

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

Nora Leuning¹, Simon Sebold², Benedikt Schauerte¹, Nikolas Mavrikakis³, Alexey Gervasyev⁴, Leo A.I. Kestens⁴, Herbert Kreuzer⁵, Stefano Cicale⁶, Kay Hameyer¹

¹ Institute of Electrical Machines (IEM), RWTH Aachen University, Germany

² Neutron Imaging Group, Heinz Maier-Leibnitz Zentrum (MLZ), Germany

³ 3OCAS NV, Belgium

⁴ Ghent University, Belgium

⁵ Voestalpine Stahl GmbH, Austria

⁶ RINA Consulting – Centro Sviluppo Materiali, Italy

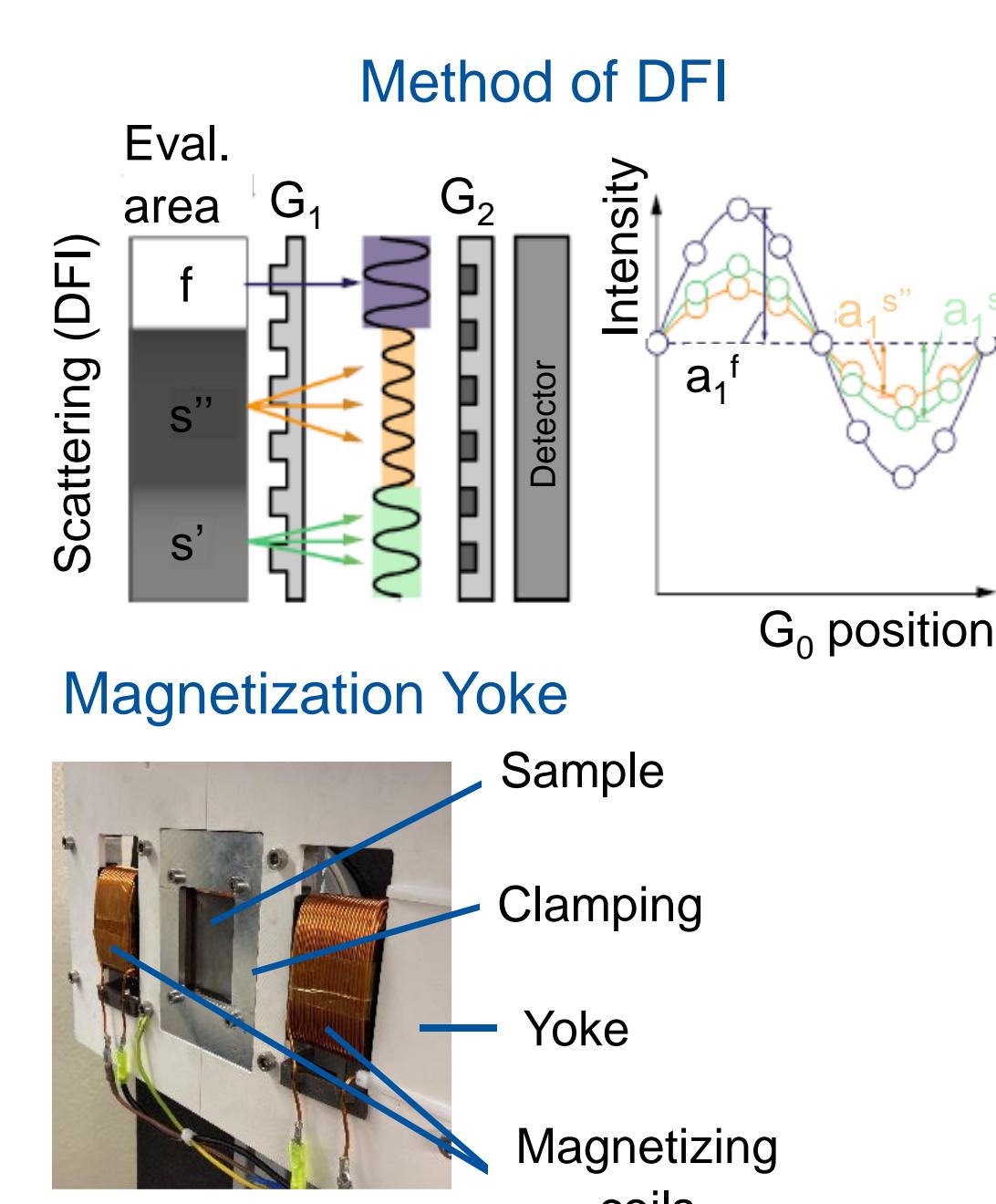
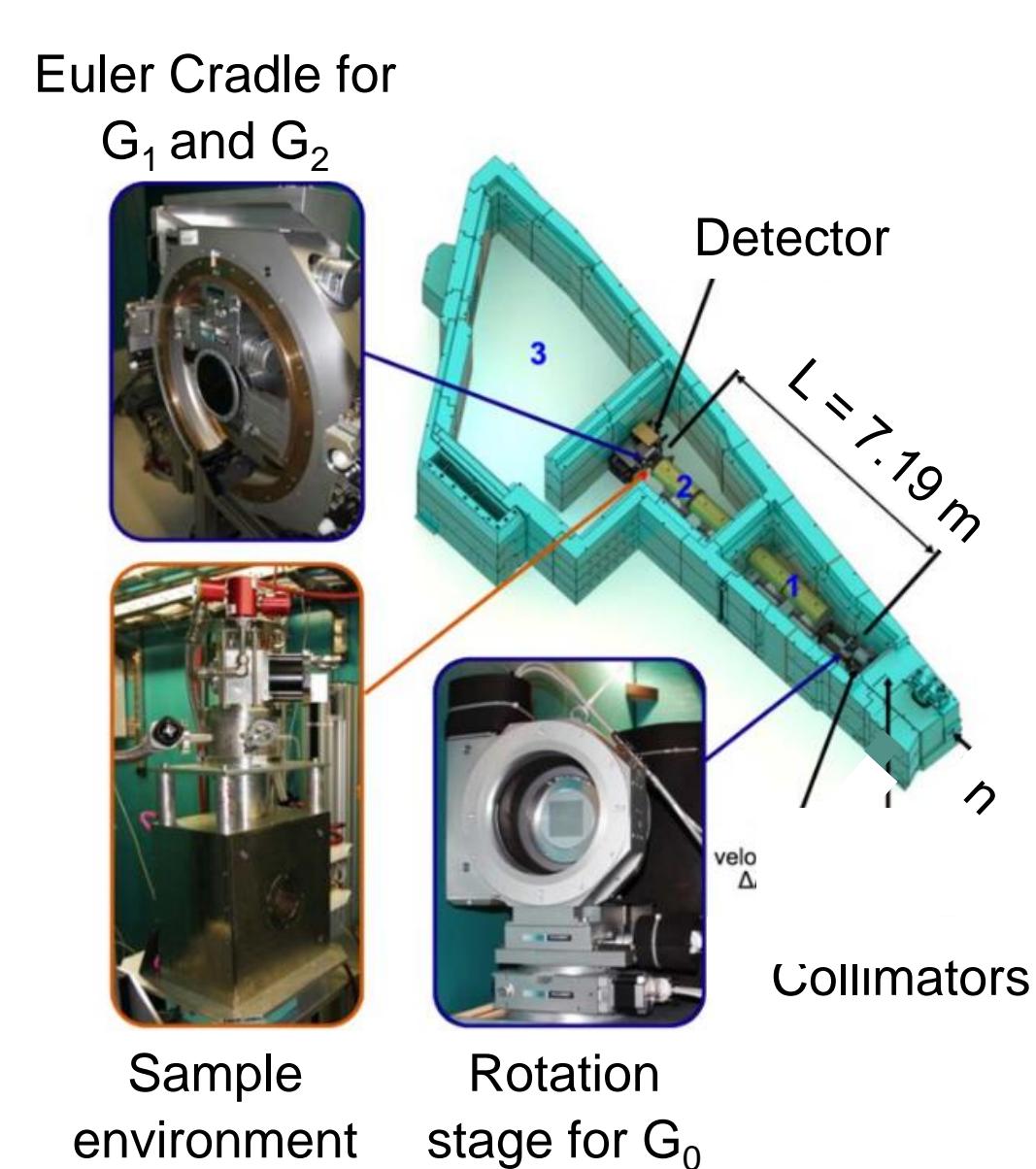
Motivation

