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STUDY ON PRODUCTION OF CONVENTIONAL GRAIN ORIENTED (CGO) SILICON STEEL WITHOUT NORMALIZING PROCESS

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The production of conventional grain oriented silicon steel without normalizing was studied by two-stage cold rolling process, and the orientation evolution was analyzed by optical microscopy (OM) and electron backscatter diffraction (EBSD) technique. The results indicate that, the key of CGO silicon steel hot rolled sheet canceling normalizing process is to obtain as many {111}<112> and Goss oriented grains as possible, meanwhile, it is to increase the nitrogen pressure appropriately during the temperature-rise stage of secondary recrystallization. By controlling the process parameters, the iron loss $P_{1,7}$ of the finished product is 1,258 W/kg, and the magnetic induction B_8 is 1,840 T. Furthermore, the cubic orientation can be retained more in CGO silicon steel after annealing due to the less influence of columnar grain.

Key words: CGO silicon steel; sheet; normalizing; annealing; microstructure

INTRODUCTION

Grain oriented silicon steel is an important soft magnetic alloy material used as transformer core, which is called “art product” in special steel. At present, it is one of the development trends of oriented silicon steel to develop low cost processes such as reducing heating temperature, canceling normalizing process or adopting thin slab continuous casting and rolling etc. It is reported that AlN particle which has the strong pinning force precipitate mainly during normalizing process, and thus the precipitation of AlN particle must be affected due to canceling normalizing, which will lead to the reduction of pinning force during the subsequent high temperature annealing process[1-4]. Consequently, two-stage cold rolling method with relatively higher intermediate annealing temperature was adopted in this work in order to increase the particle precipitation.

EXPERIMENTAL MATERIALS AND METHODS

2,4 / mm thickness CGO silicon steel hot rolled sheet was selected as the experimental material with main components of 0,058 % C, 3,31 % Si, 0,085 % Mn, 0,017 % Als and 0,04 % Sn. After the hot rolled sheet was cold rolled to 1,44 and 0,72 / mm respectively, intermediate annealing process was carried out at 1 120 / °C for 5 / min, and then the materials were second cold rolled to 0,22 and 0,29 / mm in thickness respectively. Subsequently, the materials were treated with decarburizing annealing at 850 / °C for 4 or 6 / min. Finally, high temperature annealing was carried out at 600 / °C for 1/ h, followed by the heating rate at 50 / °C/h to rise up to 1 000 / °C under the protective atmosphere (N_2/H_2 = 1:3, 1:1, 9: 1), then raised the temperature up to 1 200 / °C with the heating rate at 15 / °C/h and kept the materials at 1200 / °C for 8 / h under the protective atmosphere (pure H_2). The magnetic properties of the samples was measured by NIM-2000E magnetic properties tester. The microstructure and the orientation distribution of the samples were observed by using OM and EBSD technique respectively.

MAGNETIC PROPERTIES OF THE SAMPLES

Table 1 shows the magnetic properties of samples with different process parameters. It is indicated that the process of first small cold rolled reduction and second cold rolled reduction is beneficial to improve the magnetic properties of the samples. Meanwhile, the influence of nitrogen partial pressure during high temperature annealing is also obvious. The magnetic properties of the sample are the best under the 1:1 N_2/H_2. It is suggested that the increase of nitrogen content can properly supplement the number of inhibitors in the samples and promote the completion of secondary recrystallization. However, excessive nitrogen can cause a decrease in magnetic properties because the nitrogen cannot be removed sufficiently during high temperature annealing. Figure 1shows the macrostructure and scatter pole figures of the finished products. It can be seen that, there are still many small size grains although some grains have grown significantly and the orientation of grown

