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Evolution of Microstructure and Texture with the Low-Silicon in Non-Oriented Silicon Steel

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Abstract. Microstructure, texture, the second phase and magnetic were studied with different silicon content in non-oriented electrical steel. The results showed that: microstructure of the products in cold rolling non-oriented electrical was recrystallization of equiaxed ferrite. With the increase of silicon content, the grain size of the finished product increased; the iron loss and magnetic induction value reduced. Hot-rolled electrical steel coil without normalization treated after cold rolling deformation formed a strong {111} surface texture in finished products. After cold rolling and continuous annealing process, grain orientation is not big changes. The {100} and {Goss} texture enhancement and the {111} texture weakening in cold-rolled oriented electrical steel with low silicon, after the normalization process. In low silicon content, the square TiMnS and AlTiN as the second phase particles formed in the hot rolling austenitic area. Because without normalization process, the particles of polymer composition did not change; however, that finished product after the normalization process, the second phase exists in the form of AlN and MnS precipitates. The experimental results showed that Ti has a strong affinity with Mn, S, N and Al in high temperature; Polymer TiMnS and AlTiN can't change after the cold rolling and annealing process.

1. Introduction

Silicon element can improve the resistivity and reduce the eddy current loss and hysteresis loss of the electrical steel. The increase of silicon content makes the grain size of the cast grains bigger [1]. The addition of silicon can also make austenite area decreases. The national standard shows that the grade of cold rolled non oriented electrical steel is increased with the increase of silicon content. With cold rolled non oriented electrical steel production capacity increased, the researchers to improve the magnetic properties of silicon steel (i.e. lower iron loss and increase the magnetic sense) are more in-depth [2-10]. The research contents include: the microstructure, the macro texture, the second phase particles and the magnetic properties of the non-oriented electrical steel. The control of the microstructure of finished products, mainly in research on {100} the columnar crystal effects on the magnetic properties of electrical steel; impact of genetic characteristics and effects of the grain size changes of magnetic properties of electrical steel, and the study of plate structure on the magnetic properties of electrical steel. The control of macro texture mainly focused on reducing the proportion of {111} texture components, increasing the ratio of {100}, {110} and {Goss} texture components to improve the magnetic properties of the products. The research of the second phase particles' concentration in coarsening of second phase particles and to move into the domain together, and to eliminate the coarsening of blocks the recrystallization grain growth and improve the magnetic properties of the products [11-31].

In this paper, the structure, texture, second phase and magnetic properties of the finished product in the actual production of non-oriented electrical steel with different grades of low silicon cold rolled non oriented electrical steel were studied. Through the detection and analysis, the change of the microstructure and the inheritance of the characters of the micro structure; reason of macro texture formation and the aggregation and precipitation of the second phase particles and their effects on the magnetic properties would be found. Finally, it is hoped that the magnetic properties of the products can be improved by controlling the grain, texture and second phase particles.

2. Experimental materials and methods

The test steels were dived in A, B and C group and the chemical composition of the steel were shown in Table 1. A, B, C three groups of test steels due to the silicon content of different forms of non-oriented electrical steel three levels: 50W800,50W600 and 50W300. Steelmaking (top and bottom blowing)→ Rh treatment → continuous casting (EMS) into 240 mm thick plate → billet cooling → heating furnace (1150±20℃) were heat →7 pass hot continuous rolling (final rolling temperature in 760±20℃, 230 mm thick hot rolled coil)→normalization (B and C) → 5 stand tandem cold mill (0.5mm chill roll)→continuous annealing.

Table 1. Chemical composition of the steels tested (wt％)

No.	C	Si	Mn	P	S	ALs	Ti
A	0.0030	0.800	0.215	0.100	0.0040	0.33	0.0021
B	0.0025	1.570	0.219	0.012	0.0031	0.99	0.0023
C	0.0024	2.515	0.210	0.015	0.0037	0.66	0.0022

After annealing, test steel coils were sampled. In order to avoid the properties' difference between the head and tail of the process, the sampling site was selected in the middle of each group. Microstructure was observed by the optical microscope (OM); second phase particle observation by transmission electron microscopy (TEM). The X-ray texture tester measurement macro texture and draw the corresponding texture distribution map; Epstein's square method used in 1.5T, 50 Hz magnetic field measurement of iron loss P_{15} and under the conditions of 5000A/m measurement of magnetic induction B_{50}.

