Utilizing Neutron Grating Interferometry (nGI) to Study the Effect of Stabilizing Elements in Non-Grain Oriented Electrical Steel

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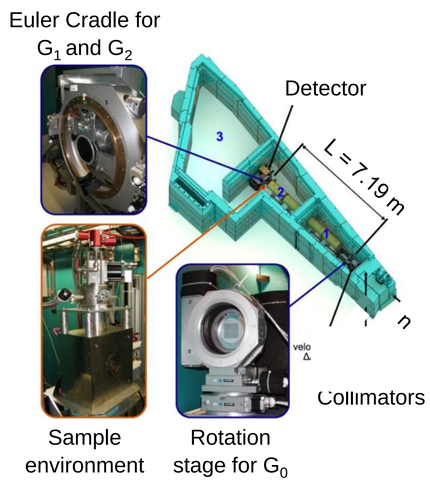
Motivation

- Part of research project "*STabilized ELectrical Steels for Electric Mobility*" with five partners from various European institutions.
- Variation of alloying and processing conditions (rolling, annealing) to develop innovative non-grain oriented (NO) electrical steel.
- Produced materials are analyzed in detail to study the effect of process variations / stabilizing elements on resulting properties.
  - Microstructure and precipitations
  - Crystallographic texture
  - Mechanical properties
  - Magnetic properties
- The imaging technique of neutron grating interferometry (nGI) is utilized to analyze the changes in domain structure and magnetization behavior of the materials.

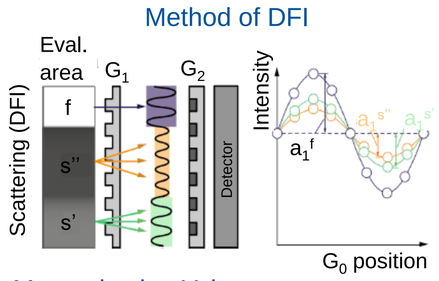
Experimental

- The measurements were performed at the ICON beamline of *Paul Scherrer Institut* (PSI).
- NGI is an advanced neutron imaging technique that enables to map neutron scattering under ultra small angles (USANS) and is recorded in the dark-field image (DFI).
- DFI is related to the magnetic domain structure of the produced samples as neutrons scatter at domain boundaries:
  - If a magnetic field is present the domains align parallel to the applied field. Larger domains lead to less scattering which manifests in higher DFI-signal.
  - Lower DFI-signal indicates more neutron scattering of more, smaller, i.e. disordered domain structures under weaker fields or smaller domains.
- Thereby the DFI signal should relate to changes in microstructure, precipitation state and alloying as these factors influence the resulting domain structure and domain mobility.

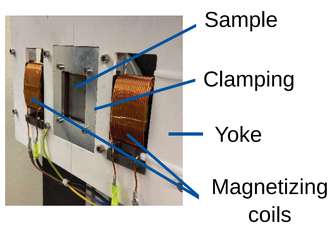
Antares Beamline [1]



Method of DFI



Magnetization Yoke



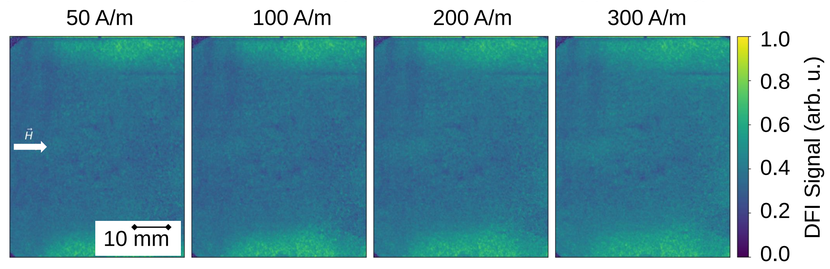
[1] Reimann, Tommy & Mühlbauer, S. & Horisberger, Michael & Betz, Benedikt & Böni, Peter & Schulz, Michael. (2016). The new neutron grating interferometer at the ANTARES beamline: Design, principles and applications. Journal of Applied Crystallography. 49.

