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Plus d'innovations pour la compétitivité des PME de l'automobile et de la mobilité

Les instituts CARNOT de l'automobile et de la mobilité

Magnetism in *Non Destructive Testing*

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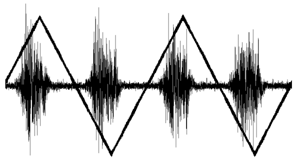
Micro-magnetic NDT

Why micro-magnetic NDT?






	Ultra-sounds	***Chemical Baths***	***Micro-magnetic NDT***	***X-Ray***
Surfacic / Sub-surfacic control	😐	🙂	🙂 !	🙂
Deep control	🙂	🙁	🙁	🙁
Production line Integration	😐	😐	🙂 !	🙁
Contamination	🙂	🙁	🙂 !	😐
Cost	😐	🙂	🙂 !	🙁

Micro-magnetic NDT vs time

1950


Magnetoscopy

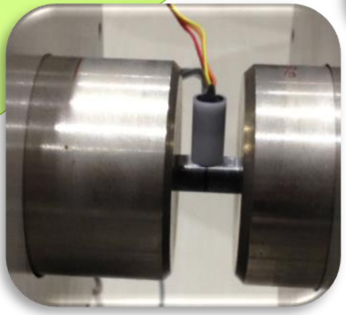
1970

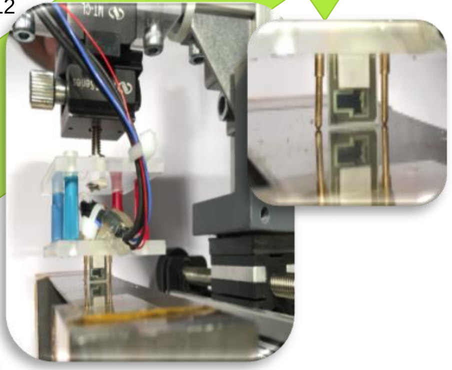
Barkhausen noise characterization



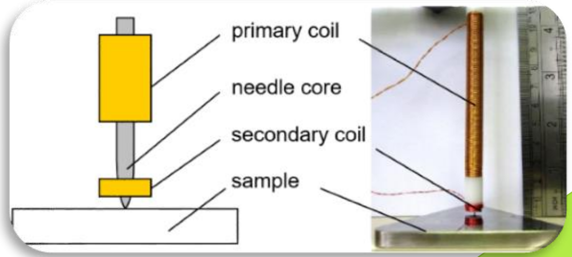
Eddy current sensor,
www.emersonprocess.com

