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Domain structure of chemically thinned non-oriented electrical sheet

M. Takezawa[a], J. Yamasaki[a], T. Honda[a], and C. Kaido[b]

[a] Kyushu Institute of Technology, 1-1 Sensui-cho, Tobata-ku, Kitakyushu, Fukuoka 804-8550, JAPAN
[b] Nippon Steel Corporation, 1-1 Tobihata-cho, Tobata-ku, Kitakyushu, Fukuoka 804-8501, JAPAN

Abstract

The anomaly factor tends to increase steeply when the thickness of non-oriented Si-Fe electrical steel sheets is decreased. To investigate the behavior of the anomaly factor in relation to the sheet thickness, magnetic domain observation was performed, using the Kerr effect. Grains of a thinned sheet exhibit a stripe domain pattern. The grains exhibiting the stripe domains on the surface had closure domain structure in a cross section of the sheet. It was found that a field applied in the sheet plane induced changes of the magnetization component normal to the surface, which may increase the anomaly factor of thin sheets.

Keywords: non-oriented Si-Fe electrical sheets, domain structure, anomaly factor

Contact author

Masaaki Takezawa, Kyushu Institute of Technology, 1-1 Sensui-cho, Tobata-ku, Kitakyushu, Fukuoka 804-8550, JAPAN, Tel: +81-93-884-3236, Fax: +81-93-884-0879, E-mail: take@ele.kyutech.ac.jp

Recently, effort has been made to decrease the iron loss of non-oriented Si-Fe electrical sheets by decreasing the sheet thickness[1-3]. It was reported that the anomaly factor, which is the ratio of the measured eddy current loss to the classical calculated value, tends to increase steeply when the thickness goes down to 0.2 mm[4]. To investigate the peculiar behavior of the anomaly factor, we viewed the change of the domain structure by reduction of the sheet thickness using a Kerr microscope.

The non-oriented 3% Si-Fe sheet (50A290) provided by Nippon Steel Co. has a dimension of 50 mm long, and 3 mm wide rectangle. The specimen was mechanical-polished and annealed in a vacuum of 1 x 10^{-3} Pa at 800ºC for 1 hour to avoid the additional introduction of mechanical stress. Chemical etching was used for thinning the sheet from 0.5 mm to 0.06 mm from the other side than that used for the observation, as shown in Fig. 1. Magnetic domain structure for the two thicknesses was observed at the same position of the sheet. We also measured the crystallization orientation of the sheet by using EBSP (electron back-scattering pattern) to clarify the relation between the domain structure and the crystallization orientation.

Fig. 2 shows domain structure of the 0.5 mm and 0.06 mm thick sheet at a remanence state after applying field of 8 kA/m along the rolling direction. In this figure, the direction of the magneto optical sensitivity is along the rolling direction. Bright and dark areas show the downward and upward directions of magnetization, respectively. It was observed that most grains of as-received 0.5 mm thick sheet exhibit complicated domain pattern, as shown in Fig. 2(a). It was found that part of the complicated domain pattern changed to the simple stripe domain drastically when the sheet thickness decreased to 0.06 mm, as shown in Fig. 2(b).

Fig. 3 and Fig. 4 show domain structure of the grains having (100) and (110) plane with β-angle less than 20 degree. Complicated stripe domain pattern was observed at the grain having (100) plane at the thickness of 0.5 mm. It was observed that the grain having (110) plane exhibits very complicated domain pattern at the thickness of 0.5 mm. On the other hand, we can see simple stripe domain configuration at the thickness of 0.06 mm being comparable to the grain size of the sheet. Such a stripe domain configuration was observed for the grains that exhibit (001) and (011).

Fig. 5 shows domain structure in a cross-section for the grain having (110) plane at the thickness of 0.06 mm. Stripe domain pattern parallel to the normal direction was observed. Furthermore, we can see the closure domain at the grain boundary inside the sample. The domain walls of the stripe domain at the surface in the thin sheet are perpendicular to the magnetization in the domains, which clearly shows that these must be closure domains. The stripe domain observed at the surface is a part of closure domain structure created by the magnetization component normal to the surface. The magnetization component normal to the surface changes when an in-plane field is applied to such a sheet. When the magnetization component inclines from the normal direction slightly, the in-plane field causes the wall displacement inside the sheet. This would generate the large eddy current loss. Hence the peculiar behavior of the anomaly factor of the thin sheet seems to originate from the magnetization component normal to the surface. It is necessary to observe the magnetization process of the sheet, which will be discussed in future work.