3. Experimental results and analysis

3.1. Observation and analysis of grain structure

Table 2 shows the process temperature and process speed of A, B and C groups. With the increase of silicon content, the annealing temperature got higher and annealing speed is slow down. The residence time of the strip in the furnace increases and with the recrystallization process more fully, grain grew larger. Because of the Si% >1.7%, there will be no austenite phase transformation in the electrical steel [1].

Table 2. Annealing processing temperature and annealing speed

No.	h, mm	Annealing temperature, ℃	Running speed, m/min
A	0.5	880	120
B	0.5	900	95
C	0.5	920	80

Group A and group B sample containing silicon were 0.800% and 1.570% &1.7%. Therefore, in the solidification process of the ingot and the heating process, group A and group B sample experienced the austenite transformation process. For the austenitic phase transformation, making hot organization more uniform. The content of silicon in C group was 2.515%>1.7%, which had not experienced the phase transformation process of austenite, and the columnar crystal was big in the slab. Because of the inheritance of the tissue, the heart grain size of the C group was still bigger than of group A and B. The coarse microstructure is difficult to deform, and the strain energy increases due to the increase of silicon content, and the deformation of group B and C are more difficult to be deformed. To reduce the deformation resistance, uniform internal structure, so that uniform organization after cold rolling, group B and group C needs to increase the normalization process, otherwise after cold rolling and annealing. The {100} columnar crystal grain broken incompletely will be formed serious feeling of corrugated shape defects on the surface of the steel plate [1].

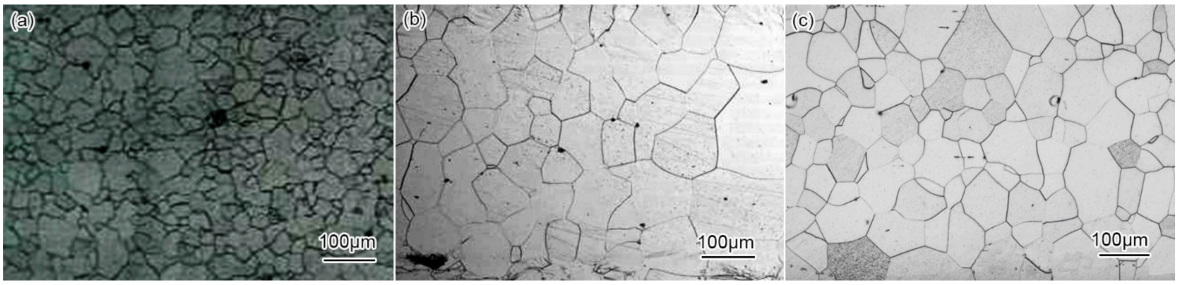

Fig 1. Optical microstructure of the specimen
(a) A-0.800%Si, (b) B-1.570%Si , (c) C-2.515%Si

Figure 1 shows that the microstructure of the cold rolled non oriented electrical steel. Group A sample grain size is 5 to 6, average grain diameter on the 49.85 μm; group B sample grain size is 4 to 5 level, average grain diameter for 74.73 μm; group C sample grain size is 4 to 5, the average grain diameter is 86.66 μm. From Fig. 1 we can see that, although the grain size is different, but the size of the finished product is uniform and the shape of the three groups is the ferrite. Whether it is the experience of the austenitic phase transformation process of the group, And group B samples and did not experience the austenitic phase transformation process of group C sample or whether it is through the normal process of group B and group C sample and without normalization process group A sample, The columnar crystal in the original structure becomes the ferrite structure after rolling and continuous annealing and experienced in the recrystallization and grain growth.