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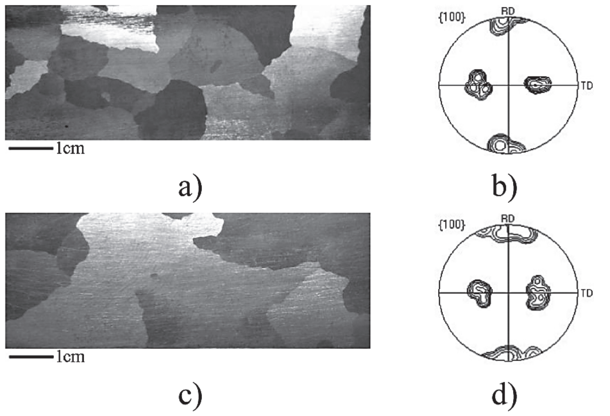

Figure 1 Macrostructure (a), (c) and scatter pole figures (b), (d) of the finished products (a), (b) sample B1; (c), (d) sample B2

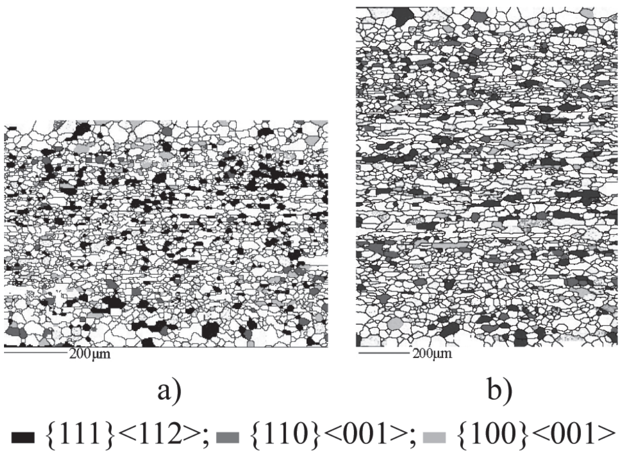

Figure 2 EBSD orientation maps of intermediate annealed sheet
(a) First cold rolled 70 / % reduction sample;
(b) First cold rolled 40 / % reduction sample

Goss oriented grains has some deviation, which indicate that Goss oriented grains have not grown fully. The results illustrate that the decrease of particle pinning force caused by insufficient inhibitors is the main reason affecting the magnetic properties of samples.

Table 1 **Magnetic property of samples with different process parameters**

Sample	$P_{1,7}$ / W/kg	B_8 / T	cold rolled reduction	N_2:H_2
B1	1,336	1,818	40 % + 85 %	1:3
B2	1,258	1,840		1:1
B3	1,577	1,779		9:1
B4	1,433	1,788	70 % + 60 %	1:3
B5	1,372	1,789		1:1
B6	1,477	1,796		9:1

INTERMEDIATE PROCESS ANALYSIS

Figure 2 shows the EBSD orientation maps of the intermediate annealed sheet on lateral face. In order to increase the number of inhibitor, a high intermediate annealing temperature was adopted in this work. All of the two types samples show the recrystallized microstructure, but the grain size is uneven, recovered elongated grains appear in the center region of the sample and the recrystallized grain size of the surface region is large. It is difficult to obtain the uniform fine primary recrystallized grain due to the increase of grain size caused by high temperature after subsequent process, and thus it is not conducive to the abnormal growth of Goss oriented grains during secondary recrystallization. The recrystallization during intermediate annealing will be affected in that the energy storage in the grains of the sample is relatively low after being 40 % reduction cold rolled, and much recovered grains can be seen in the center region of the samples. In addition, the proportion of {111}<112> oriented grains in 70 / % reduction cold rolled sample is 10,9 / % higher than 8,6 / % of the 40 / % reduction cold rolled sample, while the proportion of Goss oriented grains is 2,88 / % lower than 4,23 / % of the latter.