Fig. 6 shows the simple stripe domain pattern which crosses three grains at the thickness of 0.06 mm. [001] axes and β-angle of each grain are shown in Fig. 7. We see from these figures that the grain having (100) plane is next to the grain having (110) plane at the point. In this case, the same domain pattern appears on two kinds of plane.

It is certain that the neighbor grains affect domain structure of the thin sheet. The magneto static influence from the peripheral grains becomes small by reduction of sheet thickness. Moreover, only influence from the side grains remains because the thin sheet has only one grain in the cross-section, as shown in Fig. 8. We can conjecture that the simple domain structure of the thin sheet may be attributed to the small interaction between grains.

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Figure captions

Fig. 1 Specimen for domain observation.

Fig. 2 Domain pattern of Si-Fe sheet.

Fig. 3 Domain pattern of a grain having (100) plane.

Fig. 4. Domain pattern of a grain having (110) plane

Fig. 5 Domain structure of a cross-section.

Fig. 6. Domain pattern of Si-Fe sheet

Fig. 7 [001] orientation of each grain

Fig. 8 Magneto static interaction between grains.

Figure 1

First author’s name : M. Takezawa

Reference number : B-13

Reduction factor : 0.85

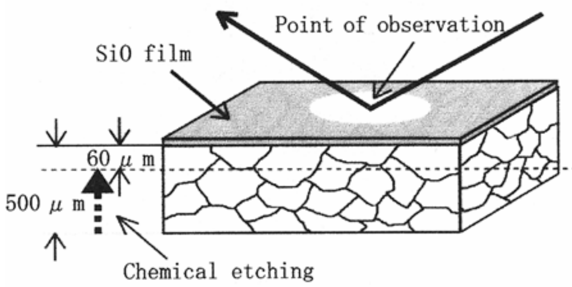


Figure 2

First author’s name : M. Takezawa

Reference number : B-13

Reduction factor : 0.85

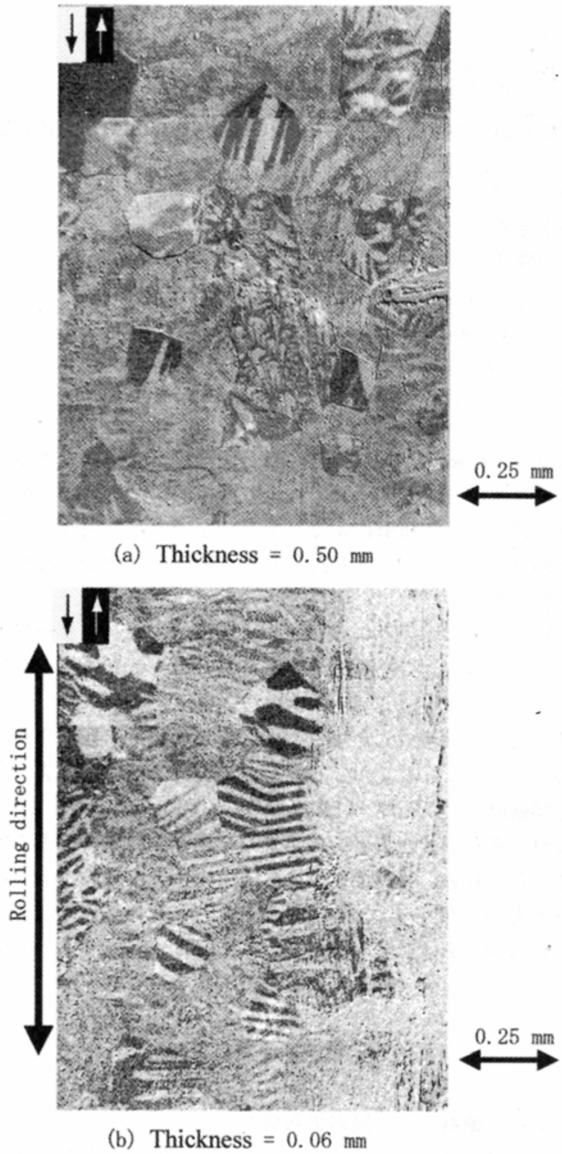
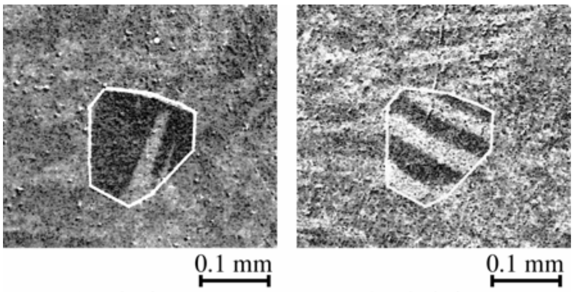