3.2. Macro texture observation and analysis

Figure 2 is an ODF texture sections at φ2=45°of cold rolled electrical steel after annealing. From the graph, we can see that the highest level of A group was 7, the highest level of B group was 10, and the highest level of C group was 12. The formation of high level texture in C group is higher because of the grain has much storage energy in the cold rolling process, and there are dense deformation zone, which is complex and intertwined with each other. In the subsequent higher temperature (higher than the A and B groups), the rolling textures quickly disappeared, and the recrystallization textures were formed in situ. The main reason for the formation of high level texture is the rapid release of the grain storage and the rapid speed recrystallization (high temperature of annealing temperature, and the acceleration of recrystallization.).

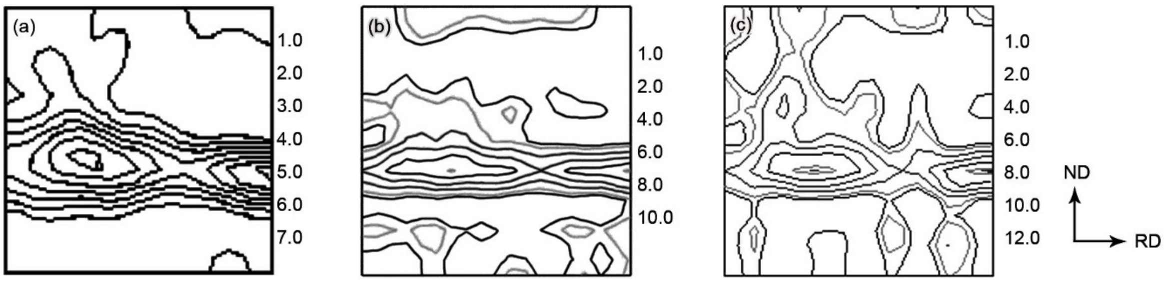

Fig 2. Sections of ODF at φ_2=45°
(a) A-0.800%Si, (b) B-1.570%Si , (c) C-2.515%Si

The percent of texture of {Goss}, {111} and {100} of the non-oriented electrical steel are shown in table3. Along with the increase of Si content, the texture level showed an increasing trend. {111} texture is the highest storage energy texture; therefore, the A group has the strongest texture after the hot rolling and cold rolling process. The content of {111} is 47.95%. The main reason that the texture{111} in group B and group C are weaker than that of in group A is hot rolled steel plate of the group B and group C, after normalization process, cold-rolled grain storage energy had reduced the most and the driving force for the formation of the {111} texture yet reduced most. Group C {111} is stronger than that of group B is that with the silicon content increase, silicon steel deformation got very difficult, under the same deformation state, after the cold rolling process, the formation of a large number of shear zones inner steel plates. The larger the grain size, the shear zone distribution density higher. Because of the high-energy storage in the shear zone, the recrystallization grain is preferentially in the shear zone. Recrystallization of grain growth belongs to be three-dimensional in situ growth, so the grain orientation will not release strongly altered, only the diffusion texture of the sharp peaks is weakened; after the continuous annealing process, the grain with higher energy to release from the slip surface and orientation rotate. The percentage amount of grain the texture of {100}, {Goss} increased.

Table 3. The percent of texture at N D (%)

No.	{100}	{111}	{Goss}
A	2.89	47.95	1.01
B	4.49	10.55	2.91
C	5.24	11.23	2.88

3.3. Observation and analysis of second phase particles
As shown in Figure 3, the second phase particles in the A group, B group, and C group test steel are Mn, Ti, Al, S, N elements of the polymer and precipitation. In the A group, the MnTiS, AlTiN, AlN, B, MnS, AlN and C, and FeTiS, and TiSO were the main groups. As the product of the A group did not have a high temperature normalizing annealing process, S and Mn had no solid solution in the ferrite matrix, but continued to maintain Ti. The next cold rolling and continuous annealing are also not without failure in the formation of the polymer MnTiS and AlTiN in these in vivo has been formed. Both the B and C groups experienced high temperature annealing process, and the Mn, Al, S and N elements were dissolved into the steel matrix, and then precipitated after cold rolling and continuous annealing. As the Ti element is not experienced in solid solution, the FeTiS and TiSO polymers are formed in the process of the integration of O, S and Fe. The AlN and MnS of Ti are no longer compatible with the precipitation of the. Square of the polymer due to the features of its shape to the domain block some more strongly, and large size circular MnS will reduce the obstacles to the domain.

