Influencing Factors of Iron Core Loss During Silicon Steel Production

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Abstract The whole production process of 50W800 grade non-oriented silicon steel hot rolling-cold rolling-annealing was observed, and the influence of its composition, structure, impurities and other factors on the iron core loss of silicon steel was analyzed. The results can be summarized as follows that: (1) The iron core loss can be reduced by increasing the silicon content within a certain range. (2) After annealing, the crystal grains become larger and the crystal defects are reduced, thereby reducing the iron loss. (3) The iron core loss is reduced by reducing the content of elements such as carbon, nitrogen, and sulfur. (4) The strength of strip steel can be enhanced by adding trace elements.

1. Introduction

The automobile industry is one of the pillar industries of my country's national economy. Fuel vehicles consume large amounts of fossil fuels, air pollution, seriously affecting the environment. The use of clean energy (new energy) alternative to traditional fuel powered automobile industry is an effective way to solve the crisis of development. New energy vehicles, including hybrid vehicles, pure electric vehicles and fuel cell vehicles, new energy vehicles can alleviate dependence on fossil fuels while car use, reduce greenhouse gas emissions, reduce environmental pollution, new energy automotive industry by the governments attention[1-3]. The development of my country's new energy automobile industry started relatively late. In 2012, the government included in the development plan and developed rapidly with the support of national policies. According to the China Association of Automobile Manufacturers statistics, in 2019 China electric vehicle production is completed 1.02 million, an increase of 3.4%, sales of complete 972,000, down 1.2 percent; fuel cell vehicles sales were completed 2833 and 2737, respectively, year on year increase 85.5% and 79.2%. The National "New Energy Vehicle Industry Development Plan (2021-2035)" (draft for comments) mentioned that by 2025, the sales of new energy vehicles and new vehicles will account for 25%, and it is clearly stated that new energy vehicles should be developed with high quality. The main line, to achieve the transition from high-speed development since 2012 to high-quality development. Affected by the preparation technology, the current research and development of pure electric vehicles has been in the growth stage of the new energy automobile industry and has broad development prospects[4], and silicon steel is an important part of the new energy
automobile engine.

Silicon steel was developed in the early 20th century and has a history of 100 years. It is widely used in the manufacture of motors, transformers, generators and other electrical components. It is an indispensable soft magnetic alloy in electronics, electric power, and military industries, and silicon steel is also one of the important metal functional materials for energy saving.

At this stage, high-grade non-oriented silicon steel has been produced, but with the development of electric vehicles, a series of requirements have been put forward for the strength of silicon steel. Until recently, the required rotation speed meant a maximum of about 100,000 revolutions per minute, and laminated silicon steel plates were used as the rotor core. It is necessary for super high-speed rotation to reach 200,000 or 300,000 RPM; that is, the centrifugal force may exceed the strength of the silicon steel plate. Magnetic motors are becoming more and more common, and the load imposed on the rotor material during the rotation process is also increasing [5-6]. When the motor speed increases (20-30)×10⁴ r/min, the silicon steel plate strength required by the high-speed motor is the yield strength (σ₀.₂) > 588 MPa, the tensile strength (σ₀.₂) is greater than 687 MPa [7], and the magnetic properties of the silicon steel plate should be guaranteed.

The researchers used dislocation strengthening, solid solution strengthening, precipitation strengthening and other strengthening mechanisms, high strength silicon steel, but there is no good way [8-10]. In order to provide a theoretical basis for the production of high-strength non-oriented silicon steel, this paper analyzes the influence of the composition, structure and impurities of 50W800 non-oriented silicon steel on the iron loss of silicon steel during hot rolling, cold rolling and annealing.

2. Experimental materials and experimental methods

The silicon steel used in the experiment was taken from a domestic steel plant. The chemical composition that affects the performance of the experimental steel is mainly manifested as follows: 0.003C-1.02Si-0.29Mn-0.016P-0.0034Si-0.351Als (wt%). The steel production process is shown in Figure 1. During the annealing process, the heating temperature is 915°C, the strip speed is 115m/min, and the total length of the annealing line is 260m. The magnetic properties, iron core loss performance and other data are shown in Table 1 through on-site sampling (with head and tail).

The strip steel is made into a steel sheet with a sample size of 10 mm×15 mm (TD×RD), polished, and then corroded with a 10% nitric acid solution for 30 seconds, followed by washing and drying. The edges, 1/4 thickness and 1/2 thickness of the strip are observed, and the changes in the metallographic structure are analyzed through a metallurgical microscope.

