Effect of high heating rate and soaking time on microstructure and magnetic properties of non-oriented electrical steel

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The magnetic properties of non-oriented electrical steels (NOESs) are influenced by the production process parameters at final annealing, which play a crucial role in the development of crystallographic texture and microstructure. This study investigates the effect of high heating rates and soaking time on the annealed microstructure and magnetic properties of an ultra-low-carbon NOES with 2%Si. The high heating rates increase the high-angle boundary line length density at the beginning of the soaking stage providing more driving force during grain growth for these samples. Despite the clear effect of heating rate and soaking time on grain size and texture, the magnetic polarization differences among the samples were negligible.

Keywords: non-grain oriented; high heating rate; electrical steels; magnetic polarization; driving force.

1. Introduction

The magnetic properties of non-oriented electrical steels (NOESs) are strongly dependent on production process parameters, i.e., grain size and crystallographic texture are affected by cold rolling reductions and annealing parameters [1]. For this reason, the final annealing heating rate, temperature, and time play a crucial role in forming annealing microstructure and texture and, consequently, magnetic properties. This work investigated the influence of high heating rates and soaking times at the final annealing of an ultra-low-carbon NOES with 2%Si.

2. Methods

The starting material is an ultra-low-carbon Fe-2%Si with 0.50 mm thick and 78% of cold-rolled reduction. Samples were cut with dimensions of 10 x 4 mm and heated in a vacuum environment by an induction furnace of a BAHR DIL 805 dilatometer at 960 ºC under 9 different combinations of heating rates (from 10 to 300 ºC/s) and soaking time (from 0 to 60 seconds). All samples were cooled down under a controlled cooling rate of 100 ºC/s in He atmosphere. The microstructure and texture characterization of the annealed samples were conducted in the longitudinal cross-sectional area by Electron Backscatter Diffraction (EBSD) measurements in a Scanning Electron Microscope (SEM) FEI model XL-30 equipped with Lab6 filament operated in 20 kV. Accessing the magnetic properties of small-sized specimens poses a significant challenge. For this reason, the magnetic polarization at 5000 A/m (J_{50}) was calculated by a linear regression to average magnetocrystalline anisotropy energy as shown by [2-4].

3. Results

Figure (1a) presents the effects of each combination of heating rate and soaking time on sample microstructures along the longitudinal section. The samples presented a fully recrystallized microstructure with equiaxed grains. Furthermore, the high heating rates increased the high angle boundary line length density (see Figure 1b) at the beginning of the soaking stage providing more driving force during grain growth for these samples, leading to a microstructure with higher grains at the end of soaking.

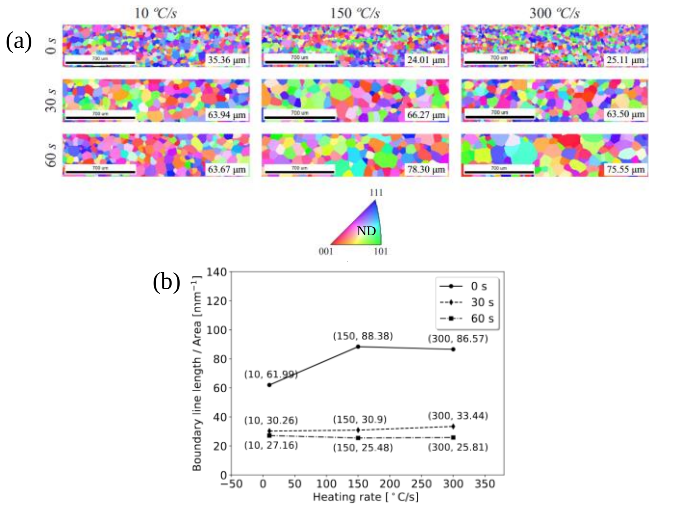

Figure 1: (a) Microstructure and average grain size of annealed samples annealed in the longitudinal section and (b) the high-angle boundary line length per area [mm^{-1}].

Nonetheless, despite the clear effect of heating rate and soaking time on grain size and texture, the average magnetocrystalline anisotropy energy and J_{50} differences among the samples were negligible. This observation is consistent with Zaizen [5] findings, which show that a significant increase in magnetic polarization caused by a high heating rate is expected to occur only in high-C electrical steels. It is well-established that increasing grain size in NOESs can significantly reduce total core loss by optimizing the balance between hysteresis and excess losses. Therefore, it is observed in samples with 60 s of soaking time that a high heating rate increased grain size, leading to a possible reduction in core losses.

References

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