

Effect of laser scribing on grain-oriented silicon steel

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Abstract. Laser scribing is widely used to reduce core loss of grain-oriented silicon steel recently. The effects of laser scribing on surface coating and magnetic properties of silicon steel were investigated in this paper. The effect of stress annealing treatment on laser scribing product has been analyzed. It was found that as laser power increased, the core loss reduced and the damage to surface coating exacerbated. Reducing the laser scribing line spacing to a certain width can achieve low core loss. The core loss of laser domain refined product will increase after annealing at certain temperature.

Introduction

Grain-oriented silicon steel is widely used for transformer cores, and reducing of iron loss is one of the most important industrial issues. The grain-oriented silicon steel core loss consists mainly of hysteresis loss and eddy current losses.

As the improvement of grain-oriented silicon steel sheet manufacturing technology, abnormal eddy current losses become the mainly composition which is about 70% of total core loss on high magnetic grain-oriented silicon steel. ^[1] Abnormal eddy current loss is based on the eddy current loss of the magnetic domain wall movement, and is proportional to the rate of movement of 180° magnetic domain wall. Under the same frequency, the domain wall moving speed is proportional to the distance moved, so the larger magnetic domain width, the more core loss. As is known, it's very effective for refining magnetic domain wall spacing and hence reducing iron loss. ^[2]

In particular, the magnetic domain-refining techniques, such as laser scribing, groove-forming and etching techniques have been developed since nearly 30 years. ^[3] However, the laser scribing is the main technique used in industry which the direction of scribing usually 90° from rolling direction. It has been speculated that the induced tensile stresses or recrystallized micro grains might be the origin of the magnetic domain refining. ^[3,4] Though laser scribing can reduce core loss effectively, silicon steel coating surface is usually damaged by the pulse laser and the effect of core loss reducing can't reserve after annealing treatment. ^[1-7]

Experimental

The continuous high-speed scanning system with CO₂ laser was used to scribe line on grain-oriented silicon steel surface along the direction vertical to rolling. The morphology of scribing line was observed by Scanning Electron Microscope (SEM) and the contents inside and outside of scribing line were analyzed using Energy Dispersive Spectrometer (EDS). In this study, high magnetic induction grain-oriented silicon steel sheets of 500×500×0.27 mm³ were used as the specimens to measure magnetic properties. Laser scribing samples were annealed at 400°C, 500°C, 600°C, 700°C and 800°C using box-type electrical resistance furnace with the protective atmosphere 70%N₂+30%H₂ for 2 hours. The SST-500 type Silicon Steel AC Magnetic Measuring Instrument made by Chinese National Institute of Metrology was used to measure magnetic properties in this paper. Rate of magnetic properties improvement: $\Delta B_{800}/P_{17/50} = (B_{800}/P_{17/50} \text{ (before laser scribing)} - B_{800}/P_{17/50} \text{ (after laser scribing)}) / (B_{800}/P_{17/50} \text{ (before laser scribing)}) \times 100\%$.

Results and discussion

Laser scribing effect on coating surface.

Fig.1 shows the morphology of the laser scribing line of high magnetic grain-oriented silicon steel which scribing line spacing is L_n (thickness=0.27mm, $B_{800}=1.931$ (T), $P_{17/50}=0.956$ (w/kg); before laser scribing). Fig.2 shows the Fe content of coating surface near the scribing line in different laser power.