Table 1 Finished product performance data sheet

| Parameter          | Iron core loss (W/kg) | Magnetic induction B5000(T) | Surface resistance | tensile strength (MPa) | Elongation (%) | hardness (HV) |
|--------------------|-----------------------|----------------------------|--------------------|------------------------|----------------|--------------|
| 50W800             | 4.297                 | 1.733                      | 1238               | 3890                   | 36             | 117          |

3. Experimental results and analysis

3.1 Experimental results

The microstructure of the hot-rolled sheet is shown in Figure 2. The fibrous structure of the 50W800 steel hot-rolled sheet is mainly equiaxed ferrite, which is due to the extremely low carbon content of the
strip steel. The grain size at the 1/4 thickness of the strip is not much different from the grain size at the edge, most of which are irregular polygons; most of the central grains have been recrystallized, with a small amount of slender fiber structure. This is because during the rolling process, there is friction between the surface of the roll and the sample, which causes the surface strain energy to increase, and the strain energy from the surface layer to the center layer decreases sequentially. Therefore, the closer the center layer is, the crystal The lower the internal storage energy, the more difficult it is to recrystallize, so in the center layer, some of the grains are elongated and flattened ferrite.

The microstructure of the cold rolled sheet shown in Figure 3. After cold rolling, the metal undergoes plastic deformation and produces a large number of crystal defects. The internal grains are elongated to form a fibrous structure along the rolling direction. This is the structure and performance changes of the cold deformed metal in the subsequent heat treatment process internal factors.

The microstructure of the annealed plate is shown in Figure 4. After the cold-rolled sheet is annealed, the fiber structure is transformed into irregular polygons. This is because the structure will return to a relatively complete, regular, and stable equilibrium state with low free energy after recrystallization, dislocations can also be eliminated and coarse recrystallized grains can be obtained.

3.2 Analysis
The two most important indicators of non-oriented silicon steel are iron loss and magnetic induction. Iron core loss into hysteresis loss, eddy current loss and abnormal loss. To reduce the eddy current loss, it can be added to silicon, silicon resistance is improved, and the magnetic anisotropy constant of iron saturation magnetostriction constant is lowered, and also can reduce carbon in the steel, oxygen and nitrogen in the α-Fe desolventizing caused magnetic aging phenomenon. However, as the silicon content increases, silicon steel will become brittle, which will not only damage the rolling die and even internal cracks during cooling and heating.

The more grain boundaries, the greater the hysteresis loss and coercive force. This is because lattice distortion, grain defects and internal stress at the grain boundary cause more energy to move the domain wall at the grain boundary during the magnetization process. After annealing, the average grain size is large, the dislocations are reduced, the number of grain boundaries is reduced, the resistance of domain wall movement is reduced, and the hysteresis loss is reduced. However, as the grains grow, the magnetic
domain size becomes larger, and the classical hysteresis loss and abnormal eddy current loss increase. Therefore, to obtain the lowest iron loss, there must be an optimal grain size.

Carbon and nitrogen are interstitial solid solution elements, and sulfur is a substitutional solid solution element, but because the atomic radius is very different from the iron atomic radius, it will cause large internal stress due to lattice distortion. The inclusions and impurity elements in non-oriented silicon steel should be as low as possible, which is an important measure to improve magnetic properties.

With the control of chemical composition and process, higher grades of non-oriented silicon steel can be produced. However, silicon steel used in the drive motor of new energy vehicles has requirements for strength. The following is an idea of strengthening strip steel at the expense of a small amount of magnetism: when titanium and molybdenum are added to the steel, the second phase particles formed by the reaction of titanium and carbon are precipitated in the iron matrix. The fine dispersion and uniform distribution in the matrix can increase the strength of the steel without damaging the toughness. The addition of molybdenum increases the number of TiC precipitates and reduces the size of the precipitates, providing relatively stable precipitation strengthening. It is expected that this solution can significantly increase the strength of strip steel at the expense of a little electromagnetic performance.

4. Conclusion
(1) The iron core loss can be reduced by increasing the silicon content within a certain range.
(2) After annealing, the grain size becomes larger and the crystal defects are reduced, thereby reducing the iron core loss.
(3) The iron core loss is reduced by reducing the content of elements such as carbon, nitrogen, and sulfur.
(4) The strength of strip steel can be enhanced by adding trace elements. For example, by adding titanium and molybdenum to produce precipitation strengthening, the strength of the strip can be significantly improved with as little magnetic sacrifice as possible.

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