

Research of Rolling Process with Warm for Cold-Rolled Non-Oriented Electrical Steel

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Abstract. The rolling process with warm for cold-rolled non-oriented electrical steel in pickling and rolling and continuous annealing was studied. Research shows when feeding the hot plate for Pickling and rolling mill in 100~120°C, pickling steel is almost no temperature rise, with the temperature of hot rolled silicon steel pickling effect is good, the cleaning rate reaches 100%; the steel sheet is stable running in looper for the strip temperature softening effect and shape of rolled strip is good, deviation below 8μm. Cold rolled plate feeding in 60~80°C for continuous annealing unit, the plate is almost no heating in Alkaline wash. Alkaline wash effect is good for the cold rolled plate with temperature steel, plate surface defect can be significantly reduced and wash rate is up to 100%; steel plate with temperature is not deviation in continuous annealing looper for softening. In addition, organization, texture, the second particles and magnetic energy also were studied. It was found that the steel sheets' microstructure is uniform after cold rolling, the grain is evenly stretched; belt warm rolling and the grain orientation of the cold-rolled sheet steel texture is obviously, which formed two main categories with {111} <uvw> and {hkl} <110> texture; after annealing, the second particles MnS and AlN particles has been roughened and close to the magnetic domain size, which reduce the obstacle second phase particles on the magnetic domains; Compared with the conventional process, the iron loss decreased slightly, magnetic induction increased slightly.

1. Introduction

Since the financial crisis, non-oriented electrical steel products showed structural overcapacity. In the non-oriented electrical steel market, product competition disorder. Product profit margins even more narrow. In order to improve production capacity and competitiveness, the production plants are improving product quality, increase the technological content of products, as well as adjust the production process. Using the residual temperature of the hot-rolled steel sheet and the residual temperature of the cold-rolled coil, it is a good way to improve the product quality and reduce the cost [1-5].

The slab of cold-rolled non-oriented electrical steel is hot-rolled into a coil, then the hot-rolled coil was cooled to room temperature. It was subjected to pickling and rolling. The cold-rolled steel coil



after pickling and rolling is then cooled to room temperature for continuous annealing production. This is a general production method for cold rolled non-oriented electrical steel. This paper improves the temperature of the steel sheet during pickling and continuous annealing. The temperature was controlled at 100 to 120°C or 60°C to 80°C. The microstructures, textures, secondary phases and magnetic properties of cold rolled non-oriented electrical steel products after annealing are changed due to the change of pre-process temperature [6-9].

The microstructures, textures, magnetic properties and magnetic properties of the steel sheet annealed at the strip temperature with continuous pickling and continuous annealing were studied by taking cold rolled non-oriented electrical steel 50W800 as an example.

It is hoped that cold rolling non oriented electrical steel sheet strip rolling can be realized by optimizing the production process and improving the magnetic properties of the product.

2. Experimented

2.1. Preparation of test steels

The slab of non-oriented electrical steel 50W800, produced by continuous casting, was hot rolled to a thickness of 2.25 mm. When the hot-rolled coil was cooled to 100°C (at 150°C in the steel coil center), the pickling cold rolling mill was started. The hot-rolled coils were rolled into five cold-rolling mills. After the rolling, the continuous annealing was started at a steel plate temperature of 60°C to 80°C. In the first process of Continuous annealing unit, the steel plate was washed in the alkaline washing unit. The second process is annealed in the continuous annealing furnace. The chemical composition of the test steel is shown in Table 1.

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

No.	C	Si	Mn	P	S	N	ALs	Ti
50W800	0.0030	0.80	0.25	0.0010	0.0040	0.0020	0.33	0.0028

2.2. Testing of steel

The coil temperature is measured with an infrared measuring instrument, and the measurement area is the coil surface. The temperature is averaged at five points. 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. Result and discussion

3.1. Cold pickling

The hot-rolled coil of the cold-rolled non-oriented electrical steel was cooled to 100°C (150°C in the steel coil center) by stacking and started to go up. The reason for choosing this temperature is the maximum temperature that the pickling mill unit can withstand. Although 100°C lower than the low-temperature tempering temperature, but due to the existence of temperature, the steel plate in the atomic energy increases, atomic active, the plate is easy to deformation. In the strip under the action of tension, the big edge of the steel plate is weakened, straight stretch, reduced. When the straightening machine, the plate has been straight. In the looper after the straightening machine, because the flat plate, plate running smoothly, will not produce deviation. The steel plate does not deviate from the side will not produce scraping edge, it will not produce scraping edge as a result of accidents, thereby reducing the accident rate and improve the effective operation of equipment time. Acid pickling

temperature of 75 ~ 85 °C. After the steel coil opened and straightened, the coil temperature just to 60 ~ 85 °C [10-12].