- Part of research project "STabilized EElectrical 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]



[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.

Managing Director:

Univ.-Prof. Dr.-Ing. habil. Dr. h. c. Kay Hameyer

Schinkelstraße 4
D-52062 Aachen

Phone:
Fax:
Homepage:

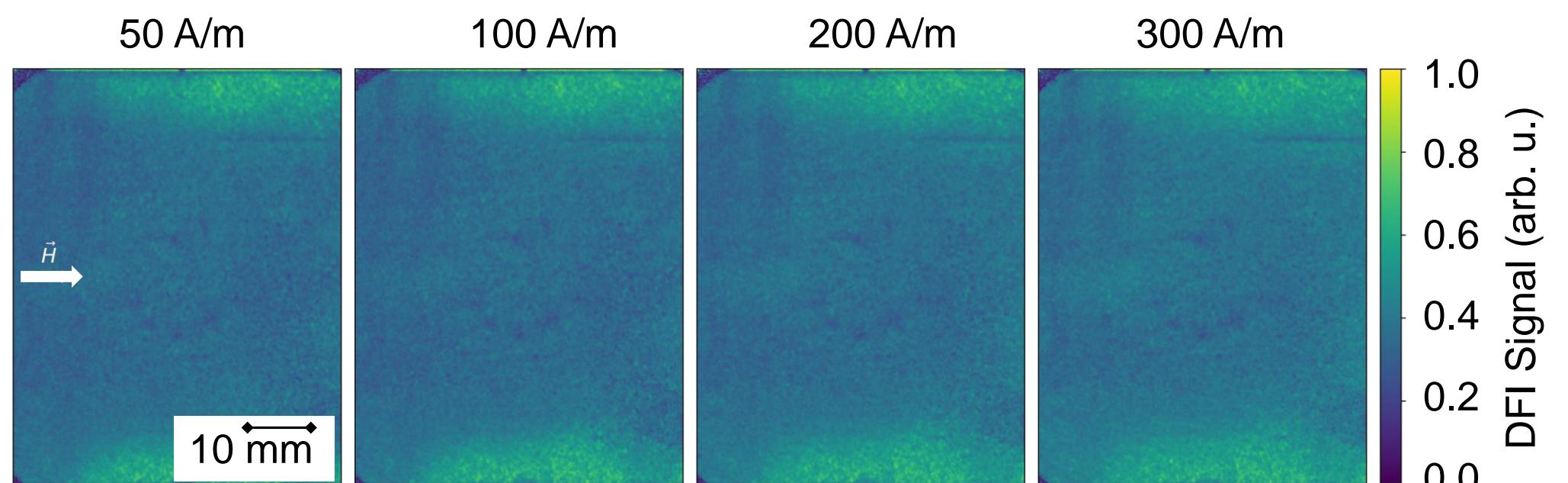
+49-241-80-97667
+49-241-80-92270
www.iem.rwth-aachen.de