1990


Incremental permeability sensor,
Gupta 2017


Double point probe sensor

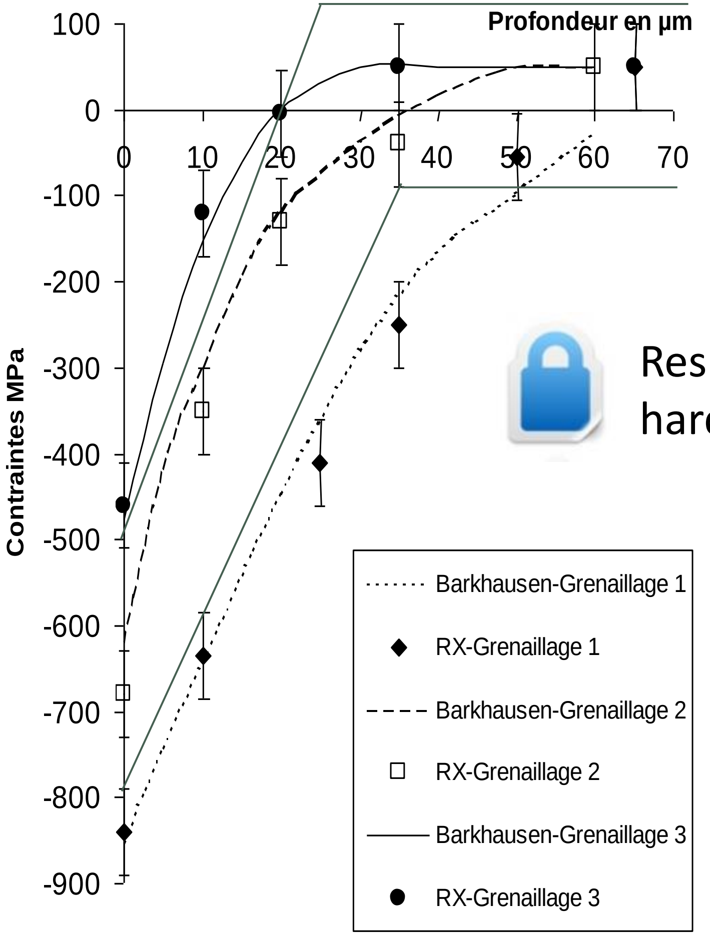
2010



Single point probe sensor, Amiri 2012

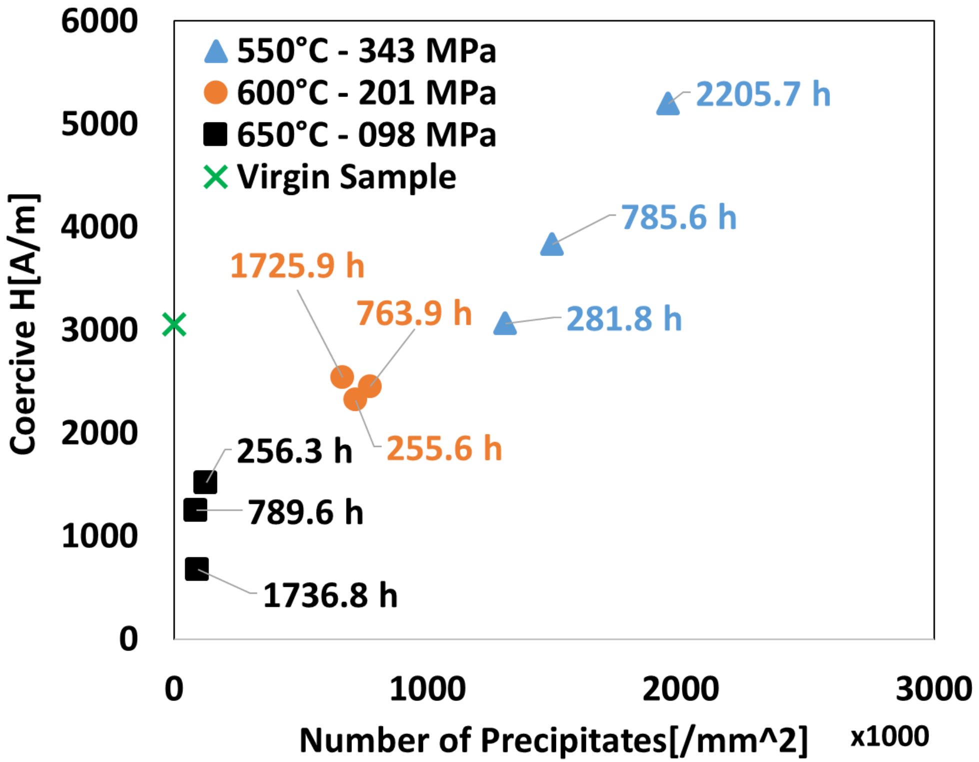

GMR vector magnetic field measurement
DOI: 10.1109/JSEN.2019.2933153

Research problematic



Residual Stress gradient / hardness

Sub-surfacic heterogeneity

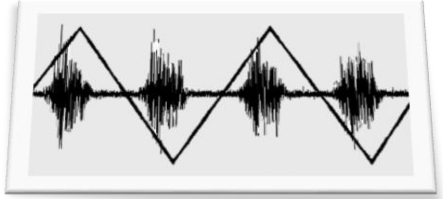


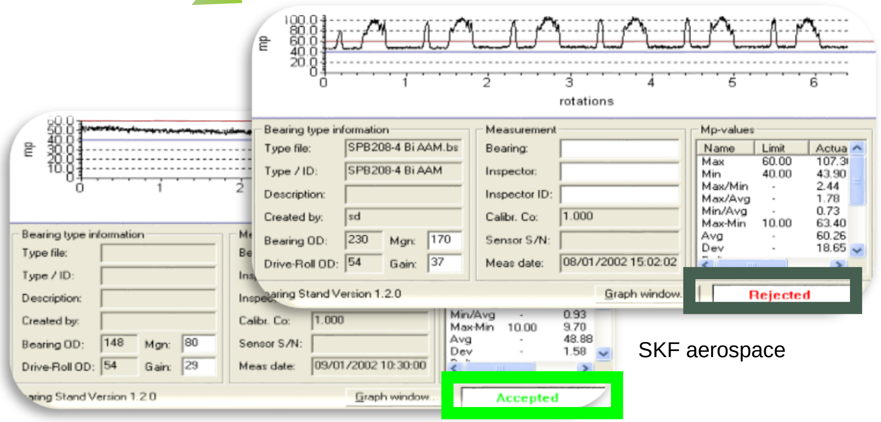
_ Correlation magnetic properties / Microstructural information
_Time variation of these parameters

Research problematic

http://ast.stresstechgroup.com

Time consuming
experimental process





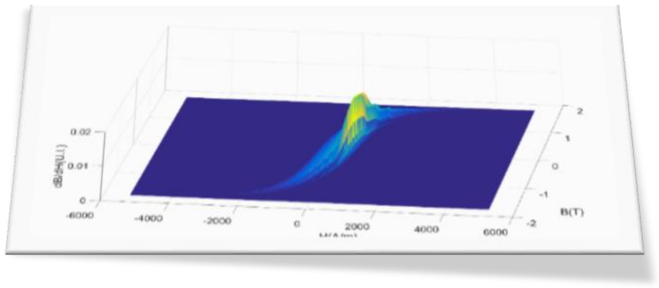
SKF aerospace

- Set rejection threshold
- Intern residual stress evaluation
- Creep evaluation

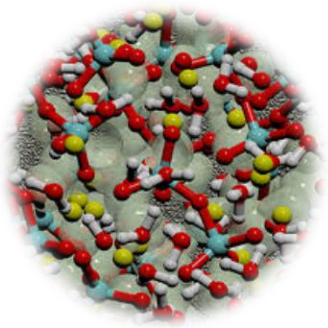
Simulation

Phenomenological vs predictive models

A **phenomenological model:**
_ Describes the empirical relationship of phenomena.
_ Consistent with the fundamental theory but not derived from.
_ Need experimental results to be parametered



Predictive modelling uses statistics and fundamental theory to predict the material behavior.



Ab initio
https://computation.llnl.gov/ab-initio-simulation-atomistic-model-cement,
www.emersonprocess.com

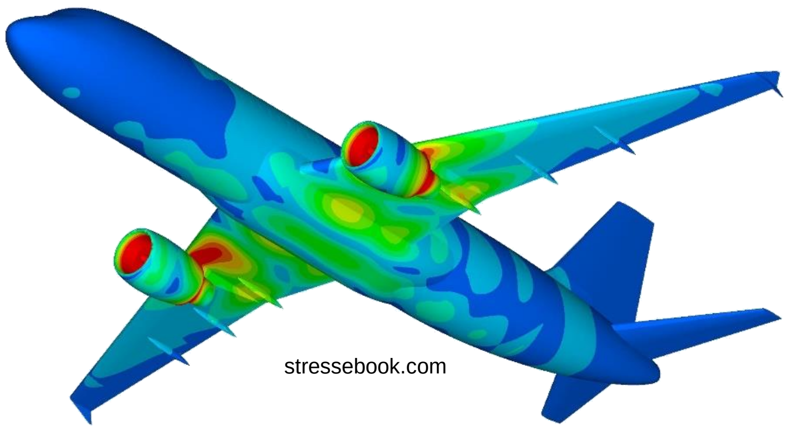
+ Accuracy
- Physical interpretation

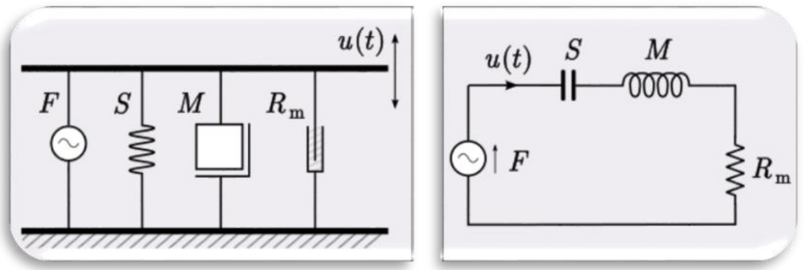
+ Physical meaning
- Time consuming and scaling issues

Space discretized vs Lump models

Discretization:
Transform continuous functions, models, variables, and equations into discrete counterparts

A **lumped element model** simplifies spatial distribution into discrete entities under certain assumptions.

