



**HAL**  
open science

## Static Hysteresis modelling of FeSi GO in rolling and transverse directions

Fabien Sixdenier, Riccardo Scorretti, Atef Lekdim

► **To cite this version:**

Fabien Sixdenier, Riccardo Scorretti, Atef Lekdim. Static Hysteresis modelling of FeSi GO in rolling and transverse directions. SMM24, Sep 2019, Poznan, Poland. hal-02284858

**HAL Id: hal-02284858**

**<https://hal.science/hal-02284858v1>**

Submitted on 12 Sep 2019

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

# Static Hysteresis modelling of FeSi NO sheets in rolling and transverse directions

Fabien SIXDENIER<sup>(1)</sup>, Riccardo SCORRETTI<sup>(1)</sup> Atef LEKDIM<sup>(2)</sup>

(1) : Univ Lyon, Université Claude Bernard Lyon 1, INSA Lyon, ECLyon, CNRS, Ampère, F-69100, Villeurbanne, France

(2) : LEM TECH FRANCE, 575-655-LES ALLEES DU PARC, 69800 SAINT PRIEST, France



## Context and objectives

1. predict magnetic losses or magnetic waveforms in NO FeSi sheets when excited in both rolling (RD) and transverse direction (TD).
2. Need for a vectorial hysteresis model
3. Modification of the vector play model [1] improved by [2]

## Original isotropic Model

$$\mathbf{h} = \mathbf{h}_{re} + \mathbf{h}_{ir} \quad (1)$$

$$\mathbf{h}_{re} = \sum_{k=1}^N \omega_k \mathbf{h}_{re}^k \quad (2)$$

$$\mathbf{h}_{re}^k = \begin{cases} \mathbf{h}_{re0}^k & \text{if } \|\mathbf{h} - \mathbf{h}_{re0}^k\| < \chi^k \\ \mathbf{h} - \chi^k \cdot \frac{\mathbf{h} - \mathbf{h}_{re0}^k}{\|\mathbf{h} - \mathbf{h}_{re0}^k\|} & \text{otherwise} \end{cases} \quad (3)$$

$$\mathbf{M} = M_{an}(\|\mathbf{h}_{re}\|) \cdot \frac{\mathbf{h}_{re}}{\|\mathbf{h}_{re}\|} \quad (4)$$

$$\mathbf{b} = \mu_0(\mathbf{M} + \mathbf{h}) \quad (5)$$

- $\chi^k$ : maximum pinning field of the  $k^{th}$  cell
- $\omega_k$ : weight of the  $k^{th}$  cell

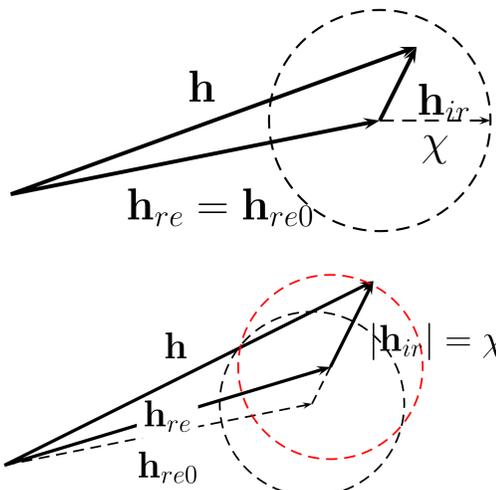


Figure 1: Example of the two situations of (3)

## Modifications to include anisotropy

Modifications proposed in [3] to take into account magnetic anisotropy in FeSi NO sheets.

1. Modifications of the anhysteretic curve (4)

$$\mathbf{M} = M_{an}(\|\mathbf{h}_{re}\|) G(\gamma) \frac{\mathbf{h}_{re}}{\|\mathbf{h}_{re}\|} \quad (6)$$

with  $\gamma$ , a scalar parameter to identify

$$G(\gamma) \frac{\mathbf{h}_{re}}{\|\mathbf{h}_{re}\|} = \begin{bmatrix} 1 & 0 \\ 0 & \gamma \end{bmatrix} \begin{pmatrix} e_{RD} \\ e_{TD} \end{pmatrix} \quad (7)$$

