Reduction of Core Losses in Thin-Gauge Non-Oriented Electrical Steels Through Stress-Relief Annealing

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This study investigated the effects of stress-relief annealing (SRA) on core loss reduction in various grades of non-oriented (NO) electrical steels. Samples were subjected to SRA at 750°C and 850°C for 2 hours in a non-oxidizing atmosphere, with core losses measured at different frequencies. Results showed that SRA effectiveness varied significantly by thickness: the 0.30 mm NO steel exhibited the most substantial reduction, the 0.25 mm specimen showed intermediate improvement, while the 0.20 mm specimen experienced minimal change or even increased losses. For all specimens, the 750°C SRA treatment consistently provided better core loss reduction than the 850°C treatment. This suggests that optimizing both SRA temperature and understanding thickness-dependent responses are critical for effectively reducing core losses in thin-gauge NO electrical steels.

Keywords: Non-oriented electrical steel; Stress-relief annealing; Core loss reduction; Grain size distribution; Thin-gauge electrical steel

1. Introduction

Non-oriented electrical steel (NOES) is crucial in motor applications, where recent electric vehicle advancements have driven rotation speeds from traditional 3,600 rpm to up to 30,000 rpm. To reduce iron losses—comprised of hysteresis, eddy current, and anomalous eddy current components—high-performance EVs use thin-gauge (0.2-0.3mm) electrical steel. While stress-relief annealing (SRA) effectively reduces iron loss in low-alloy steels through both stress removal and grain growth, its effectiveness is limited in high-alloy thin-gauge steel due to restricted grain growth. Despite this challenge, SRA is being reconsidered to maximize motor efficiency. This study aims to investigate texture changes, magnetic properties, and grain growth mechanisms during SRA in thin-gauge NOES, addressing the lack of metallurgical research on optimal SRA parameters for these materials.

2. Results and discussion

The experiments were performed on three commercial NO steels. Each sample contained 3.5% silicon, which is typical for traction motor grade NOES.

Table 1 : Prepared NO steels

Sample	Thickness, mm	Resistivity, μΩ·cm	$W_{10/400}$, W/kg	B_{50}, T
0.20 mm NO	0.20	65	10.6	1.63
0.25 mm NO	0.25	59	12.1	1.66
0.30 mm NO	0.30	59	14.4	1.66

The iron loss under axial magnetization was calculated using the modified Steinmetz formula [1]:

$$\mathrm{W_{total}} = \mathrm{W_{hysteresis}} + \mathrm{W_{anomalous}} + \mathrm{W_{eddy\ current}} \quad \cdots\cdots\cdots (1)$$

If the eddy current loss is regarded as a classical current loss, it can be expressed as follows:

$$\mathrm{W_{total}} = k_H \cdot \mathrm{B_m^2} \cdot f + k_A \cdot \mathrm{B_m^{1.5}} \cdot f^{1.5} + 0.1645 \cdot \frac{\mathrm{t^2} \cdot \mathrm{B_m^2} \cdot f^2}{\rho \cdot \mathrm{d}} \cdots (2)$$

$$\frac{\mathrm{W_{total}} - \mathrm{W_{eddy\ current}}}{f} = k_H \cdot \mathrm{B_m^2} + k_A \cdot \mathrm{B_m^{1.5}} \cdot f^{0.5} \cdots\cdots (3)$$

SRA effectiveness varied significantly by thickness: 0.30 mm NO specimens showed the highest iron loss reduction, while 0.20 mm specimens experienced minimal changes or increased losses. For all specimens, 750°C SRA treatment consistently provided better iron loss reduction than 850°C treatment. SRA primarily influenced anomalous loss components, which contributed significantly to the observed changes in total iron losses.

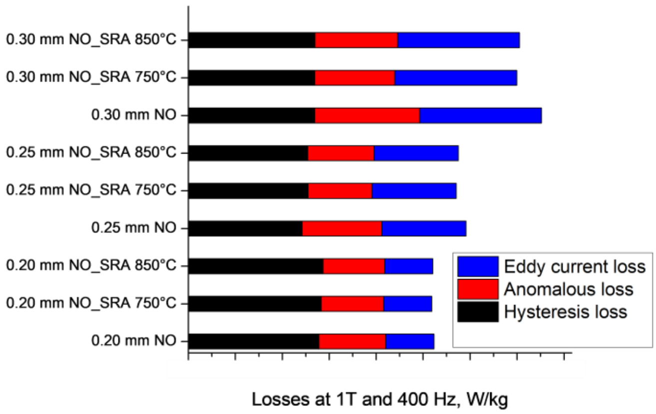

Figure 1. Decomposed core losses before and after SRA for three types of specimens. Stress-relief annealing was performed at 750°C and 850°C in a nitrogen atmosphere.

References

[1] G. Bertotti, IEEE Trans. Magn. 24 (1988) 621–630.