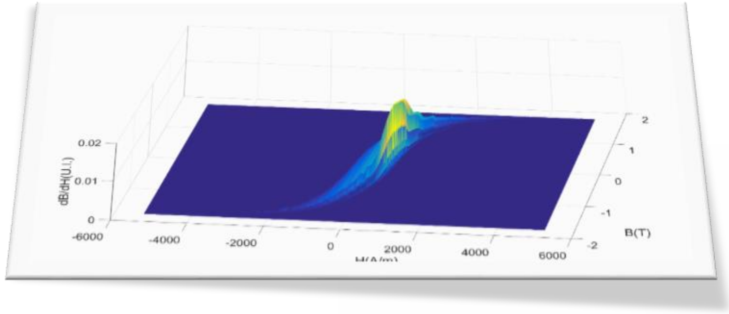




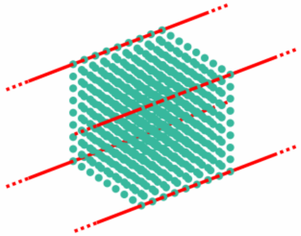
- (+) Accuracy
- (−) Time consuming simulation, convergence issues

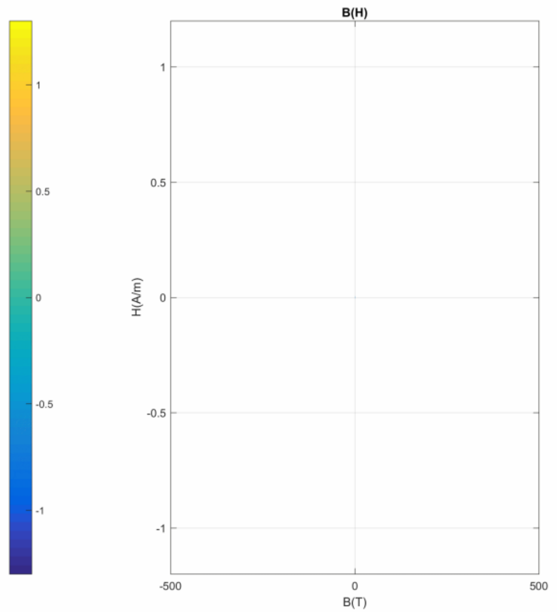
- (+) Simple solution
- (−) Restrictive assumption

Numerical tool, space discretization approach



$$
\begin{cases}
\rho.\dfrac{dB(t)}{dt} = H(t) - f^{-1}{}_{static}(B) \\
\Delta H(t) = -\sigma.\dfrac{dB(t)}{dt} \\
\Delta H(t) = -\dfrac{\sigma}{\rho}.\left(H(t) - f^{-1}{}_{static}(B)\right)
\end{cases}
$$



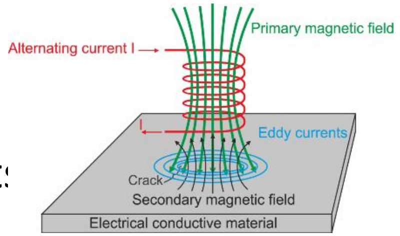


Local magnetic simulation, two contributions:

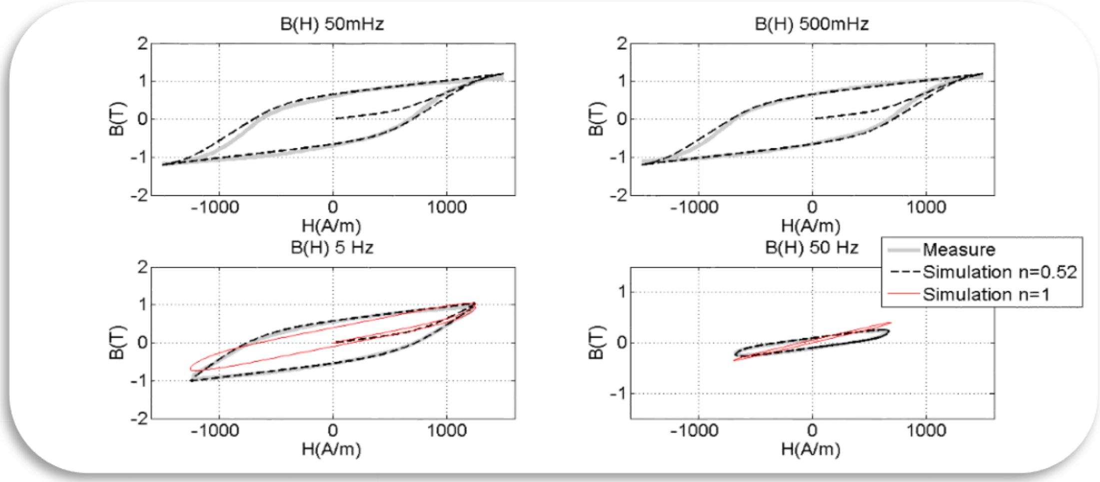
increasing H

_ domain wall motions

_ Macroscopic eddy currents



Numerical tool, lump model approach



$$\begin{cases} \rho.\dfrac{d^nB(t)}{dt^n} = H(t) - f^{-1}{}_{static}(B) \\ \rho.\dfrac{d^nB(t)}{dt^n} = \rho.\left[\lim\limits_{h\to 0} h^{-n}\sum\limits_{k=0}^{m}(-1)^k\dfrac{\Gamma(n+1)}{\Gamma(k+1)\Gamma(n-k+1)}B(t-kh)\right] \\ \rho.\left[\lim\limits_{h\to 0} h^{-n}\sum\limits_{k=0}^{m}(-1)^k\dfrac{\Gamma(n+1)}{\Gamma(k+1)\Gamma(n-k+1)}B(t-kh)\right] = H(t) - f^{-1}{}_{static}(B) \end{cases}$$

➕ Numerical simplicity:

_ Physical meaning (Jiles-Atherton theory)