2. Modifications of the coercivity (pinning field) by making cells ellipsoidal.

$$\chi^k(\alpha, \beta) = \chi_{RD}^k (1 + (\beta - 1)(1 - \alpha^2)) \quad (8)$$

with :

- $\beta$  : a scalar parameter to determine
- $\chi_{RD}^k$  : pinning field of the  $k^{th}$  cell in RD.
- $\alpha$  : cosine of the angle between  $\mathbf{h} - \mathbf{h}_{re0}^k$  and  $\mathbf{e}_{RD}$

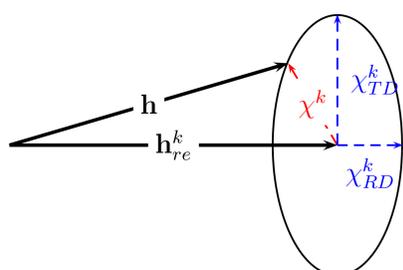


Figure 2: Illustration of ellipsoidal spheres

## Tested material and methods

- FeSi 3%wt 0.5 mm thick non oriented material
- Characterizations have been made by CADEMA group from Torino for the TEAM32 problem [4]
- Several static loops were measured on Epstein device along different angles with respect to RD for different amplitudes.
- Loops measured at RD and TD are used for tests and identification of parameters.
- Loops at intermediate directions are only used for tests.

## Identification Results

the  $(\omega_k, \chi^k)$  sets have been identified following the protocol described in [5].

Table 1: Values of  $\omega_k$  and  $\chi^k$  sets in RD

$\omega_k$	0.021	0.237	0.3954	0.1681	0.1773
$\chi^k$	0	25.1	51.2	70.4	127.7
$\gamma$	0.965				$\beta$ 1.3

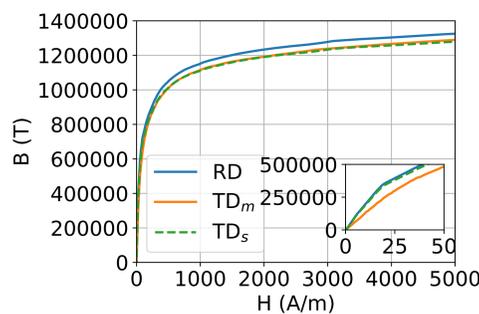


Figure 3: Measured and simulated anhysteretic functions in RD and TD

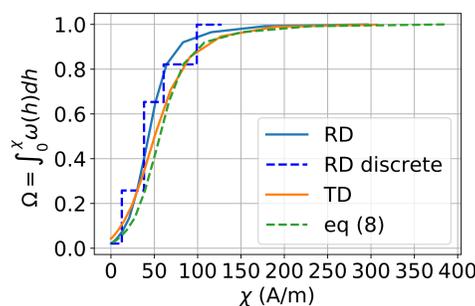


Figure 4: Cumulative distribution of the weights versus pinning field in RD and TD and result of eq (8)

## Example of results

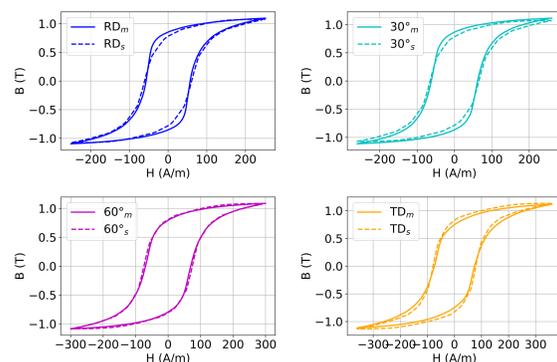


Figure 5: Comparison of measured and simulated loops at 1.1 T for different angles

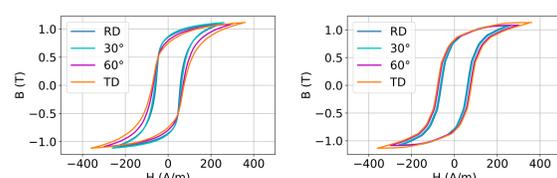


Figure 6: Measured (left) and simulated (right) loops at 1.1 T for different angles

