Production of ultra thin grain oriented silicon steel sheets

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Production of Ultra Thin Grain Oriented Silicon Steel Sheets

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***Abstract*- Grain texture and magnetic properties of ultra thin silicon steel sheets were investigated. The sheets were produced using two kinds of starting materials. One was conventional grain oriented silicon steel sheet and the other was hot rolled silicon steel. Ultra thin sheets were obtained by cold rolling with intermediate annealing. By annealing in a high vacuum a recrystallization using surface energy occurred and very sharp (110)[001] texture was obtained in sheets of 5-8 μm thick. The B_8 of the ultra thin silicon steel sheets obtained were over 1.95 T.**

I. INTRODUCTION

Thickness of grain oriented silicon steel sheet has great relationship with its iron loss. By reducing the thickness, the eddy current loss decreases and the hysteresis loss increases. Therefore, the iron loss as the sum of the eddy current loss and the hysteresis loss has the minimum value at a certain thickness. We already reported the iron loss of very thin grain oriented silicon steel sheets is minimum at a thickness of 40 μm at a frequency of 50 Hz [1]. However, for the silicon steel sheet used at higher frequencies, the optimum thickness becomes smaller because the eddy current loss becomes dominant at higher frequencies.

One hopeful method for obtaining ultra thin (less than 10 μm) grain oriented silicon steel sheet is to use surface energy. By using surface energy, selective grain growth can occur and a sharp (110) texture obtained [2]. The purpose of this paper is to investigate the grain texture and magnetic properties of ultra thin silicon steel sheets after recrystallization using the surface energy and to produce the ultra thin grain oriented silicon steel sheets.

II. EXPERIMENTAL PROCEDURE

Ultra thin (less than 10 μm) rolled sheets were produced by two types of processes. The first type was as follows: Conventional grain oriented silicon steel sheets of 300 μm thickness were cold rolled to the thickness of 5 μm. During this process the sheet was intermediate annealed at 1100 °C for 1 h in a vacuum at the thickness of 20 μm. The second type was as follows: Hot rolled sheets of 2 mm thickness were cold rolled to the thickness of less than 80 μm. The intermediate annealing condition of this process was at 1250 °C for 10 h in a vacuum at the thickness of 300 μm.

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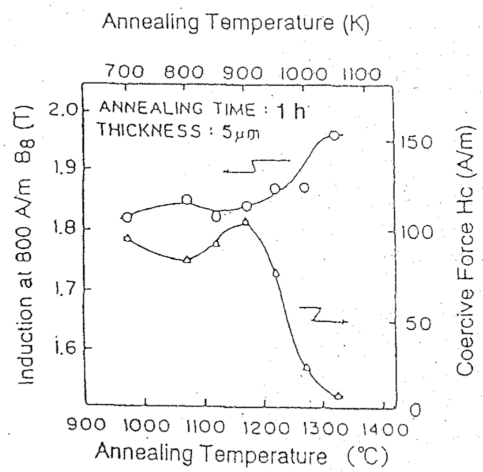

Fig. 1. Dependence of magnetic properties on annealing temperature

Thin rolled sheets obtained by two types of processes were cut into pieces of 100 mm long, 5-7 mm wide and annealed using an infrared image furnace for 1 h at various temperatures in a vacuum of 1×10^{-3} Pa.

The recrystallized texture was observed by means of X-ray diffraction and etch-pit. The static coercive force and the magnetic induction were measured by a dc B-H loop tracer.

III. RESULTS AND DISCUSSION

A. Ultra Thin Silicon Steel Sheets Produced from Conventional Grain Oriented Silicon Steels

In this section, we tried to produce ultra thin silicon steel sheets from conventional grain oriented silicon steel sheets of the thickness of 300 μm. Thin (80 μm - 20 μm) grain oriented silicon steel sheets can be obtained by cold rolling and

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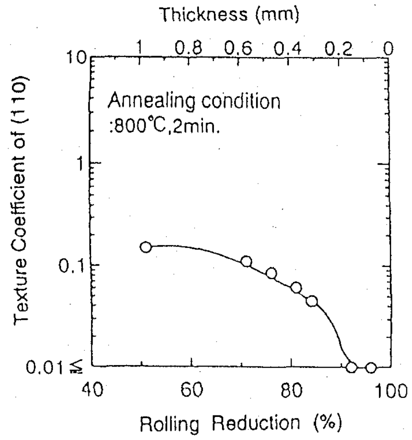

Fig. 2. Dependence of texture coefficient on thickness

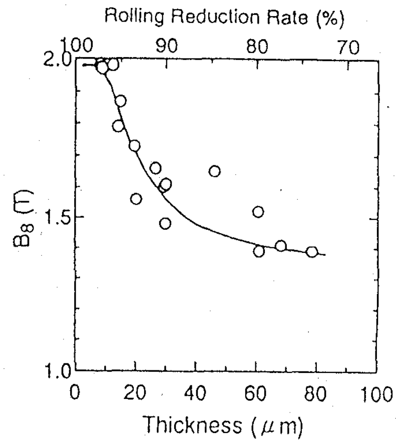

Fig. 3. Dependence of B_8 on thickness

annealing the conventional grain oriented silicon steel sheet using the recrystallization by the surface energy [2],[3]. However, a cold rolling from the thickness of 300 μm into under 20 μm is technically very difficult because of the work hardening. Therefore, we tried to produce 5 μm thick silicon steel sheets with intermediate annealing.