Figure 3 shows the EBSD orientation maps of the decarburizing annealed sheet on lateral face. The grains of 85 / % reduction cold rolled sample are finer and more uniform than that of 60 / % reduction cold rolled sample. The high reduction cold rolled sample can be obtained more {111}<112> oriented grains (the proportion is 28,1 / %), while the proportion is only 16,5 / % in 60 % reduction cold rolled sample. Obviously, sharp {111}<112> texture can be more likely formed under the cold rolling process system of first small reduction and second high reduction. However, the intensity of Goss texture is reduced correspondingly, accounting for only 0,56 / %. Moreover, very few Brass oriented ({110}<112>) grains are obtained in the two types of samples (the proportion is less than 0,1 / %), which is indicated that the competition of Brass texture with Goss texture in the secondary recrystallization can be ignored. Due to the strong pinning force of AlN, it does not require too many primary recrystallized Goss oriented grain nucleus in HiB silicon steel after decarburizing annealing but only the accuracy of the orientation is required. However, the opposite is true for CGO silicon steel without normalizing process in that the precipitation of AlN must be affected, and thus it will require more Goss oriented grains after decarburizing annealing to make them grow abnormally during secondary recrystallization. As a result, in the case of the pinning force being reduced, the suitable cold rolling process system is that, firstly, it can be obtained as many {111}<112> oriented grains as possible after decarburizing annealing; secondly, it can be obtained as many primary recrystallized Goss oriented grains as possible of which the orientation is accurate.

HEREDITY OF COLUMNAR GRAIN IN ANNEALED SHEET

The reason for the cubic orientation being formed in the intermediate annealed sheet is different between equiaxed and columnar grains sample. The size of deformed grains is relatively uniform and fine in the equi-

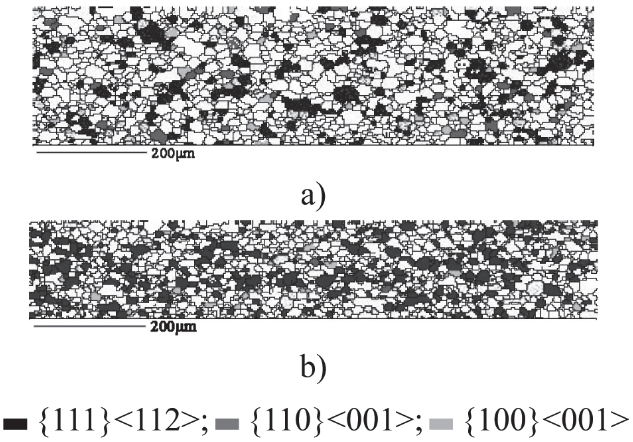

Figure 3 EBSD orientation maps of decarburizing annealed sheet
(a) Second cold rolled 60 / % reduction sample;
(b) Second cold rolled 85 / % reduction sample

axed grain sample, meanwhile, there is no influence of coarse deformed {100}~{111}<110> oriented grains in the columnar grain sample after hot rolling. Therefore, the large-angle grain boundary of the deformed grains in equiaxed polycrystalline sample can migrate successfully, and then recrystallization will occur so that the cubic orientation can be retained during annealing. However, the cubic orientation is retained near the grain boundaries due to its heredity in columnar grain samples, and it cannot take place recrystallization during annealing due to the interference of neighboring coarse deformed grains. In addition, it is reported that the Goss oriented grains in the surface region of hot rolled sheet will rotate to {111}<112> around transverse direction of <110> after cold rolling, but it will change to a rotation around rolling direction of <001> to cubic orientation if the rotation is obstructed [5]. Therefore, the cubic oriented grains often appear in the surface region of the annealed sheet as shown in Figure 2. In conclusion, it can be obtained more cubic oriented grains in CGO silicon steel after annealing in that there is no restriction of the columnar grain boundary and influence of coarse {100}<011> oriented grain.

CONCLUSIONS

The control points of CGO silicon steel hot rolled sheet without normalizing are as follows: one is to obtain as many {111}<112> oriented grains and primary recrystallized Goss oriented grains as possible, and the other is to increase the nitrogen pressure appropriately during the temperature-rise stage of secondary recrystallization.

After canceling the normalizing process, by changing the cold rolling and high temperature annealing process parameters, the optimum magnetic properties of the finished product are as follows: the iron loss $P_{1,7}$ is 1,258 / W/kg, and the magnetic induction B_8 is 1,840 / T.

The cubic orientation can be retained more in CGO silicon steel after annealing due to the less influence of columnar grain.

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