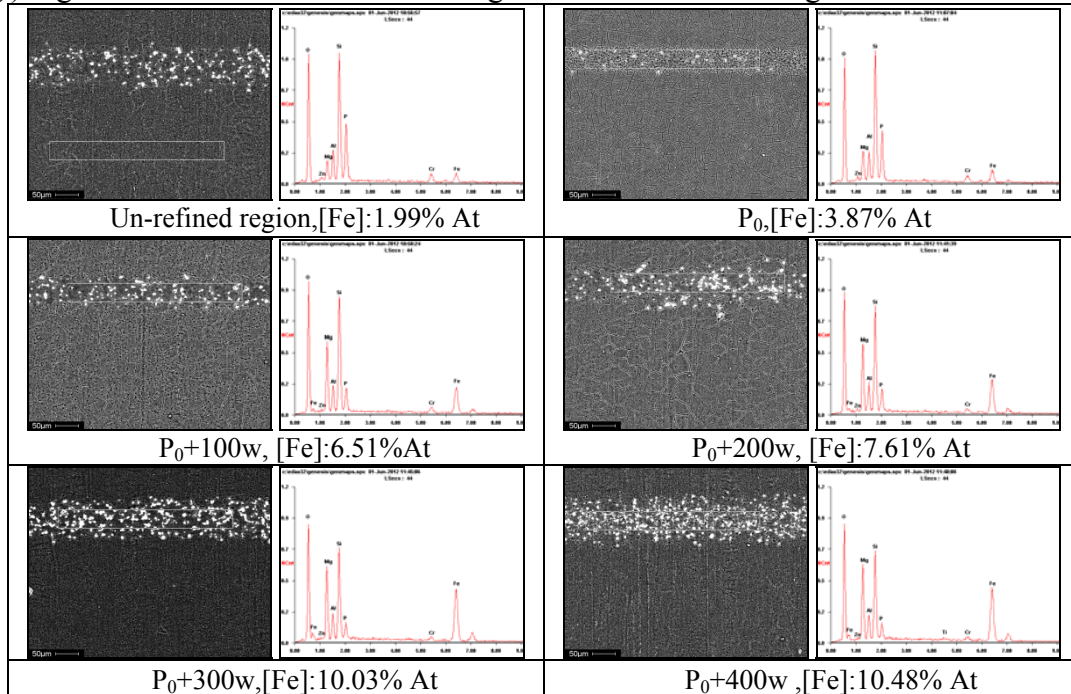


Fig.1. Morphology and composition near the refine line in different laser power

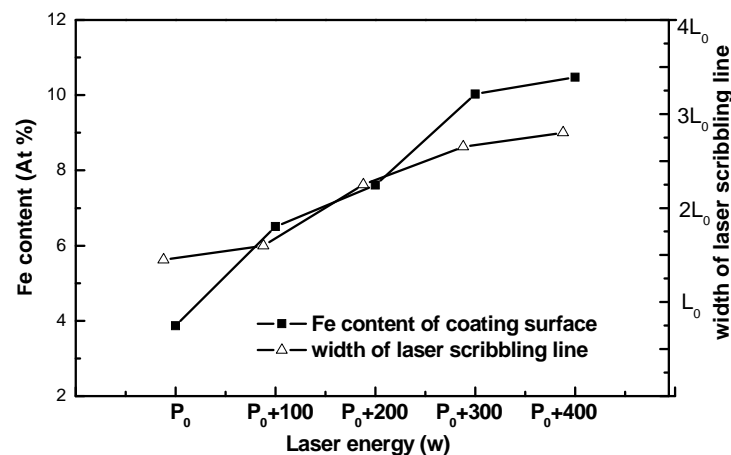


Fig.2. Fe content and width of scribing line in different laser power

Grain-oriented silicon steel has formed a layer of insulating coating on the surface before laser scribing. It can estimate the degree of damaging coating by analyzing the width of scribing line and Fe content within the line. Fig.1 and Fig.2 shows all specimens' coating has damaged by laser beam in different degree. The lasers power more higher, the more width of scribing line and the more much Fe content within scribing line. Laser power P_0 , the scribing line width is about $30\mu\text{m}$ and [Fe] is 3.87%; when laser power increased 300w, the line width become about $50\mu\text{m}$ and [Fe] increased to 10.03%. The laser power to further increase, the width of line has no significant change. If the laser power is increased more 200w, the damaging of coating become serious and Fe content of coating surface increased rapidly. As is to know, energy and holding time within line zone of laser beam are main factor which damaged coating, and the former decided by laser power, the later decided by laser scanning speed. [5, 6] At the same laser scanning speed, laser power is the most significant factor.

Laser scribing effect on magnetic property.