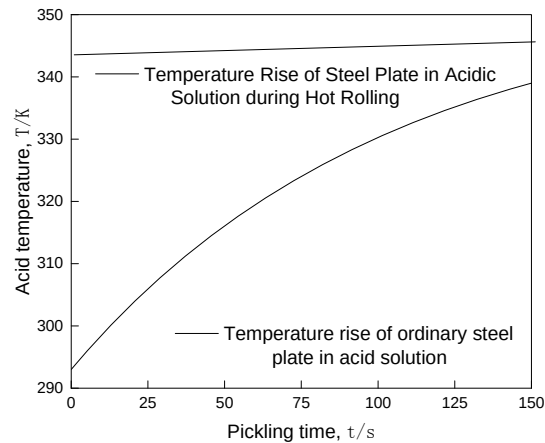


Fig 1. Temperature rise curve of cold rolled steel plate in acid solution

As shown in Fig. 1, the temperature of the steel plate is close to the temperature of the acid, and the steel plate does not undergo the obvious temperature rise of the exponential curve after pickling, but tends to be straight straight line. The steel plate will only absorb a small amount of acid heat, the temperature of the acid pool acid temperature stability, and thus the effect of good pickling turbulence. Since the temperature of the steel plate is close to that of the acid, the pickling effect is also optimum. Because, ideally, the strip temperature and acid temperature is the same, can play the best chemical reaction rate. In addition, because the temperature with the material, steel surface oxidation is not serious, the inner layer does not form a very thick FeO layer, so pickling up easily. The acid pickling loop to enter the cold rolling mill before the plate with the temperature can be reduced to 40 ~ 60 °C. At this time for cold rolling, unit rolling force reduction, strip plate type of small fluctuations, as shown in Fig.2, strip transverse thickness of less than 8 μ m.

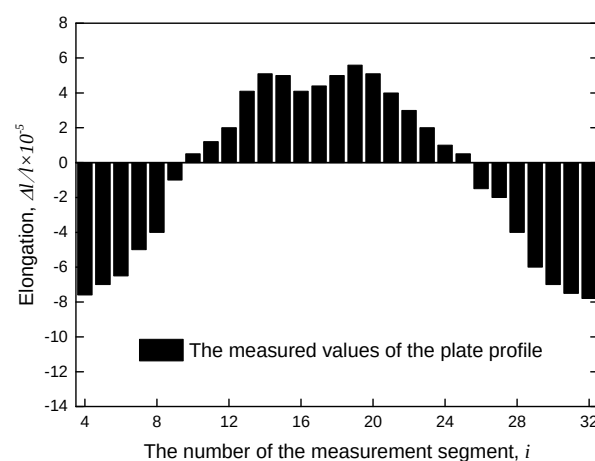


Fig 2. Profile of the Cold rolled steel sheet

3.2. Coil with temperature and continuous annealing

The steel sheet temperature after the cold rolling is still about 80 to 120°C. Coil stacking in the rolling warehouse to about 60°C to the continuous annealing unit feeding. Electrical steel because of silicon

content than other high steel, steel surface easily oxidized. The steel plate surface is too late oxidation, reducing the difficulty of caustic washing; steel plate into the continuous annealing of the alkaline washing unit still has about 50 °C temperature, alkali when the steel plate with a higher temperature, the process through the alkali tank will not absorb a lot of lye heat. Steel surface with high temperature, grease and other dirt will accelerate the dissolution and promote the oil chemical reaction. The surface of the steel plate has a relatively high temperature, will relatively improve the degreasing agent working temperature, in general, degreasing bath temperature for each 10 °C, the chemical reaction rate can be increased by 1 times, alkali washing effect is significantly enhanced. As shown in Fig.3, steel plate temperature at 60 °C, the cold-rolled silicon steel washing rate of up to 100% of the washing unit. As the steel temperature, the steel plate to reduce the stress, the plate will become good, smooth running in the loop, reducing the incidence of broken band, increase the effective working hours of the unit, indirectly reduce production costs. As the plate washed more clean, reducing the plate due to dirt caused by the furnace roll nodules, an increase of the service life of the bottom roller, reducing the use of the cost of the bottom roller; the same time, reducing the use of alkali degreasing process, Thereby reducing the cost of the alkaline washing process.