Materials

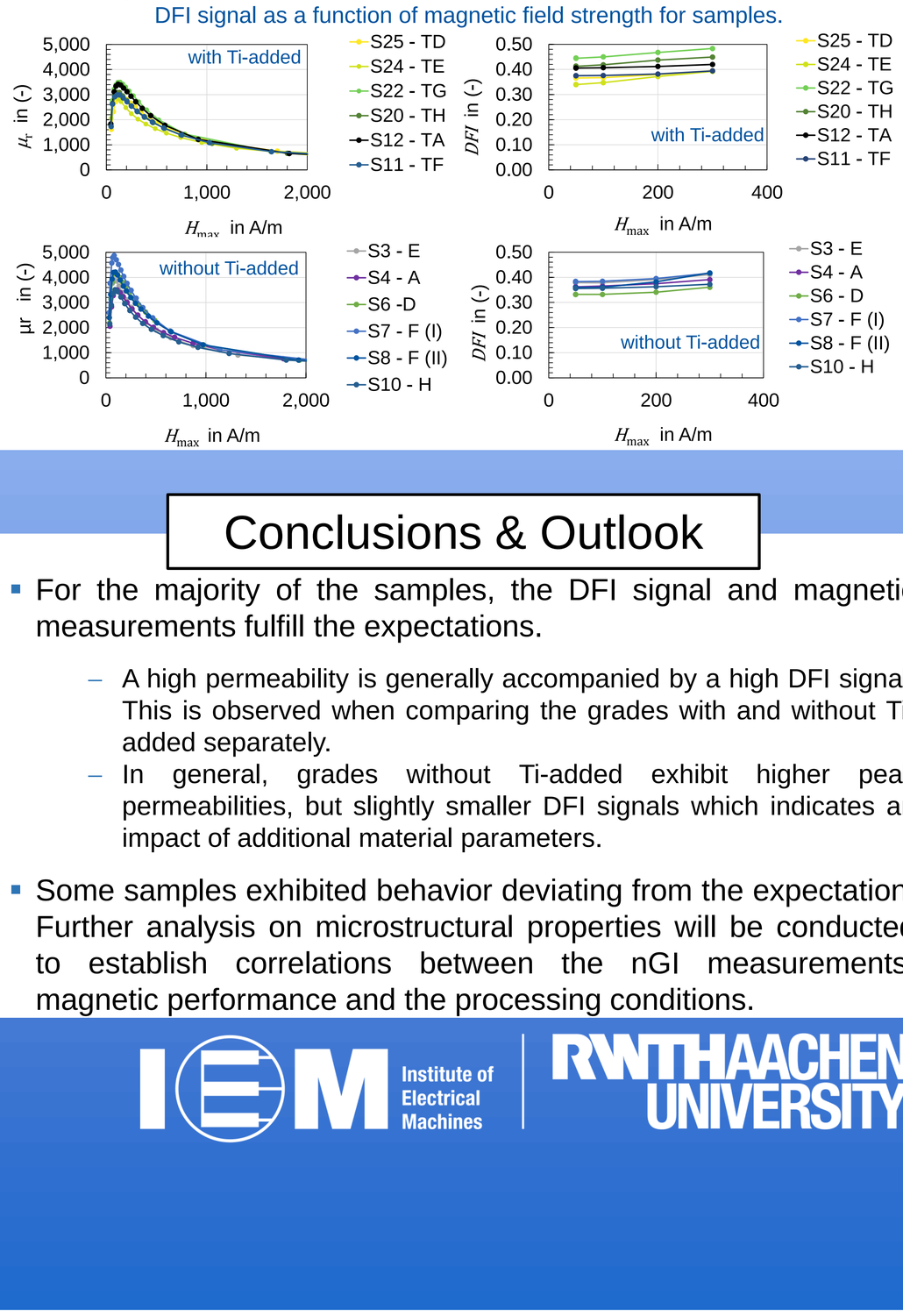
Sample	Alloy		Hot Rolling		Hot band Annealing	Annealing	
	Ti	Si	Reheat. Temp.	Cooling Temp.		Intermediate	Final
S3 - E	no Ti added	high Si	1050	700	NOHBA	1050	1000
S4 - A	no Ti added	high Si	1250	700	NOHBA	1050	1000
S6 - D	no Ti added	low Si	1250	Water quenched	NOHBA	950	1000
S7 - F (I)	no Ti added	low Si	1050	700	NOHBA	950	1000
S8 - F (II)	no Ti added	low Si	1050	700	HBA	950	1000
S10 - H	no Ti added	low Si	1050	Water quenched	NOHBA	950	1000
S11 - TF	Ti added	low Si	1050	700	NOHBA	1100	1070
S12 - TA	Ti added	high Si	1250	700	HBA	1125	1080
S20 - TH	Ti added	low Si	1050	Water quenched	NOHBA	1100	1070
S22 - TG	Ti added	high Si	1050	AC	NOHBA	1125	1070
S24 - TE	Ti added	high Si	1050	700	NOHBA	1125	1070
S25 - TD	Ti added	low Si	1250	Water quenched	NOHBA	1100	1080

Results

Examples of DFI Images from Sample S 10 at various applied magnetic fields.



Permeability at 50 Hz measured on a 60 mm x 60 mm Single Sheet Tester for samples and DFI signal as a function of magnetic field strength for samples.



Conclusions & Outlook

- For the majority of the samples, the DFI signal and magnetic measurements fulfill the expectations.
  - A high permeability is generally accompanied by a high DFI signal. This is observed when comparing the grades with and without Ti-added separately.
  - In general, grades without Ti-added exhibit higher peak permeabilities, but slightly smaller DFI signals which indicates an impact of additional material parameters.
- Some samples exhibited behavior deviating from the expectation. Further analysis on microstructural properties will be conducted to establish correlations between the nGI measurements, magnetic performance and the processing conditions.

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