Materials

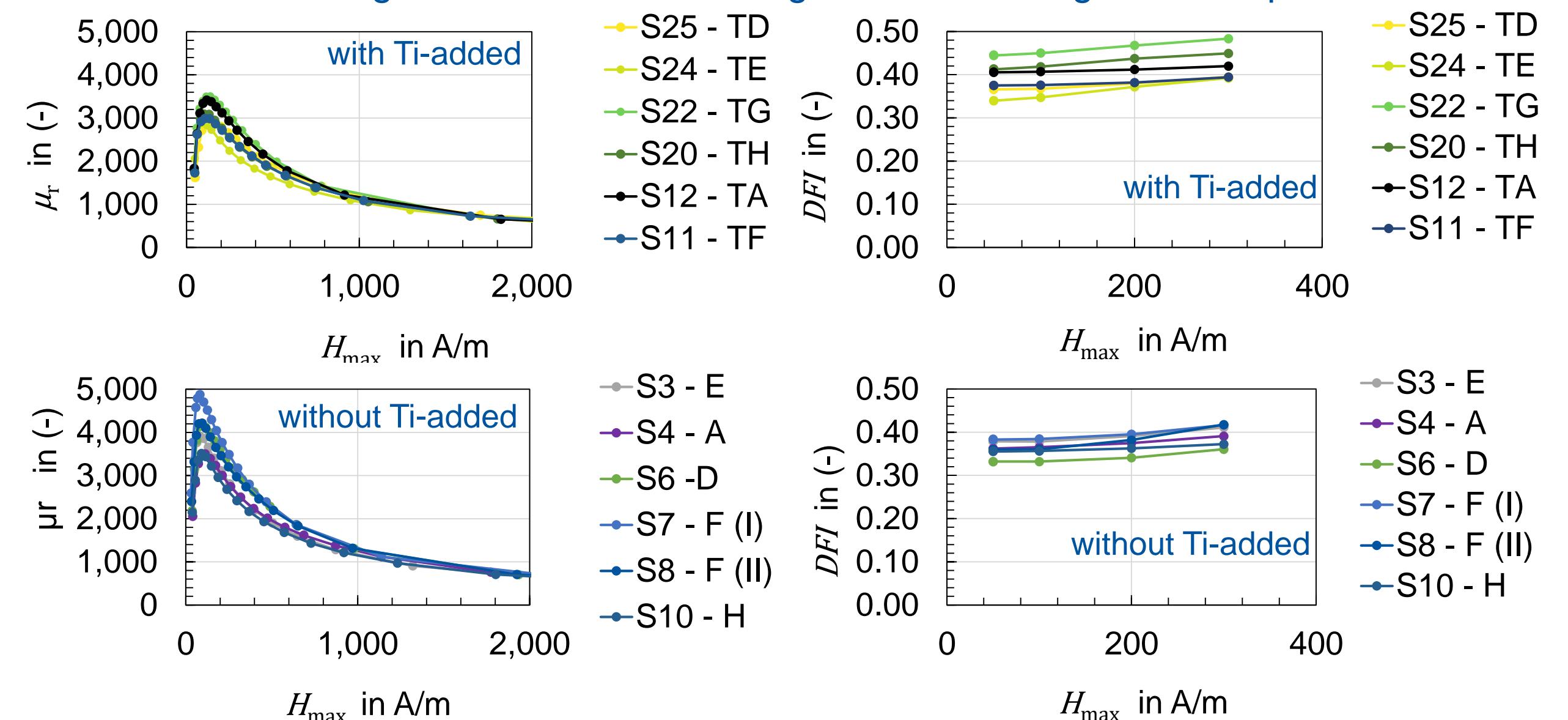
Sample	Alloy		Hot Rolling		Hot band Annealing	Annealing	
	Ti	Si	Reheat. Temp.	Cooling Temp.		Intermediate	Final
S3 - E	no Ti added	high Si	1050	700	NOHBA	1050	1000
S4 - A	no Ti added	high Si	1250	700	NOHBA	1050	1000
S6 - D	no Ti added	low Si	1250	Water quenched	NOHBA	950	1000
S7 - F (I)	no Ti added	low 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.



Research Fund for Coal and Steel project
101034063 – StEELS-EM – RFCS-2020