The volume fraction, size, shape and distribution of the second phase particles play an important role in the properties of the steel. Therefore, to control the content of the second phase in the steel, and reduce its influence on magnetic properties. Reduce the content of Ti, in order to reduce the Ti and S, Mn, the role of the formation of granular composite inclusions.

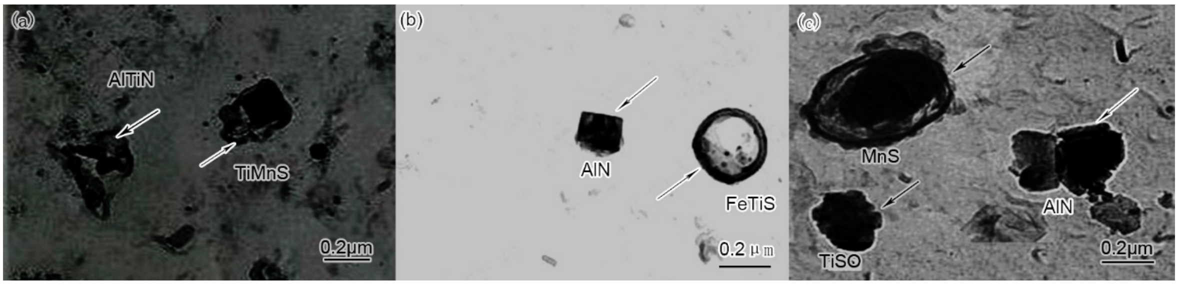

Fig 3. Morphology of the second particles sections by TEM
(a) A-0.800%Si, (b) B-1.570%Si , (c) C-2.515%Si

3.4. Magnetic energy and analysis

Iron loss $P_{1.5}$ decreased and the magnetic induction B_{50} remained unchanged, or increased at the same time were hoped in optimization of cold rolled non oriented electrical steel process; Production technicians are hard working in this direction. However, it be found in the study that the improvement and optimization of the texture, increase in grain size and uniformity, reduce electrical steel inclusion and lower second phase on the grain hindering effects, but the magnetic sense still showed a decreasing trend. Research has also found that when the grain size more than 80 μm, with the increase of the grain size of the iron loss decreased gradually, magnetic field strength showing a downward trend becomes not obvious. Because the more grain boundary, the higher the magnetic hysteresis loss. With the grain growth, the grain boundary decreases and the hysteresis loss decreases. At the same time, the grain size is larger; the grain boundary is less, and the magnetic-field intensity is higher than that of existing the more grain boundary. However, the results are often not so, because the grain size changes usually result in the crystal texture also changes, and the influence of the texture on the magnetic sense is more complex, and the influence of the texture is more than that of the grain size. So the magnetic induction is not necessarily increased with the increase of grain size. Based on the experimental results, with the increase of silicon content, iron loss and magnetic showed a decreasing trend.

The microstructure, texture, second phase and magnetic properties of electrical steels with different silicon content were studied. It was found that the microstructure of low silicon cold rolled non oriented electrical steel with different silicon content was similar, and the dispersion degree of texture was similar; The microstructure of the finished product is more uniform in the final continuous annealing process, and The texture of {100} and {Goss} for favorable magnetic properties are increased. Therefore, optimizing the process temperature and control process speed is one of the main ways to improve the magnetic properties of the products; because of the difference in the production process of low silicon cold rolled non oriented electrical steel, the formation of the second phase of the product is very different. For low silicon electrical steel without normalizing annealing process, it is necessary to control the composition of MnTiS and AlTiN in the process of steel making. To reduce the number of AlTiN phase MnTiS, can reduce the movement of the magnetic domain block, can improve magnetic properties of the products. And the second phase of electrical steel with normalizing annealing process is MnS and AlN. By controlling the annealing temperature, the MnTiS, AlTiN, they were coarsening, reduce the pinning of the domain and the obstacle of magnetic domain motion, to improve the magnetic properties of products. With normalizing annealing process of electrical steel in the presence of the second phase AlN and MnS need to control the annealing temperature and make them coarsening, reduce the domain pinning and improve the magnetic properties of products.