_ Fractional derivation

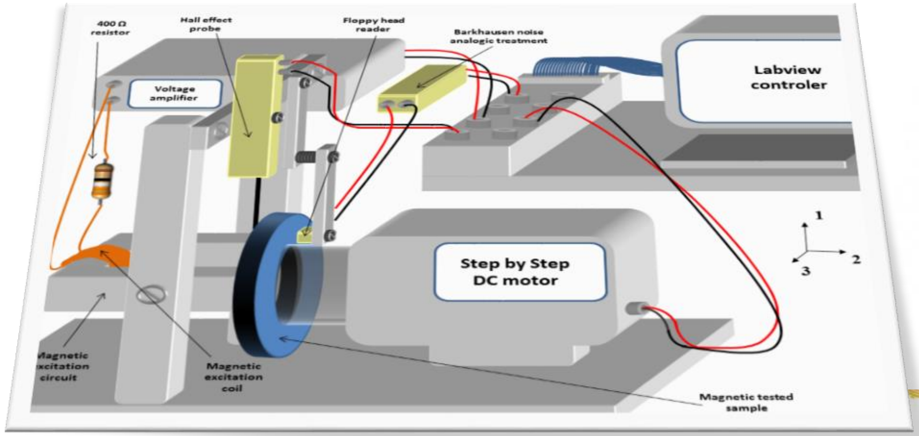
La recherche CARNOT FILIERES pour les entreprises CARNAUTO

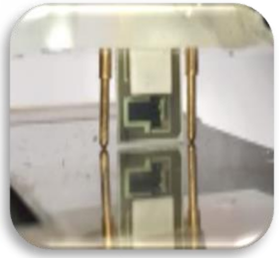
Numerical tool:

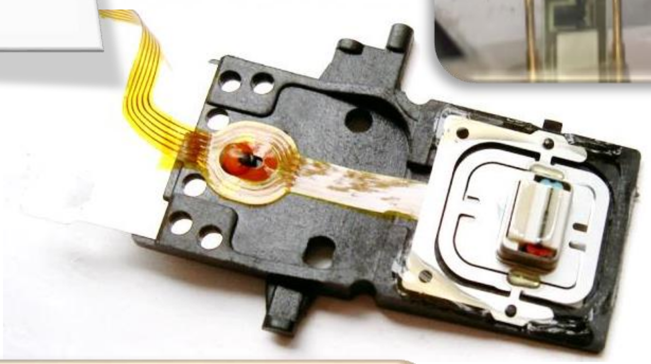
- Limited number of parameters
- Reduced simulation time
- Physical meaning
- Relation electrical / magnetic quantities
- Vector quantities

