated sheets extracted at 97% recrystallization.

Conclusion

1. In the cold-rolled sheet, relatively strong α -fiber and weak γ -fiber textures were developed in all layers. The Goss-oriented grains were mostly developed in the strongly deformed micro or shear bands.
2. The fraction of Goss oriented grain is increased with the volume fraction of recrystallization. And more Goss oriented grains are developed in the inside of the sheet.

References

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2. M. Matsuo, T. Sakai, M. Tanino, T. Shindo, and S. Hayami, Proc. 6th Int. Conf. on Textures of Materials, Ed. by Nagashima ISIJ, Tokyo, 11, 918