H. Y. WANG, Y. Y. SHAO, Z. W. JIA, Q. GUO

ISSN 0543-5846
METABK 63(3-4) 357-359 (2024)
UDC – UDK 669.15.782:541.452-669.71:538.11.22=111

EFFECT OF ACID-SOLUBLE ALUMINUM CONTENT ON PRECIPITATES AND MAGNETIC PROPERTIES OF GRAIN ORIENTED SILICON STEEL

Received – Primljeno: 2023-12-18
Accepted – Prihvaćeno: 2024-02-25
Original Scientific Paper – Izvorni znanstveni rad

The effect of acid-soluble aluminum content on precipitates and magnetic properties of grain oriented silicon steel was researched by optical microscopy and zeiss ultra 55 Scanning Electron Microscope (SEM) technique respectively. The results show that the number of precipitates increases with the increase of acid-soluble aluminum content, and the size of precipitates is relatively large after hot rolling. Under the low hot rolling temperature, the number of precipitates in the samples is large and the size is small, moreover, the grain size of the primary recrystallized grain is small. The matching of process parameters under different production process lines is the key to obtain good magnetic performance. The effect of nitriding on magnetic properties of the samples is related to the acid-soluble aluminum content of the samples. Too much acid-soluble aluminum can deteriorate the magnetic properties.

Key words: grain oriented silicon steel; acid-soluble aluminum; precipitates; magnetic properties

INTRODUCTION

Grain oriented silicon steel which is known as cold rolled transformer steel is prepared by the principle of secondary recrystallization[1]. The purpose of preparing oriented silicon steel is to obtain sharp {110}<001> texture during secondary recrystallization. The secondary recrystallization process of grain oriented silicon steel inhibit the normal growth of primary recrystallized grains through the pinning of the second phase particles, so that the {110}<001> oriented grains can swallow other grains and grow abnormally, obtaining excellent magnetic properties[2-4]. It is reported that AlN particle which has the strong pinning force precipitate mainly during normalizing process[5,6]. Therefore, it is very significant to clarify the relationship between the precipitates and the magnetic properties during the preparation of grain oriented silicon steel. The effect of hot rolling process parameters on microstructures and textures of the grain oriented silicon steel was studied in previous studies [7,8], and the effect of acid-soluble aluminum on precipitates and magnetic properties will be researched in this paper.

EXPERIMENTAL MATERIALS AND METHODS

Grain oriented silicon steel was selected as the experimental material with different acid-soluble aluminum content, and of which the main components are 0,053 % C, 3,18 % Si, 0,11 % Mn and 0,05 % Sn. The samples designated as A1, A2, A3 and A4 were prepared by hot rolling, normalizing, cold rolling, decarburization annealing, nitriding treatment (with different amount of ntriding) and high temperature annealing. The main process parameters and the magnetic properties of the finished products were exhibited in Table 1. The lateral section of the hot rolled and normalized sheets were polished. Then the microstructure was observed by using optical microscopy technique. The characteristics and distribution of precipitates during hot rolling and normalizing were observed by using ZEISS ULTRA 55 Scanning Electron Microscope (SEM) technique.

Table 1 **Main process parameters, nitriding process and magnetic properties of the samples**

Sample	A1	A2	A3	A4
Als content / %	0,04	0,027	0,03	0,025
Hot rolling temperature / °C	1 150		1 200	
Normalizing temperature / °C	two stage 1 100+920		two stage 1 120+900	
Nitriding temperature / °C	800~850		850~900	
Nitrogen content during nitriding / 10^{-6}	230	260	190	180
Magnetic induction, B_8 / T	1,577	1,876	1,795	1,792

RESULTS AND ANALYSIS

Figure 1 shows the precipitates of the hot rolled sheets with different acid-soluble aluminum content. There are less precipitates can be seen in the samples on

H. Y. Wang, Y. Y. Shao: College of Applied Technology, University of Science and Technology Liaoning, Anshan, Liaoning, China
Z. W. Jia: Iron and Steel Research Institutes , Ansteel Co. Ltd., Anshan, Liaoning, China
Q. Guo: Cold Rolling Silicon Plant, Ansteel Co. Ltd., Anshan, Liaoning, China
Corresponding author: Y. Y. Shao (Email address: shaoyy1980@163.com)

the whole. The number and size of precipitates in samples with high aluminum composition are larger. In contrast, the number of precipitates in samples at low hot rolling temperature is large and the size precipitates is relatively small. The main reason is that the solid solution temperature of AlN is higher than the heating temperature of the continuous casting billet, and there are coarse AlN particles in the hot rolled sheet that cannot be solidly dissolved completely. The number of AlN particles in the continuous cast billet increases with the increase of hot rolling temperature, and the peak temperature of AlN precipitation is lower than the finishing temperature, resulting in more redissolved AlN particles not being able to precipitate at 1 200°C.