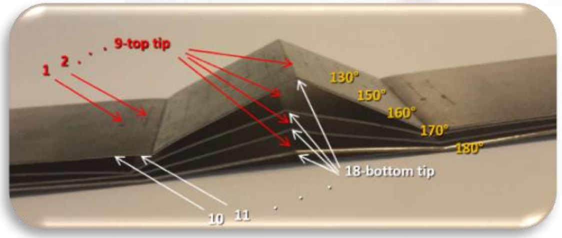
Instrumentation

local magnetic characterization,



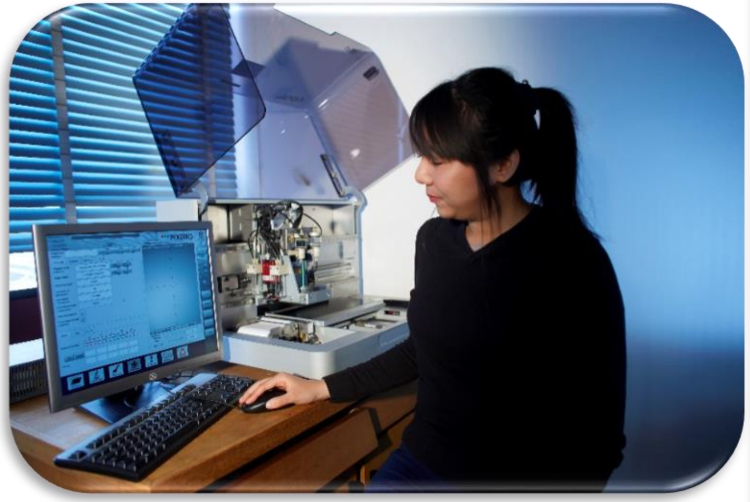




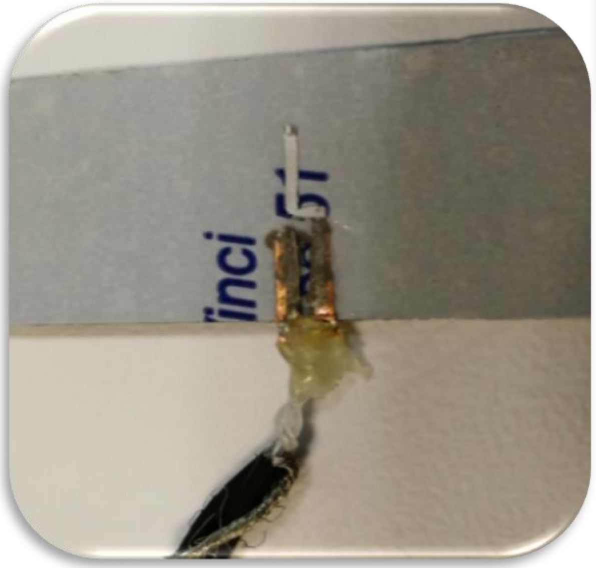


→ Vector quantities, collinear situation

Printed sensors for NDT



→

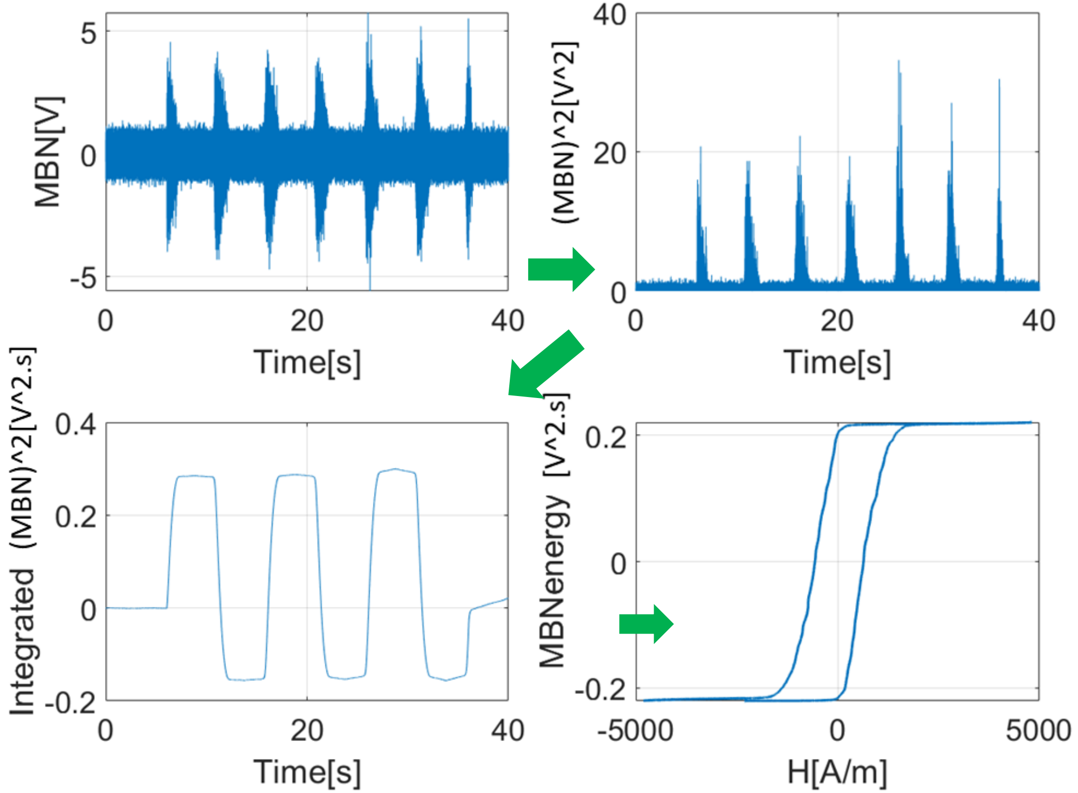


→ To embed sensors

→ Hidden components

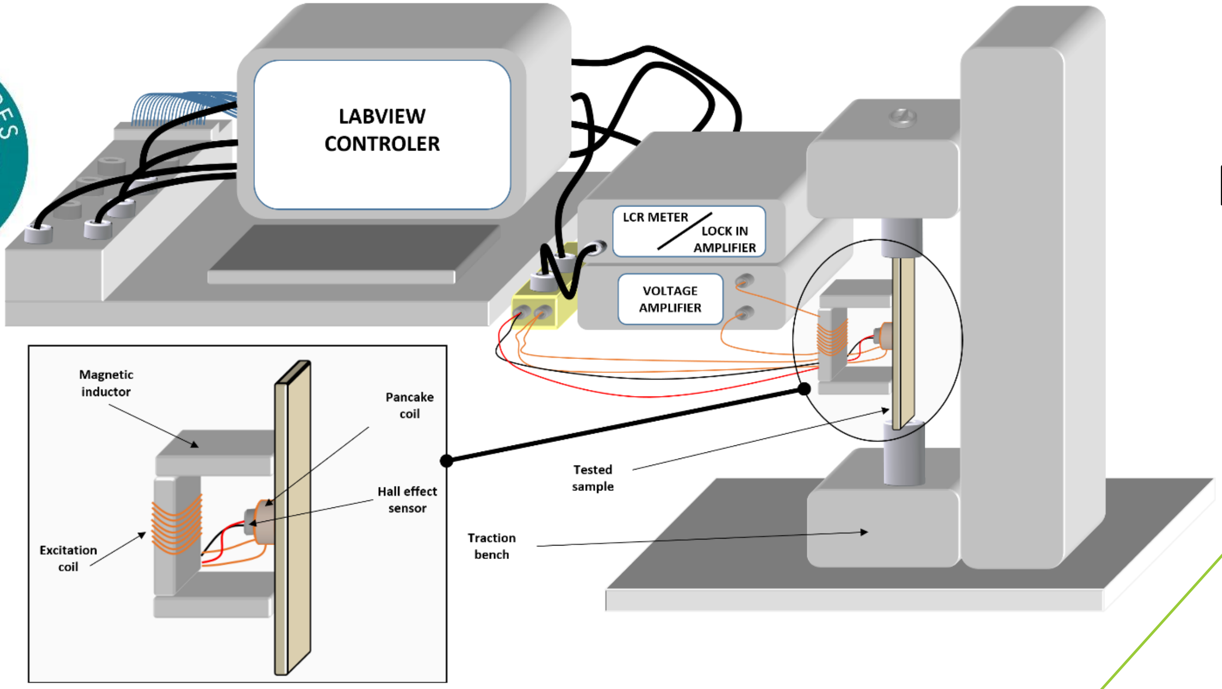
Reproducibility and stability

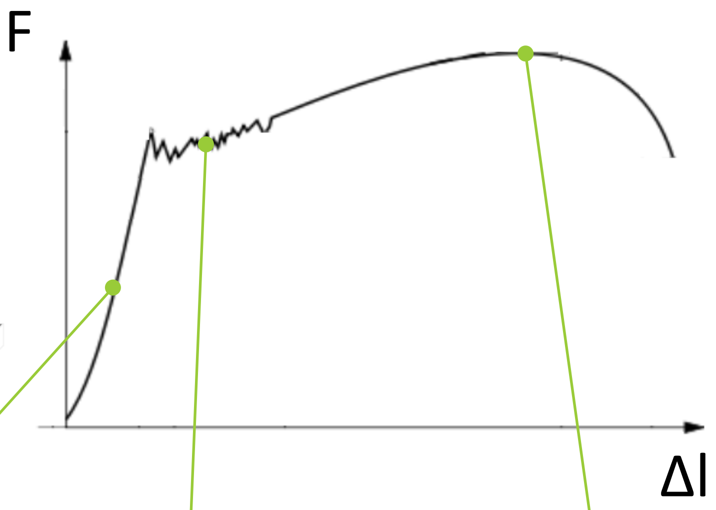
- The magnetic Barkhausen noise energy

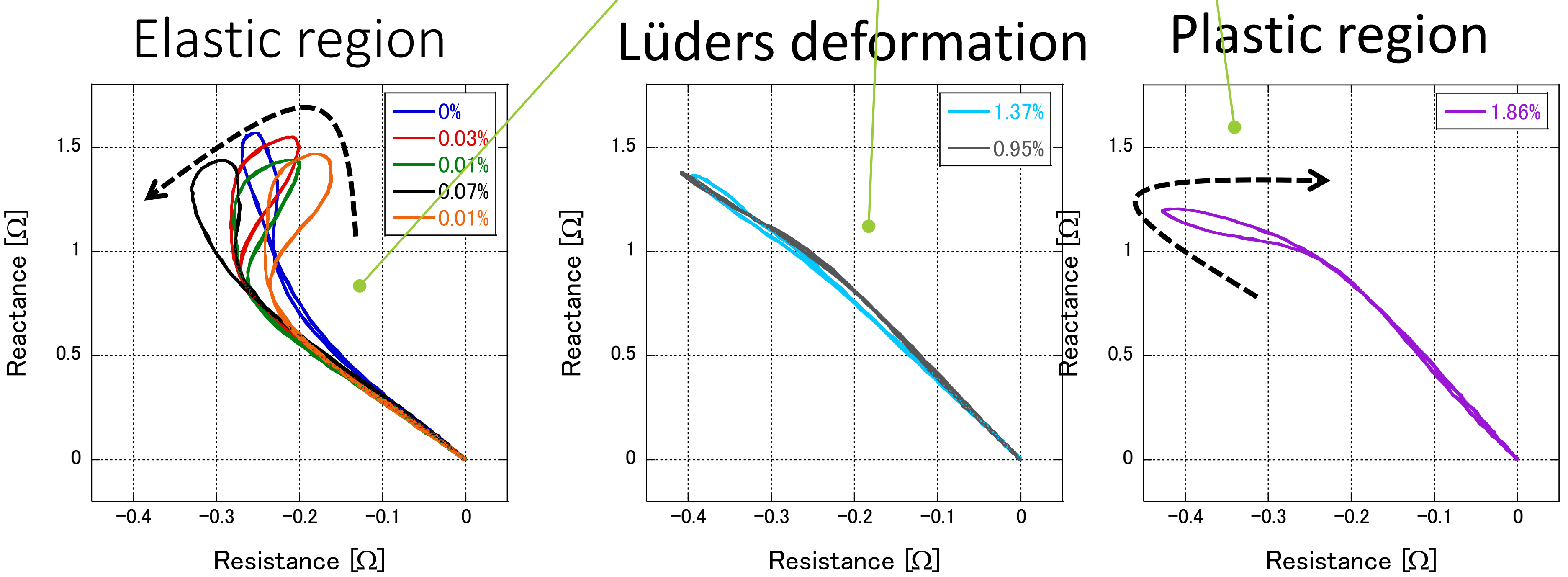


$$MBN_{energy}(H) = \left(\int_0^T Bark(t)^2 . sign\left(\frac{dH}{dt}\right) dt \right)(H)$$