## Accuracy analysis of the loops

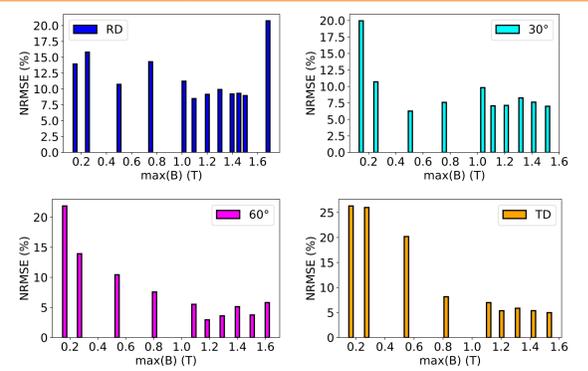


Figure 7: Accuracy versus amplitude of the loops in each direction

## behavior of the losses vs angle

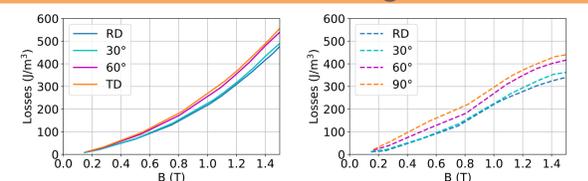


Figure 8: Measured (left figure) and simulated (right figure) losses vs  $B_{max}$  for different angles

## Discussion

- Accuracy in RD is not so good for two reasons:
  - coercivity can not be considered as constant along the  $M_{an}(H_{an})$  curve.

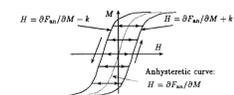


Figure 9: Assumption to respect [1]

- identification of first cells following [5] may be inaccurate. Following [6] can improve accuracy in this region as recently shown in [7].
- Proposed modifications are sufficient to qualitatively take into account of the anisotropy
- Losses behaviour vs angle is qualitatively well retrieved. Accuracy of computed losses should be improved.

## Conclusions and perspectives

- A readily vectorial hysteresis model including anisotropy has been tested.
- Better identification of  $(\omega_k, \chi^k)$  or/and improvements of the original model must be made (constant coercivity assumption) for FeSi materials
- More complex modifications can be imagined to improve the accuracy such as
$$\mathbf{M} = \begin{pmatrix} M_{anRD}(\|\mathbf{h}_{re}\|) \\ M_{anTD}(\|\mathbf{h}_{re}\|) \end{pmatrix} \frac{\mathbf{h}_{re}}{\|\mathbf{h}_{re}\|} \quad (9)$$
- inverse the model to have  $\mathbf{h}(\mathbf{b})$
- Test this approach with FeSi GO materials

## References

- [1] A. Bergqvist. Magnetic vector hysteresis model with dry friction-like pinning. *Physica B: Condensed Matter*, 233(4):342–347, 1997.
- [2] V. François-Lavet, F. Henrotte, L. Stainier, L. Noels, and C. Geuzaine. Vectorial incremental nonconservative consistent hysteresis model. In *Proceedings of the 5th International Conference on Advanced Computational Methods in Engineering (ACOMEN2011)*, Lige, Belgium, November 2011. ACOMEN2011.
- [3] Simon Steentjes, François Henrotte, and Kay Hameyer. Energy-based ferromagnetic material model with magnetic anisotropy. *Journal of Magnetism and Magnetic Materials*, 425:20–24, 2017.
- [4] Description of team problem: 32 a test-case for validation of magnetic field analysis with vector hysteresis.
- [5] Kevin Jacques, Simon Steentjes, François Henrotte, Christophe Geuzaine, and Kay Hameyer. Representation of microstructural features and magnetic anisotropy of electrical steels in an energy-based vector hysteresis model. *AIP Advances*, 8(4):047602, 2018.
- [6] Fabien Sixdenier and Riccardo Scorretti. Numerical model of static hysteresis taking into account temperature. *International Journal of Numerical Modelling: Electronic Networks, Devices and Fields*, pages e2221–n/a, 2017. e2221.jnm.2221.
- [7] Maria Roberta Longhitano, Fabien Sixdenier, Riccardo Scorretti, Christophe Geuzaine, François Henrotte, and Laurent Krähenbühl. Comparison of identification protocols of a static hysteresis model. In *Compumag 2019*, Paris, France, July 2019.