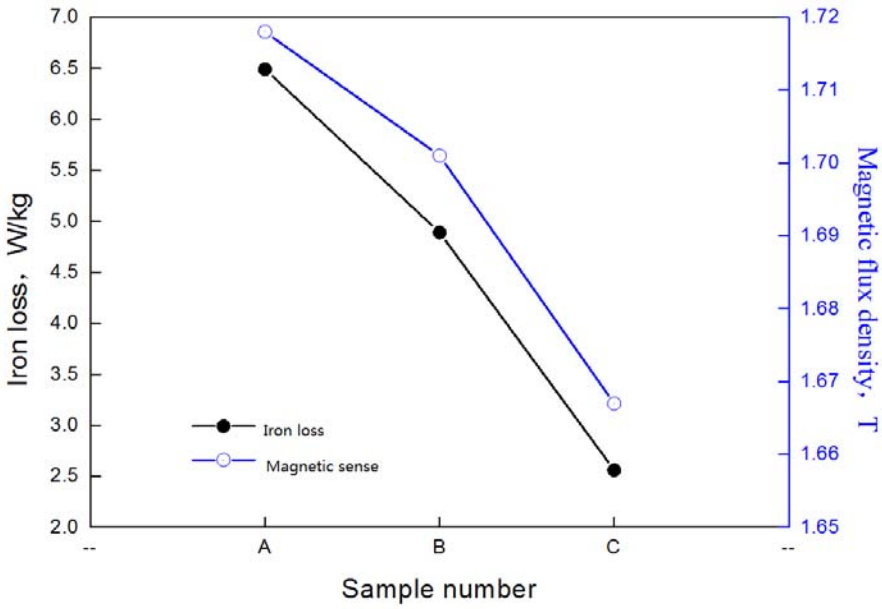

Fig 4. Magnetic properties after continuous annealing
(a) A-0.800%Si, (b) B-1.570%Si , (c) C-2.515%Si

4. Conclusion

(1) With the increase of silicon content, the process temperature increases and the process speed decreased of the non-oriented cold-rolled electrical steel which made stay time of the finished strip in furnace increases; the initial grain grows up; lower iron loss and magnetic induction intensity increased.

(2) The {111} surface texture in the finished product of electrical steel is very strong, which is related to the strong deformation of cold rolling. Although the cold rolling electrical steel has a continuous annealing process, because of the inheritance of texture, the proportion of {111} surface texture is still very high.

(3) The continuous annealing process makes the whole organization of silicon steel become equiaxed ferrite, but it cannot eliminate the genetic characteristics of the microstructure and texture of silicon steel. The grain orientation change in the grain is small, and the overall orientation of the grain is still dispersed in the small range.

(4) With the increase of silicon content, values of iron loss and magnetic are decreased; however, with the adjustment of the annealing process, the {100} and {Goss} texture of advantage magnetic properties showed increasing trend, weakened the adverse effects on the magnetic with the grain size increased.

(5) Although the {100} and {Goss} texture in non-oriented electrical steel in content is very low, and the texture close to the slow dispersion, however, by adjusting the process, {100} and {Goss} texture contented relative increase, iron loss reduction and magnetic induction increased in the overall.

(6) Mn, Al, S, N is not associated with Ti in the process of normalization, but in the continuous annealing process, the second phase AlN and MnS separate precipitated. FeTiS and TiSO polymer were formed by the combination of Ti and S, Fe, and O in the process of normalization.

Acknowledgments

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