Predictive measurement



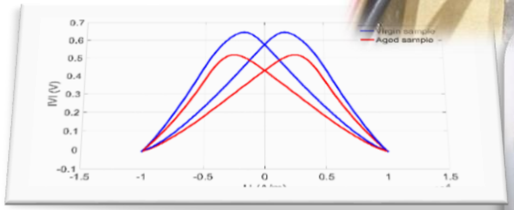


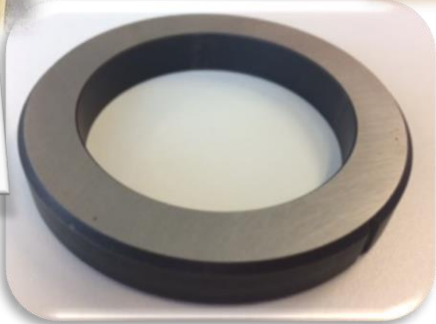


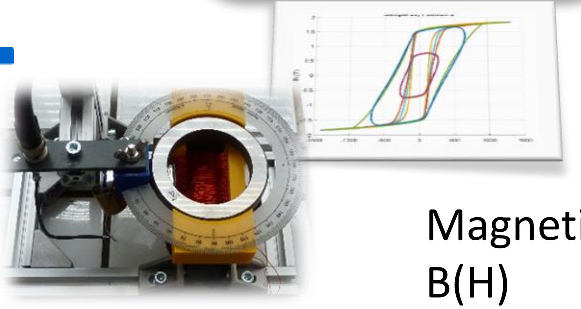
Instrumentation:

- Local information (in-depth informations)
- Real time control (SHM)
- Most signifiant/stable indicator
- Relation electrical / magnetic quantities
- Vector quantities

Exemple 1:



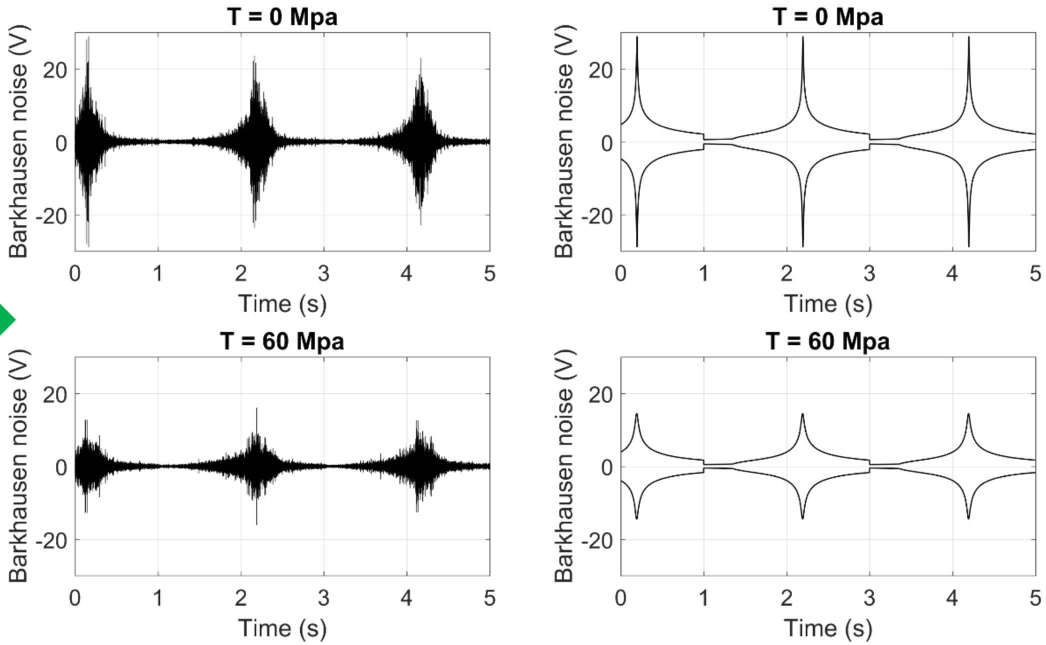




Magnetic incremental permeability

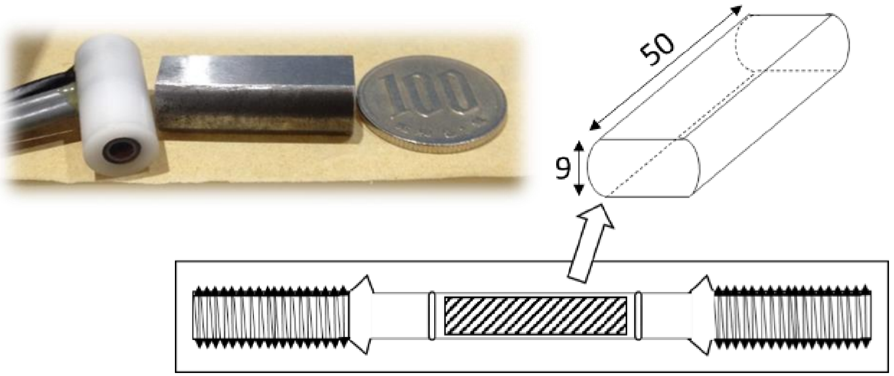
Magnetic Barkhausen noise

Magnetic hysteresis cycle B(H)