The desired domain refining results can be achieved by adjusting scribing line spacing when choosing suitable laser power, while not damaging coating seriously. If laser power is too big, the reduction of eddy current loss will be offset by increased hysteresis loss addition to damaging coating.^[6]

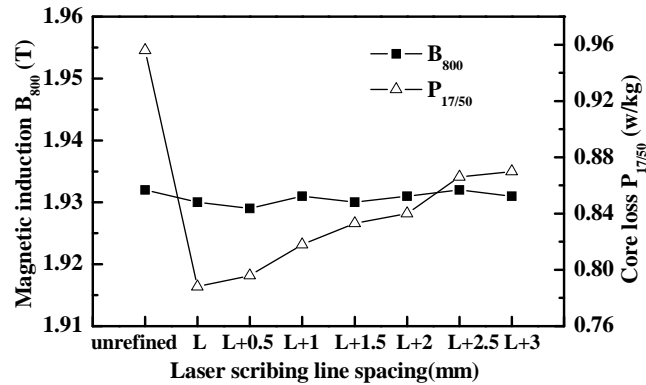


Fig.3. The effect of laser scribing line spacing on magnetic properties

Fig.3 shows the effect of laser scribing line spacing on the rate of core loss and magnetic induction improvement (laser power: P_0+100 w). With the narrowing of scribing line spacing, magnetic induction changed little and core loss reduced significantly. While the scribing line spacing is narrower than $L+2.5$ mm, the rate of core loss improvement increases substantially. However, if the spacing is narrower than $L+1$ mm, the changing of core loss becomes little. The results are mainly because of laser scribing line spacing values close to the domain width threshold.^[5]

Annealing treatment effect on laser domain refined product.

Fig.4 shows the variation of magnetic induction and core loss affected with annealing temperature. Annealed at different temperatures, the sample magnetic induction changes slightly but iron loss varies within wide limits (0.27 mm, B_{800} : 1.931 T, $P_{17/50}$: 0.956 w/kg; before laser scribing).

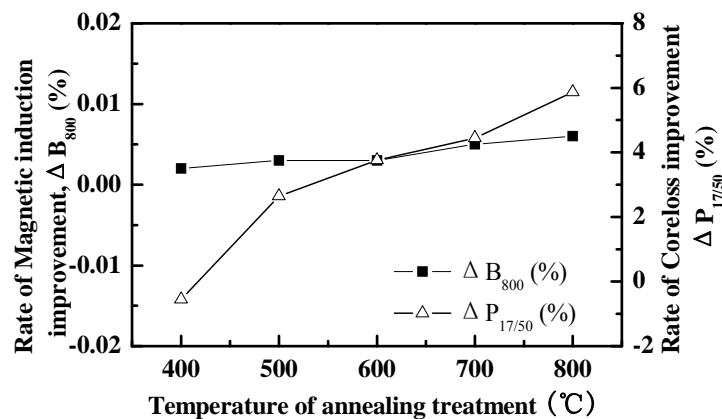


Fig.4. The variation of magnetic properties affected with annealing temperature.

Sample core loss reduced slightly after annealing at 400°C , but it increased significantly when the annealing temperature is more than 500°C . Annealing can lighten the adverse effects of residual stress and shear stress on magnetic properties. At the meantime, annealing treatment can weaken or eliminate domain refinement effects arising from tensile stress. And so, core loss reduction caused by laser scribing is weakened and even eliminated. Fig.4 indicates that annealing treatment more than 400°C has almost the same effect on magnetic induction; it may be because annealing at 400°C to 800°C could not change the Gauss-grains deviation angle.

Conclusions

Laser scribing is the usually means of reducing core loss in the large-scale industrial producing grain-oriented silicon steel, when laser energy increased, the core loss reduced more and the damage of coating surface exacerbated.

Controlling the damage to coating surface by chooses a suitable laser power, and it can achieve optimal iron loss reduction by decreasing the laser scribing line spacing to a certain width.

The core loss of laser scribing domain refined product will increase after annealing treatment on certain temperature, and it sharp increased when the annealing temperature more than 500°C。

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