Figure 3

First author’s name : M. Takezawa

Reference number : B-13

Reduction factor : 0.85



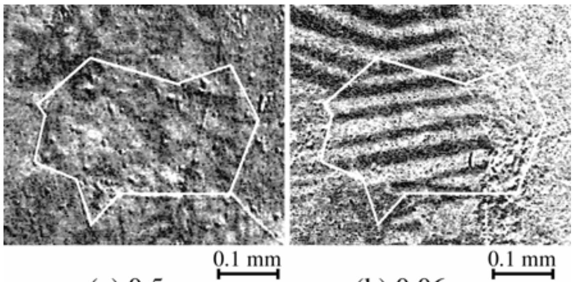
(a) 0.5 mm (b) 0.06 mm

Figure 4

First author’s name : M. Takezawa

Reference number : B-13

Reduction factor : 0.85



(a) 0.5 mm (b) 0.06 mm

Figure 5

First author’s name : M. Takezawa

Reference number : B-13

Reduction factor : 0.85

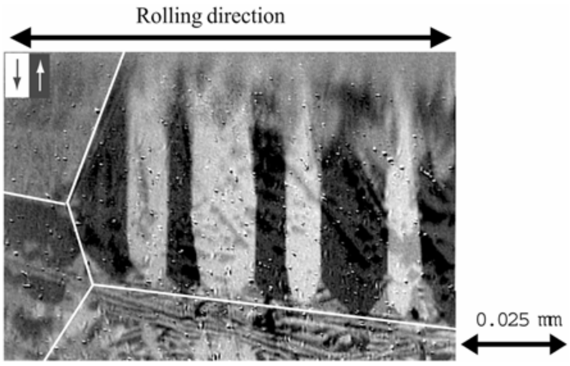


Figure 6

First author’s name : M. Takezawa

Reference number : B-13

Reduction factor : 0.85

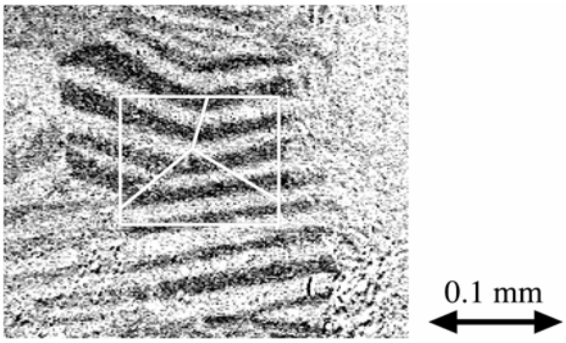


Figure 7

First author’s name : M. Takezawa

Reference number : B-13

Reduction factor : 1.0

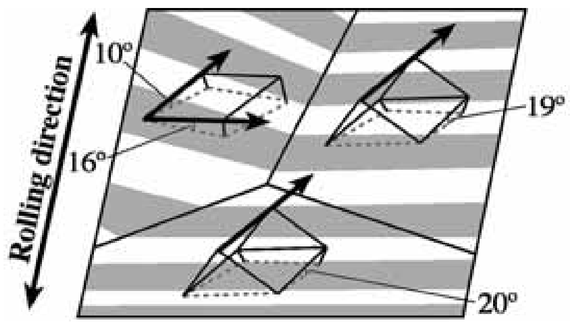


Figure 8

First author’s name : M. Takezawa

Reference number : B-13

Reduction factor : 0.85