B. Ducharne, B. Gupta, Y. Hebrard, J. B. Coudert, “Phenomenological model of Barkhausen noise under mechanical and magnetic excitations”, IEEE Trans. on. Mag, vol. 99, pp. 1-6, 2018.

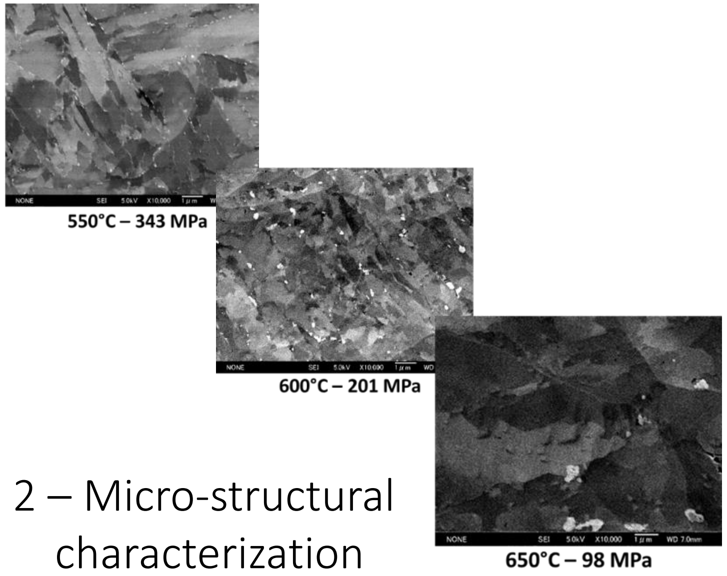
Exemple 2:



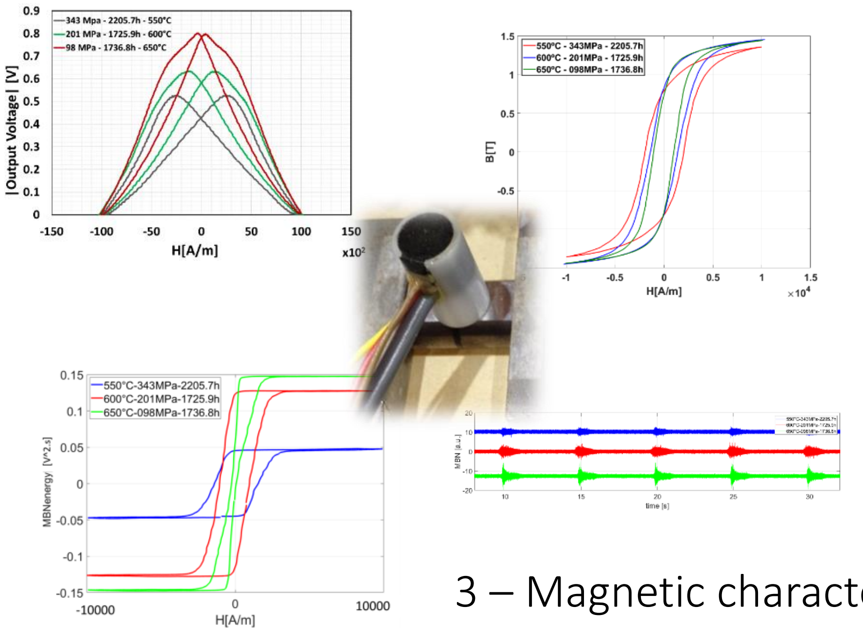
Sample number	Stress [MPa]	Temp [°C]	Test time [h]	LMP*
0	-	-	-	-
1	343	550	281.8	18479
2	343	550	785.6	18846
3	**343**	**550**	**2205.7**	**19215**
4	201	600	255.6	19565
5	201	600	763.9	19980
6	**201**	**600**	**1725.9**	**20289**
7	98	650	256.3	20686
8	98	650	789.6	21137
9	**98**	**650**	**1736.8**	**21453**