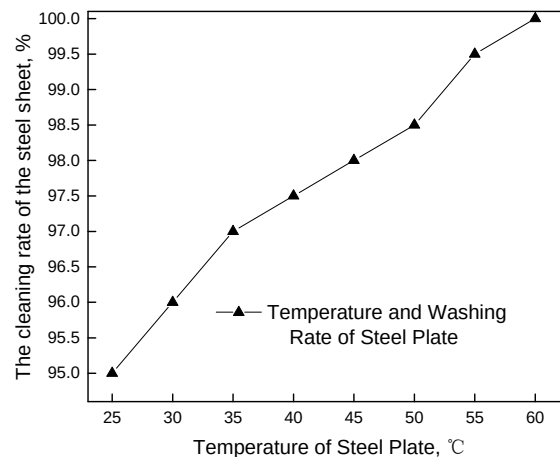


Fig 3. Plate temperature and Wash rate in Alkali washing unit

3.3. Cold - rolled texture

During the cold rolling deformation, the grain orientation of the bcc is different from that of the face centered cubic, so the grain orientation distribution is different in the recrystallization. During the cold rolling, the steel plate is deformed by sliding. When the crystal is changed, the internal crystal grains rotate and change the direction until the crystal does not rotate. This plastic deformation by slip is gradual and continuous. This slip is enhanced when the strip is warm, and therefore, the formation of the texture is promoted.

Fig.4 is the texture diagram of the cold rolling electrical steel 50W800. The {001} (110) and {112} (110) textures are mainly formed on the α -oriented line as the amount of cold rolling deformation increases, and the {111} <011> and {111} <211> textures were also enhanced on the γ -oriented line. Since the cold-rolled sheet is made of hot-rolled sheet, the strength of each component in the cold-rolled texture is related to the proportion of each component in the hot-rolled sheet, and Cold-rolled texture is the diffuse and divergent orientation of the continuity of these components. As the cold rolling pressure is huge, along the rolling to be elongated grain, part of the grain crushing, part of the grain will also occur dynamic recrystallization.

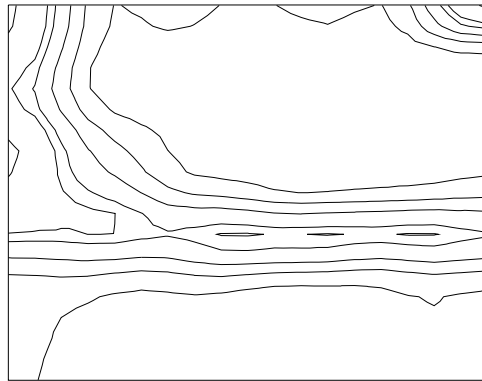


Fig 4. Sections of ODF at $\phi_2=45^\circ$ (level: 1, 4, 8, 12)

Therefore, the orientation of grains is obviously enhanced by the rolling force, and the main texture of $\{111\} \langle uvw \rangle$ and $\{hkl\} \langle 110 \rangle$ are formed, such as $\{112\} \langle 110 \rangle$, $\{111\} \langle 110 \rangle$, $\{111\} \langle 112 \rangle$, $\{001\} \langle 110 \rangle$, and $\{110\} \langle 110 \rangle$ [13-18].

3.4. Annealing texture

The large rolling force affects the growth direction of the primary nuclei, but with the onset of dynamic recrystallization, the orientation of the grains continues to change. As the cold-rolled silicon steel with high temperature energy, and thus easy to deformation, the process of cold-rolled steel plate to promote the formation of a large number of shear bands, and the larger the grain size, shear band distribution density is higher. When the grain recrystallization, the recrystallized grains preferentially nucleate in the shear band due to the high energy storage in the shear zone. The recrystallization in the annealing process belongs to in-situ recrystallization. The annealing process not only eliminates the internal stress of the cold-rolled steel coil, but also changes the grain orientation. This orientation belongs to the spatial adaptation of the grain body. Therefore, although the orientation is correspondingly but the improvement range is limited and the orientation distribution is increased by about 0.5 level. Fig.5 is the Euler angle of 45° after the annealing of cold-rolled electrical steel ODF texture shots.



