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# Magnetic Properties Evolution During Thermal Ageing of High Permeability Nanocrystalline FeSiNbCuB Alloys Annealed under Magnetic Longitudinal Field

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## Introduction

### Context

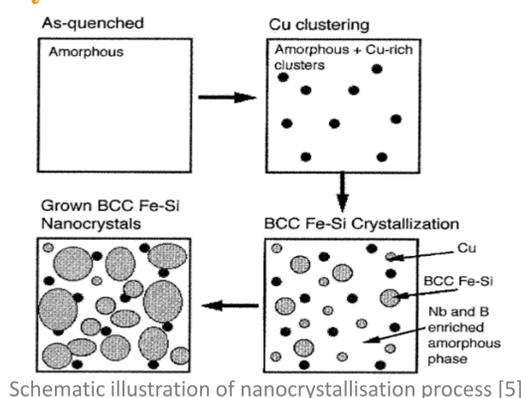
In aircraft applications and electric vehicles industry, the compactness of electrical systems is very important to increase energy efficiency but this reduction of mass and volume exposes magnetic components to high temperatures and decreases their magnetic properties over time. In this paper we study particularly nanocrystalline materials ageing at four temperatures.

### Objectives

- Nanocrystalline  $\text{Fe}_{73.5}\text{Cu}_1\text{Nb}_3\text{Si}_{15.5}\text{B}_7$  magnetic behavior during thermal ageing.
- Comparison between three nanocrystalline materials nuances (annealed differently).

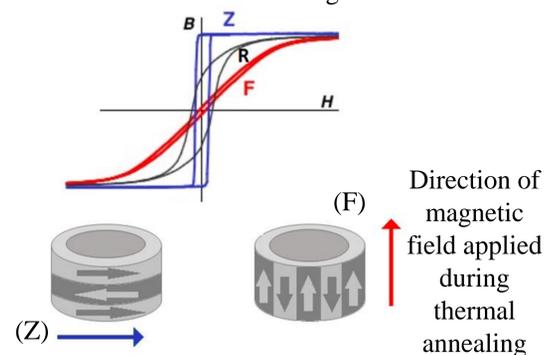
## Tested Materials & Methodology

### Nanocrystalline microstructure



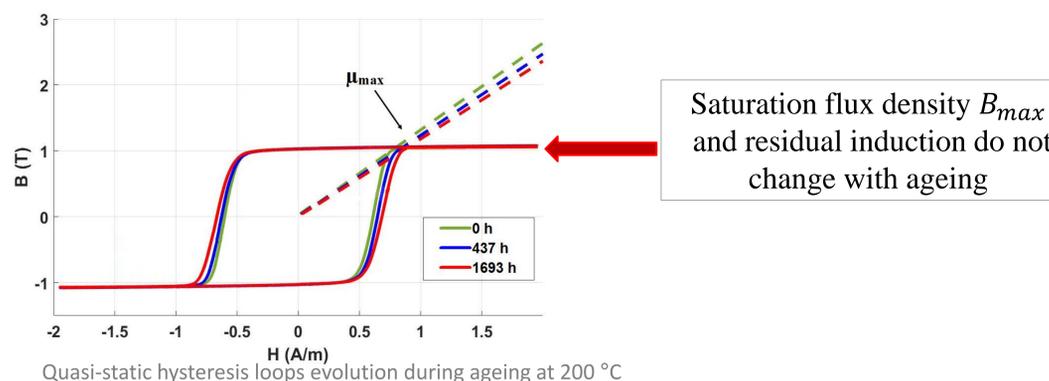
### Different annealing methods

- (R) : annealed without magnetic field
- (Z): annealed with longitudinal magnetic field
- (F): annealed with transversal magnetic field