****Larson Miller Parameter***

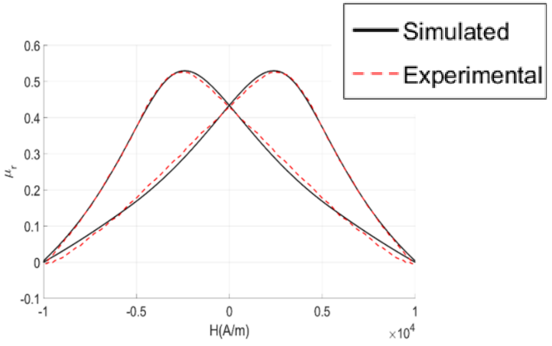
1 - Ageing

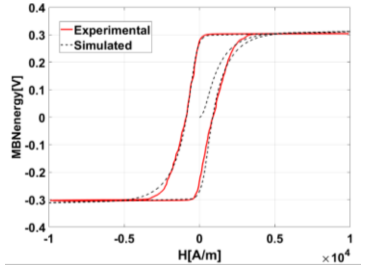


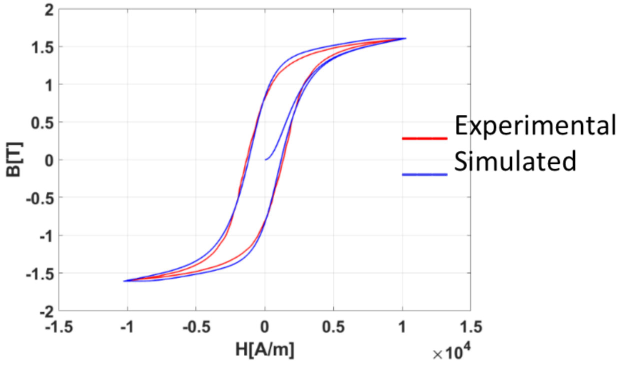
2 – Micro-structural characterization



3 – Magnetic characterization





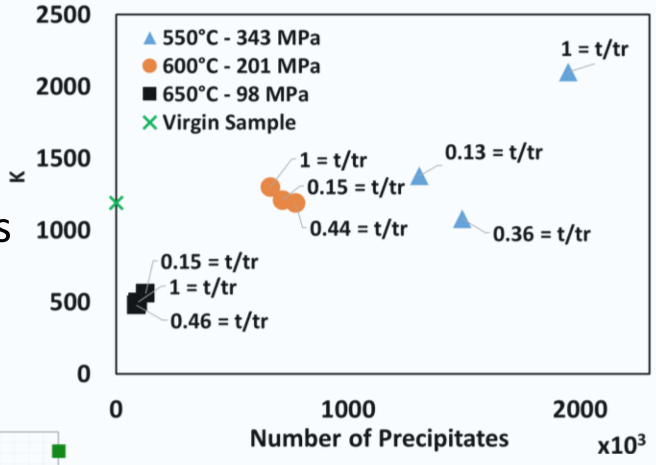


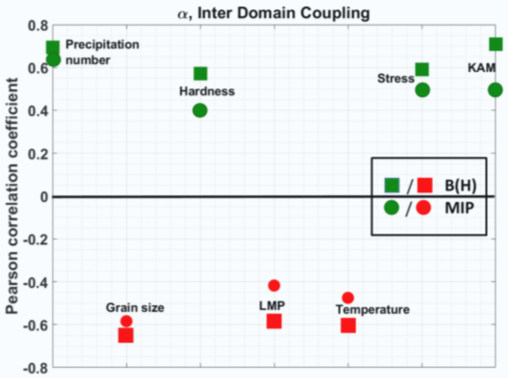
4 - Simulation

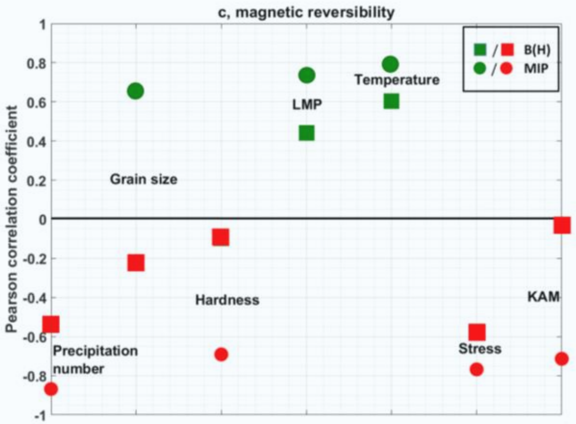
Exemple 2:

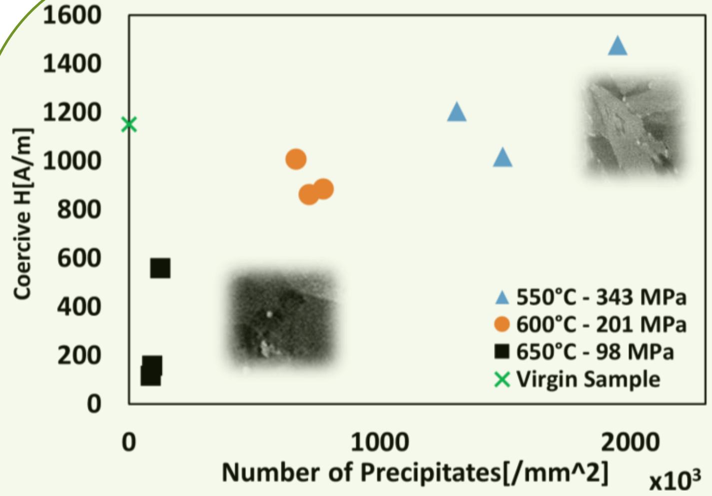
5 – Analysis and correlation

Correlation simulation/micro-structural parameters

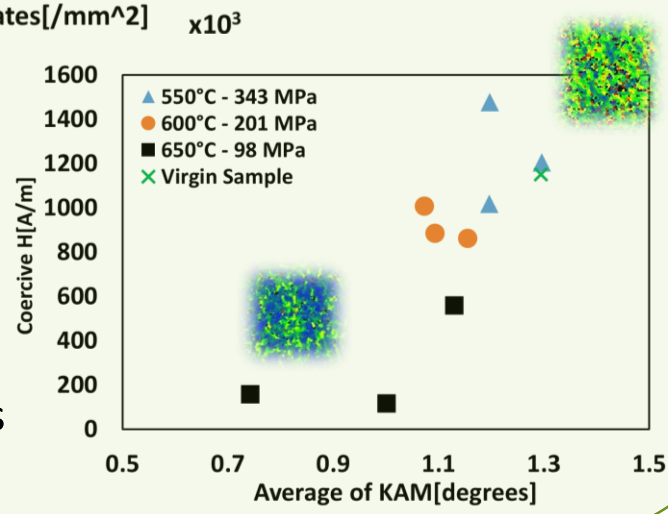








Correlation magnetic/micro-structural parameters



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B. Gupta, T. Uchimoto, B. Ducharne, G. Sebald, T. Miyazaki, T. Takagi, “Magnetic incremental permeability non-destructive evaluation of 12 Cr-Mo-W-V Steel creep test samples with varied ageing levels and thermal treatments”, NDT & E Int., accepted for publication, 2019.

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T. Matsumoto, T. Uchimoto, T. Takagi, G. Dobmann, B. Ducharne, S. Oozono, H. Yuya, “Investigation of Electromagnetic Nondestructive Evaluation of Residual Strain in Low Carbon Steels Using the Eddy Current Magnetic Signature (EC-MS) Method”, J. of Mag. and Mag. Mat., vol. 479, pp. 212-221, 2019.

B. Gupta, B. Ducharne, T. Uchimoto, G. Sebald, T. Miyazaki, T. Takagi, “Non-destructive Testing on Creep Degraded 12% Cr-Mo-WV Ferritic Test Samples using Barkhausen Noise”, J. of Mag. and Mag. Mat., 166102, 2019.

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B. Ducharne, MQ. Le, G. Sebald, PJ. Cottinet, D. Guyomar, Y. Hebrard, “Characterization and modeling of magnetic domain wall dynamics using reconstituted hysteresis loops from Barkhausen noise”, J. of Mag. And Mag. Mat., pp. 231-238, 2017.