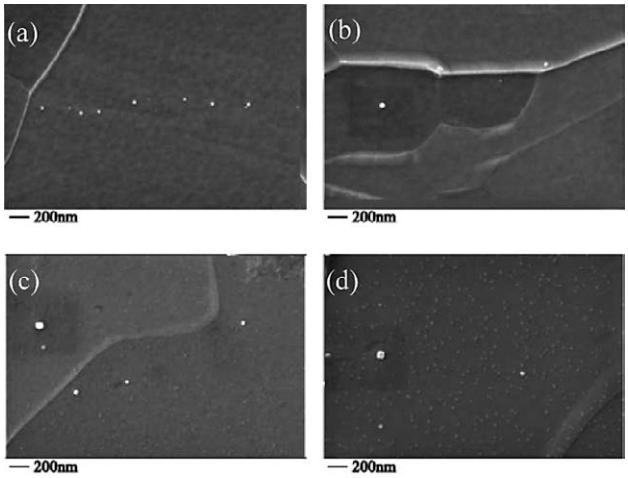

Figure 1 Precipitates of hot rolled sheets. (a) A1-sample; (b) A2-sample; (c) A3-sample; (d) A4-sample

Figure 2 illustrates the precipitates of the normalized sheets with different acid-soluble aluminum content. It can be seen that the number of precipitates in the samples increases significantly compared with that in the hot rolled sheets after normalizing. The number of precipitates of A1-sample with high aluminum composition is higher than that of A2-sample with low aluminum composition, and the size difference of precipitates is not obvious. By comparison, there is little difference in the number and size of precipitates between A3-sample and A4-sample, and more large size precipitates can be found in A3-samples. The reason is that the solid solubility of the particles is high at 1 120 °C during the normalizing process, which makes the difference between the number of precipitates in the two samples little. Moreover, some large size precipitates solubilizes incompletely during hot rolling process, so a certain amount of large size precipitates can be seen in normalized sheets of A3-sample.

Figure 3 demonstrates the microstructures of decarburized strips. According to the statistical results, the average primary recrystallized grain size of the four samples is 19,06 μm, 20,34 μm, 15,48 μm and 15,58 μm respectively. It can be recognized that the acid-soluble aluminum content has little effect on grain size of primary recrystallized grain, while the hot rolling temperature exerts great influence. By comparison, the primary

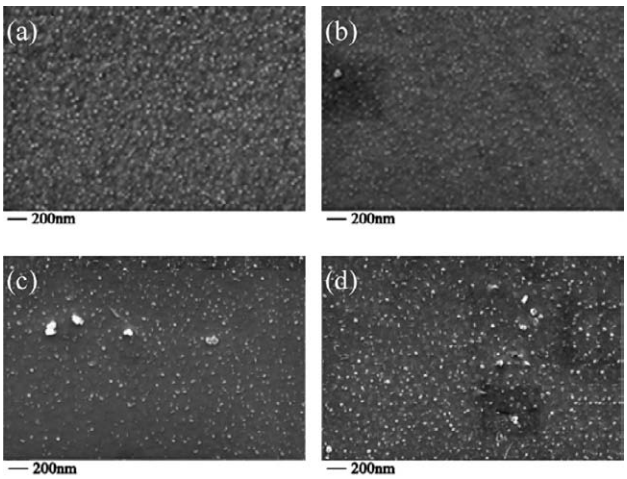

Figure 2 Precipitates of normalized sheets. (a) A1-sample; (b) A2-sample; (c) A3-sample; (d) A4-sample

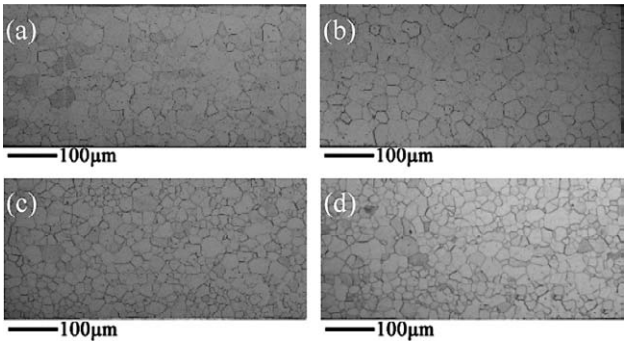

Figure 3 Microstructures of decarburized strips. (a) A1-sample; (b) A2-sample; (c) A3-sample; (d) A4-sample