Fig 5. Sections of ODF at $\phi_2=45^\circ$ (level: 1, 2, 4, 8, 10)

3.5. The organization of the cold rolling

The hot rolling of cold rolled silicon steel was rolled by five cold tandem rolling mills. The microstructure of the polycrystalline steel after plastic deformation was obviously changed under rolling force. A large number of slip bands appear in the grains. The grain shape also changes step by step. As the deformation increases, the original equiaxed grains elongate in the direction of

deformation. The greater the deformation, the greater the degree of grain elongation. When the deformation is very large, showing a piece of such as fiber-like stripes, as shown in Fig.6.



Fig 6. Optical microstructure of the specimen

3.6. Annealed tissue

Cold-rolled electrical steel coil annealing is carried out under the protective gas, the protective gas not only to prevent the surface oxidation of steel, but also with sulfur, carbon, nitrogen, oxygen, and other harmful impurities chemical reaction. These impurities will be oxidized into gas and with the furnace gas to eliminate, therefore, the steel will become more pure, so as to improve the electromagnetic properties of cold-rolled non-oriented electrical steel.

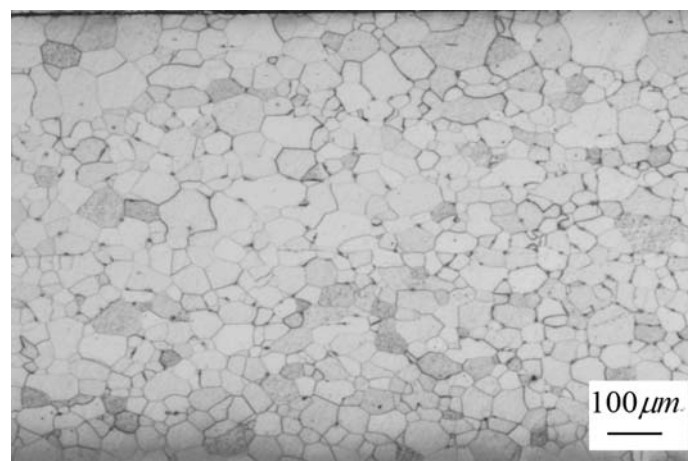


Fig.7 optical microstructure of the specimen

During the annealing process, three phases of recovery, recrystallization and grain growth (polymerization recrystallization) occur in the cold rolled electrical steel. The results show that the microstructure after annealing at 50W800 is equiaxed ferrite, the grain boundary is clear and regular, the degree of homogenization is high, and there is no mixed crystal phenomenon. As shown in Fig.7, the grain structure of annealed 50W800 cold-rolled sheet can be seen, and the average grain size can not be more than 75μm. Along the width of the plate, there is little difference in the transverse and longitudinal structures. The difference of longitudinal and transverse microstructures is small, which is beneficial to reduce the anisotropy of magnetic properties.

3.7. Second phase

The volume fraction, size, shape, distribution, and other properties of the second phase particles play an important role in the electrical properties of steel. Before cold-rolling, the second phase of the belt-heated electrical steel sheet has softened, and thus, the cold-rolled strip has a more uniform texture. Fig.9 shows the second phase of the cold-rolled non-oriented electrical steel 50W800. The second phase of the test steel is Mn, Ti, Al, S, N elements of the polymer. The two-phase particles in the hot-rolled sheet are MnS. $(001)_{M(C,N)} // (001)_{\gamma}$, $[010]_{M(C,N)} // (001)_{\gamma}$ in austenite form a parallel semi-coherent relationship with austenite, the interface can be tri-homogeneous. Therefore, the shape of the second phase should be spherical or cubic mostly round. The shape of MnS is circular, and its diameter is $100 \sim 300\text{nm}$. The temperature of the continuous annealing is controlled to control the size of the MnS-based precipitation and the MnS particle size. Small MnS particles can reduce the barriers of its magnetic domain, and thus improve the product's high magnetic properties. TiSO content is small, because of its shape and size close to the magnetic domain, so it is less hindering the magnetic domain. However, although AlN has a small content, the magnetic properties of the AlN are severely deteriorated due to the nail-pinning effect on the magnetic domains. Therefore, AlN is reduced in its precipitation or coarsened by temperature control as much as possible.