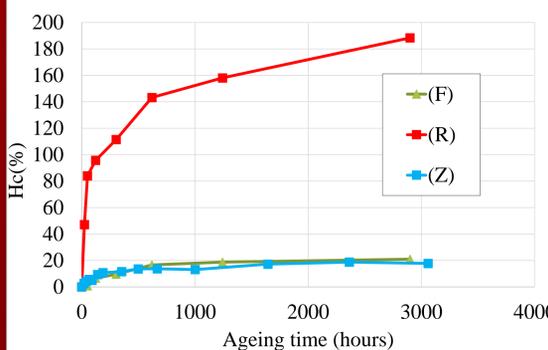
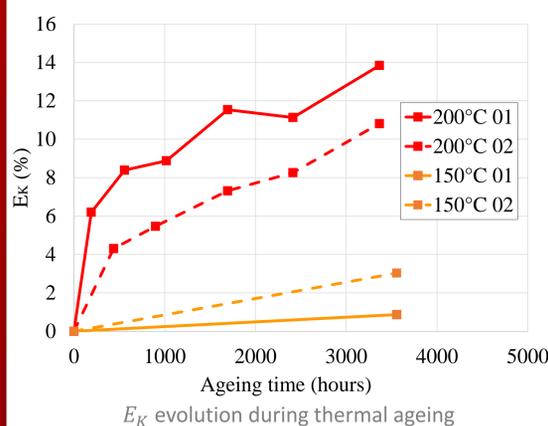
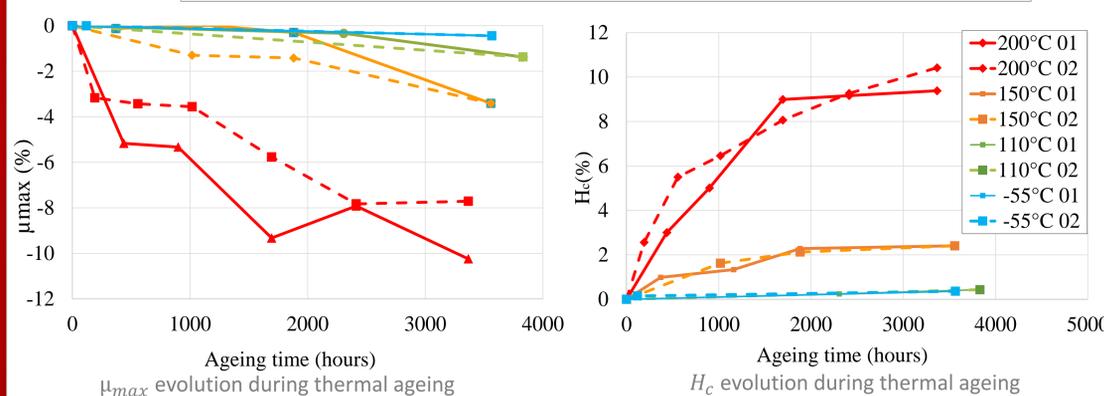


- Quasi-static hysteresis loops were measured on nanocrystalline (Z) cores.
- Monitoring macroscopic magnetic properties during ageing at four temperatures.

## Results & discussion



Remarkable degradation in coercive force  $H_c$  and maximal permeability  $\mu_{max}$  at 200 °C



Nanocrystalline (R) annealed without field aged a lot more than other nuances

## Conclusion & perspectives

- During ageing, the increase of total anisotropic energy doesn't come from the existing energies in the material. We suppose that a new energy appeared over time which disturbs domain patterns.
- Due to the applied field during the annealing, domains are forced to follow a specific direction so the new energy introduced by ageing disturbs the domain less than the case of materials annealed without field.
- We assume that the degree of this disturb depends on the competitiveness of the introduced energy with ageing compared to the anisotropy energy initially dominating in the material.
- Kerr images will be observed in further studies in aim to prove these hypotheses.

## References

- [1] Y. Yoshizawa, S. Oguma, and K. Yamauchi, "New Fe-based soft magnetic alloys composed of ultrafine grain structure," *J. Appl. Phys.*, vol. 64, no. 10, pp. 6044–6046, 1988.
- [2] G. Herzer, "Grain structure and magnetism of nanocrystalline ferromagnets," *IEEE Trans. Magn.*, vol. 25, no. 5, pp. 3327–3329, 1989.
- [3] A. Lekdim, L. Morel, and M. Raulet, "Magnetic ageing study of high and medium permeability nanocrystalline FeSiCuNbB alloys," *J. Magn. Magn. Mater.*, vol. 428, no. December 2016, pp. 260–268, 2017.
- [4] K. Yoshizawa, Y. Yamauchi, "Effect of magnetic field annealing on magnetic properties in ultrafine crystalline Fe-Cu-Nb-Si-B Alloys," *IEEE Trans. Magn.*, vol. 25, no. 5, pp. 3324–3326, 1989.
- [5] G. Herzer, Chapter 3 Nanocrystalline soft magnetic alloys, *Handb. Magn. Mater.* 10 (1997) 415–462.

Total anisotropic energy  $E_K$  increased with ageing, this energy calculated using the initial magnetization curve :

$$E_K = \int_0^{B_{sat}} H \cdot dB \approx \langle E_{K1} \rangle + E_{\lambda\sigma} + E_{Ku}$$

- Random magnetocrystalline energy

$$\langle E_{K1} \rangle \approx \langle K_1 \rangle = f_x^2 \cdot \frac{K_1 \cdot D^6}{A^2} \quad (\text{G. Herzer})$$

Microstructure measurements showed that this energy has not changed during ageing.

**This energy dominates in nanocrystalline (R)**

- Magnetoelastic energy

$$E_{\lambda\sigma} \approx K_{u\sigma} = -\frac{3}{2} \cdot \lambda_s \cdot \sigma$$

Supposing that internal stress  $\sigma$  is a constant, magnetostriction  $\lambda_s$  measurements showed that  $E_{\lambda\sigma}$  energy has decreased during ageing.

- Induced energy during annealing  $E_{Ku}$

**This energy dominates in nanocrystalline (F) and (Z)**