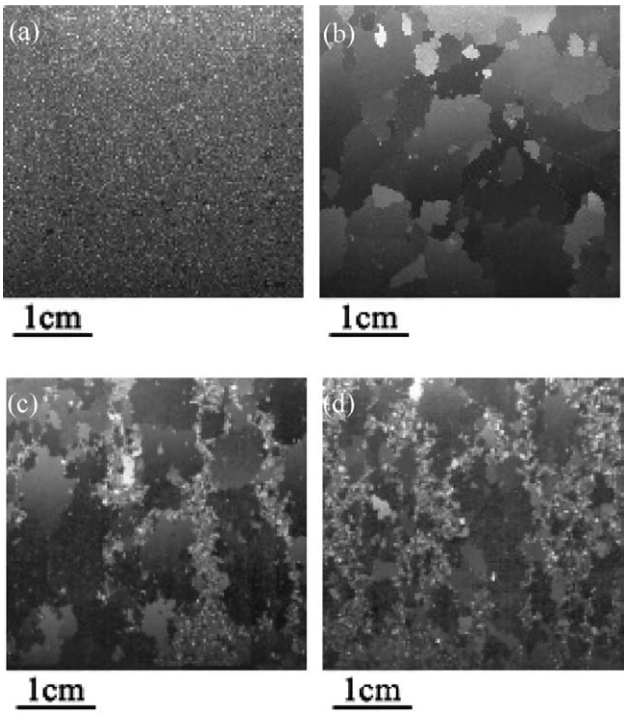

Figure 4 Macrostructures of finished products. (a) A1-sample; (b) A2-sample; (c) A3-sample; (d) A4-sample

recrystallized grain size of the samples with more acid-soluble aluminum content is smaller under the same production process.

Figure 4 indicates the macrostructures of finished products. Secondary recrystallized structures can be seen in A2-sample of which the magnetic property is the best, while a large number of fine grain structures can be seen in A1-sample. It can be recognized that the effect of nitriding on magnetic properties is related to the content of acid-soluble aluminum in the samples. Although the A1-sample contains the most acid-soluble aluminum, the magnetic properties of it is the worst. The reason is that too much acid-soluble aluminum leads to excessive inhibition.

CONCLUSIONS

The grain oriented silicon steel with different acid-soluble aluminum content are prepared under different process conditions, and the conclusions are as follows:

The number of precipitates increases with the increase of acid-soluble aluminum content, and the size of precipitates is relatively large after hot rolling.

Under the low hot rolling temperature, the number of precipitates in the samples is large and the size is small, moreover, the grain size of the primary recrystallized grain is small.

The matching of process parameters under different production process lines is the key to obtain good magnetic performance. The effect of nitriding on magnetic properties of the samples is related to the acid-soluble aluminum content of the samples. Too much acid-soluble aluminum can deteriorate the magnetic properties.

Acknowledgements

This work is financially supported by Liaoning province Department of Education fund item, No. LJKZ0305.

REFERENCES

[1] G. T. Liu, Z. Q. Liu, P. Yang, et al. Effect of primary recrystallized microstructure and nitriding on secondary recrystallization in grain oriented silicon steel by low temperature slab reheating [J]. Journal of Materials Engineering, 46(2018)1, 16-24.

[2] Y. Zhao, Z. He. Advances in research on the mechanism of secondary recrystallization in grain oriented silicon steels [J]. Journal of Iron and Steel Research, 3(1991)4, 79-90.

[3] K. Jenkins, M. Lindenmo. Precipitates in electrical steels [J]. Journal of Magnetism and Magnetic Materials, 320(2008), 2423-2429.

[4] F. L. Alcantara, R. Barbosa, M. A. Cunha. Study of aluminum nitride precipitation in Fe-3% Si steel [J]. Materials Research, 16(2013)5, 1039-1044.

[5] T. Sakai, M. Shiozaki, K. Takashina. A study on AlN in high permeability grain-oriented silicon steel [J]. Journal of Applied Physics, 50(1979)3, 2369-2371.

[6] Z. B. Meng, Y. Zhao, Z. Z. He. Precipitating morphology of inhibitor particles in high-induction grain-oriented Si steel [J]. Metallic Functional Materials, (1997)1, 34-37.

[7] C. J. Wang, Q. Guo, Y. Y. Shao. Effect of hot rolling temperature on microstructures and textures of grain oriented silicon steel [J]. Metalurgija, 60(2021)3-4, 216-218.

[8] Y. Y. Shao Z. W. Jia, Q. Guo. Effect of hot rolling reduction on microstructures and textures of grain oriented silicon steel [J]. Metalurgija, 61(2022)3-4, 697-699.

Note: The responsible translator for English is Yuan Yuan Shao, University of Science and Technology Liaoning, Anshan, China