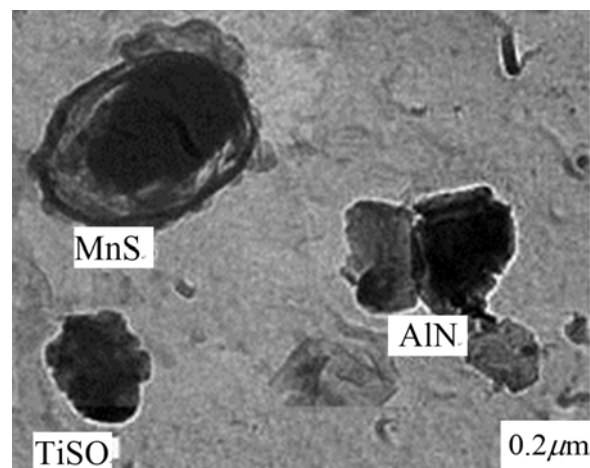


Fig 8. Morphology of the second particles sections by TEM

3.8. Magnetic properties

The 50W800 cold rolled nonoriented electrical steel was selected as the test object. It is found that the magnetic properties of electrical steel produced by belt-temperature process are improved. Iron loss slightly decreased to 6.49 W / kg , 0.05 W / kg lower than the target value; magnetic susceptibility slightly increased to 1.717 T , lower than the target value of 0.005T . Fig. 8 shows the magnetization curves of the cold-rolled non-oriented electrical steel produced by a belt-temperature process. The magnetization curve shows that the magnetic properties of cold rolled non-oriented electrical steel produced by belt-temperature production process are good.

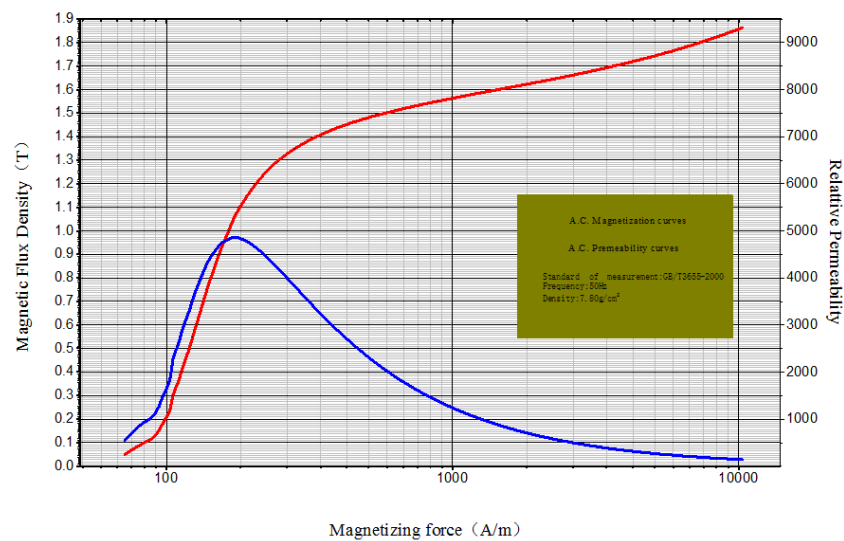


Fig. 9 magnetization curve of electrical steel 50W800

4. Conclusion

In this paper, cold-rolled non-oriented electrical steel in the pickling and continuous annealing temperature with the production process were studied. The cold rolled non-oriented electrical steel sheet with the temperature production has good performance indexes and the production efficiency is improved.

1) The hot rolled plates of 100 to 120 °C were produced in pickling and rolling mills. When pickling, the steel plate almost no temperature rise. The hot-rolled electrical steel sheet with a good effect of pickling, washing rate of 100%; with the softening steel for the temperature in the live sets, the strip running smoothly. The cold-rolled steel sheet had a good plate shape with a deviation of 8 m or less.

2) When the cold-rolled electrical steel plate temperature is 60 ~ 80 °C, the annealing unit began production. When the steel sheet is causticized, the steel sheet is hardly heated. With the temperature of the cold-rolled plate alkali washing effect is good, the steel surface defects significantly reduced, the cleaning rate of up to 100%; plate due to temperature and softening, even in the production line does not run deviation.

3) The microstructures and microstructures of the cold-rolled steel sheets were investigated by means of microstructure, texture and magnetic properties. The microstructure of the cold-rolled steel sheets was uniform and the grains were uniformly elongated. The main textures of {111} <uvw> and {hkl} <110> are formed.

4) After annealing, the MnS and AlN particles were coarsened and close to the magnetic domain size, which reduced the magnetic domain resistance. Compared with the conventional process, the iron loss ratio decreased by 0.05 W / kg, the magnetic induction intensity 0.005T.

Acknowledgments

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