LABORATOIRE D'ELECTROTECHNIQUE ET D'ELECTRONIQUE DE PUISSANCE DE LILLE

# Master project, 2025 - 26

— Exploratory Study of the Effect of a Thermal Pre-Aging Treatment on the Aging of Electrical Steels and Its Consequences on Magnetic Properties —

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## Context

Magnetic properties of electrical steels (ES) can deteriorate due to the presence of inclusions and precipitates, which hinder the motion of magnetic domain walls during the magnetization process. Subsequent precipitation of second-phase particles − such as iron carbides − at room temperature over long periods of time, or at elevated temperatures for shorter periods of time, can degrade the magnetic performance, a phenomenon known as *magnetic aging*. Magnetic aging refers to the irreversible degradation of magnetic properties in ES. As shown in Fig. 1, this can lead to an increase of more than a 30% increase in iron losses after 300 hours at 180 °C, for a typical electrical steel grade [1]. The proposed topic was inspired by an old but insightful publication [2] on a related subject, which sparked reflection during L. Saleh's PhD thesis (ANR MASTERMIND 2) and motivated a deeper investigation of carbide precipitation mechanisms in ES. Through an experimental approach, the study aims to identify the thermal conditions that allow for precise control of magnetic properties throughout the ES life cycle.

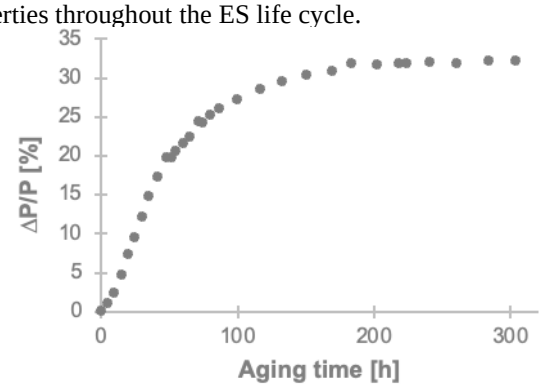


Fig. 1: Increase in iron losses with aging time at 180 °C, measured under a sinusoidal magnetic flux density with a peak value of 1.5 T and a frequency of 50 Hz, for the electrical steel grade M470-50A.

## Objective

Explore the impact of an initial short-duration high-temperature heat treatment (pre-aging) on the magnetic behavior − particularly iron losses − of electrical steels subjected to long-duration low-temperature aging.

## Work steps

- Literature Review: bibliographic study on magnetic materials, electrical steels, magnetic aging, inclusions and precipitates in electrical steels;
- Material Selection: selection of typical non-oriented (NO) and grain-oriented (GO) ES for the study.
- Application of different time/temperature combinations for an initial short-duration heat treatment at temperatures exceeding 350 °C;
- Applications of a second heat treatment at lower temperatures (150–200 °C) for several hundred hours;
- Determine whether pre-aging significantly reduces carbon supersaturation in solid solution, thereby leading to less carbide precipitation during the second thermal aging process, and thus a measurable reduction in iron losses compared to ES that have not undergone pre-aging.

## Key words

Electrical steels, magnetic aging, magnetic properties, temperature, time

*References*

*[1] Lea Saleh, Oualid Messal, Abdelkader Benabou, Interpretation of the isothermal aging of industrial non-oriented electrical steels based on the iron loss separation approach: Experimental study and modeling, Journal of Magnetism and Magnetic Materials, Volume 630, 2025, 173360, ISSN 0304-8853, https://doi.org/10.1016/j.jmmm.2025.173360.*

*[2] G.M. Michal and J.A. Slane, Carbide Precipitation in Electrical Steels, JOURNAL OF METALS, January 1986.*