Figure 1 shows the annealing temperature dependence of the magnetic induction and the coercive force of the sheet with 5 μm thickness. After the annealing at 1050 °C for 1 h, we obtained the sheet with (110)[001] texture and excellent soft magnetic properties such as the magnetic induction at 800 A/m (B_8) of 1.96 T and coercive force (Hc) of 6.6 A/m. From this result, it was clear that 5 μm thick grain oriented silicon steel sheets with excellent magnetic properties can be obtained.

B. Ultra Thin Silicon Steel Sheets Produced from Hot Rolled Silicon Steels

Ultra thin silicon steel sheet with (110)[001] texture were formed by the method described above. However, the method needs grain oriented silicon steel sheets as starting material. Therefore we tried to produce the ultra thin grain oriented silicon steel sheets from hot rolled silicon steels of 2.0mm thick.

It is known that there is strong (110)[001] texture near a surface of hot rolled silicon steels. Therefore there is large possibility of realization of the ultra thin grain oriented silicon steel sheets using this texture. However, the (110) texture in the hot rolled sheet is decreased by a high reduction of cold rolling [4]. Therefore, the intermediate annealing is required at an optimum thickness.

The recrystallization texture and the magnetic properties of intermediately annealed sheets were observed. We observed the primary texture because the seed of the final (110)[001] grain is primary (110)[001] grains. By observing the primary (110) texture, we can estimate the possibility of grain growth of (110)[001] in the ultra thin Si–Fe sheets. Figure 2 shows the thickness dependence of a texture coefficient [5] of (110) calculated by the intensity observed by X–ray diffraction. We choose 800 °C for 2 min as the optimum annealing condition to form the primary recrystallization. From this figure, it is clear that the intensity from (110) decreased with decreasing sheet thickness. At the thickness of 100 μm, the (110) texture almost disappears. Therefore, to form the (110) texture of ultra thin silicon steels, the intermediate annealing is required over 300 μm.

The intermediate annealed sheets were cold rolled and annealed. Figure 3 shows the thickness dependence of B_8. The B_8 increased with increased reduction rate. At the thickness of 8 μm, the B_8 increased to an extremely high value of 1.95 T. The grain growth of (110) grains were completed in all sheets shown in Figure 3. The reason of the increasing tendency of the B_8 with increasing reduction rate was a difference of [001] orientation. Figure 4 shows angles between [001] axis and rolling direction (α angle) in the samples with various thickness. With increasing the thickness, the [001] orientation became worse. From this result, it was clear that the better orientation of (110)[001] was obtained in higher reduction rate.

IV. Conclusions

Ultra thin silicon steels (less than 10 μm) were produced by two types of processes. The results are summarized as follows:

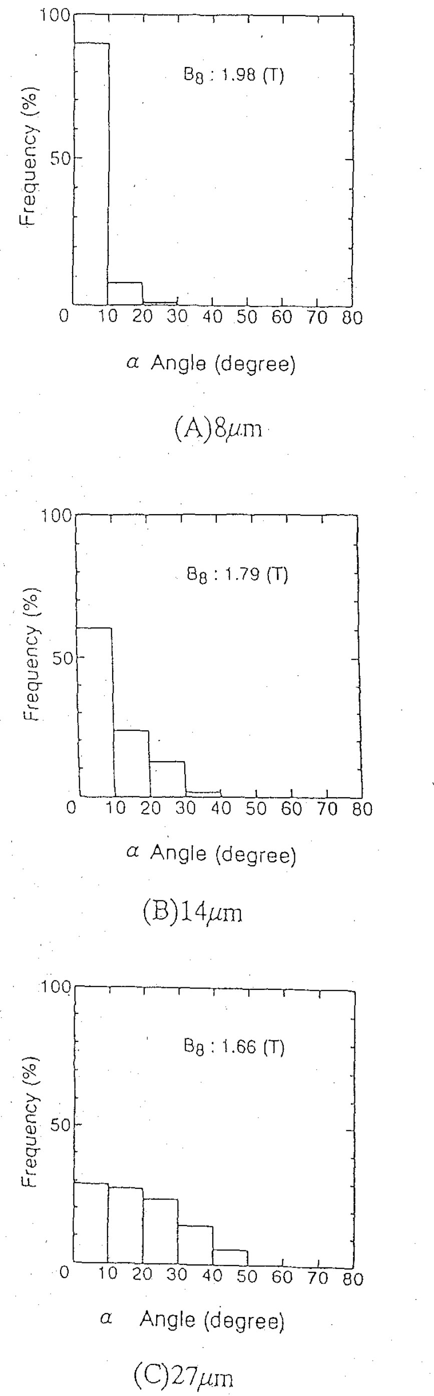

Fig. 4. Grain orientation of samples produced by various rolling reduction rate

(1) 5 μm thick silicon steels with B_8 over 1.95 T can be produced from conventional grain oriented silicon steels.

(2) In the process of producing ultra thin silicon steel sheets from hot rolled steels, B_8 increased with increasing reduction rate of the cold rolling. At the thickness of 8 μm, the B_8 increased to an extremely high value of 1.95 T.

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