

The Strategic University Steel Technology and Innovation Network Presents

# T8: Smart sensors for real-time measurement: Electromagnetic sensors

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University of Warwick

The logo for SUSTAIN features the word "SUSTAIN" in a bold, white, sans-serif font. The letter "I" is replaced by a stylized white knot or infinity symbol. The background of the slide is a dark green, geometric pattern of interlocking lines that create a sense of depth and perspective, resembling a complex lattice or a series of overlapping planes.

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*Future Steel Manufacturing Research Hub*

The UKRI logo consists of the letters "UKRI" in a white, bold, sans-serif font, set against a dark blue square background.

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The WMG logo features a stylized white circular icon to the left of the letters "WMG" in a bold, white, sans-serif font. Below "WMG" is the text "THE UNIVERSITY OF WARWICK" in a smaller, white, sans-serif font.

**WMG**  
THE UNIVERSITY OF WARWICK

# People

**Professor Claire Davis**



**Dr Frank Zhou,**



# Introduction to Project

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- Improved monitoring of steel production allows for greater digitisation and control, leading to more efficient, less energy intensive manufacturing. Improved monitoring of processes is a key part to sustainability, growth and modernisation for the steel industry. Significant improvements have been made in real-time monitoring and feedback control, but several areas have been highlighted where insufficient information is currently available requiring new and improved sensing approaches.
- One area is microstructural monitoring during processing and electromagnetic (EM) sensors are ideal candidates. The project is focusing on development of new EM sensors and signal-microstructure relationships for use in steel processing.

# Aims and Impact

- Aims

- Design, build and installation of a sensor array into furnace-run out table for wire-rod and narrow strip production
- Experimental trials for EM sensor array inspection
- Sensor-sample models for complex geometries
- Extension of permeability–microstructure model for complex microstructures
- Development of full magnetic behaviour-microstructure model

- Impact

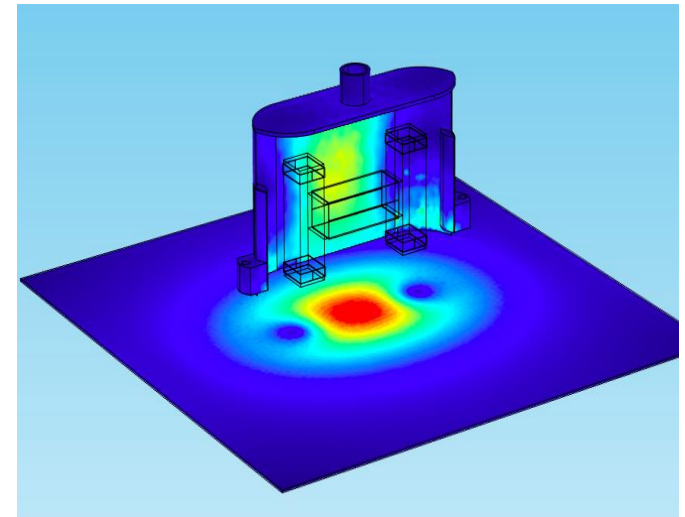
- EM sensor arrays for real-time in-situ monitoring, characterisation and control of steel microstructures during steel processing for a range of grades and applications.



# Progress to Date

## WP1: Multiple sensor / sensor array modelling

- Current commercial sensor design (EMspec™) is suitable for wide strip where the material under the sensor can be considered as uniform (microstructure and temperature) and there is no geometry effect.
- The sensor array (multiple sensor heads) will allow an effective mapping of the material (microstructure and geometry) below the sensor including for in-situ phase transformation monitoring. Will allow more complex geometries to be characterised.
- Industrial input from Primetals Technology Ltd for drawings and discussion about the current sensor casing design. Liberty Steel and British Steel for installation constraints for target mill installations and steel grades for consideration.

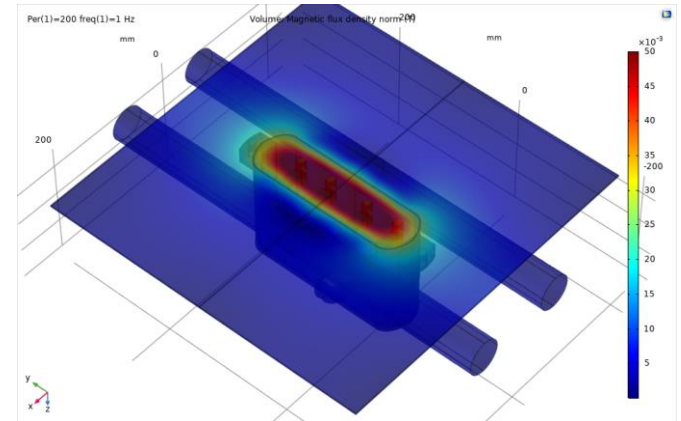
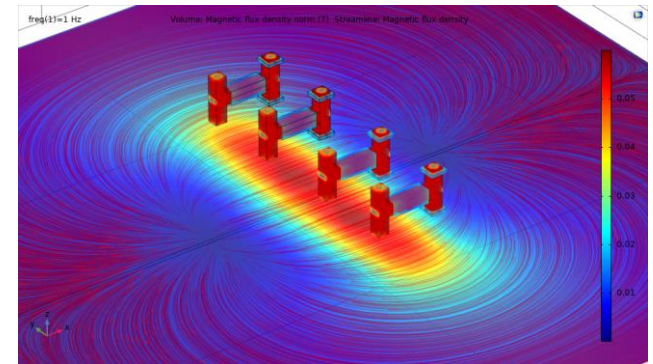


EMspec™ sensor

# Progress to Date

## WP1: Multiple sensor / sensor array modelling

- Design and modelling of an EM sensor array for the furnace-run out table at WMG and also suitable for target industrial applications.
- The size of the sensor head, casing, number of sensor heads and spacing between them has been determined to optimise the sensitivity to microstructure changes.
- The next stage is to source the materials required for building the sensors and to design the sensor casing to fit into the run out table (collaboration with Dr Russ Hall and linking with High Value Manufacturing Catapult funded project to upgrade the furnace-roller table).
- In addition further modelling is required for the sensor phase excitation design, to optimise signals and signal interpretation, and to generate the sensor-sample models for the complex geometries of the target applications.



# Progress to Date

## WP2: In-situ annealing study

- Aim to explore feasibility of in-situ monitoring of microstructural change due to annealing, which requires a sensor that can withstand high temperatures.
- Previous work has shown that recovery and recrystallisation for an IF steel sample can be monitored using a laboratory high temperature cylindrical sensor.
- Initial work to determine whether the microstructural changes due to annealing for the target applications gives magnetic changes that are sufficient for EM sensor measurement.

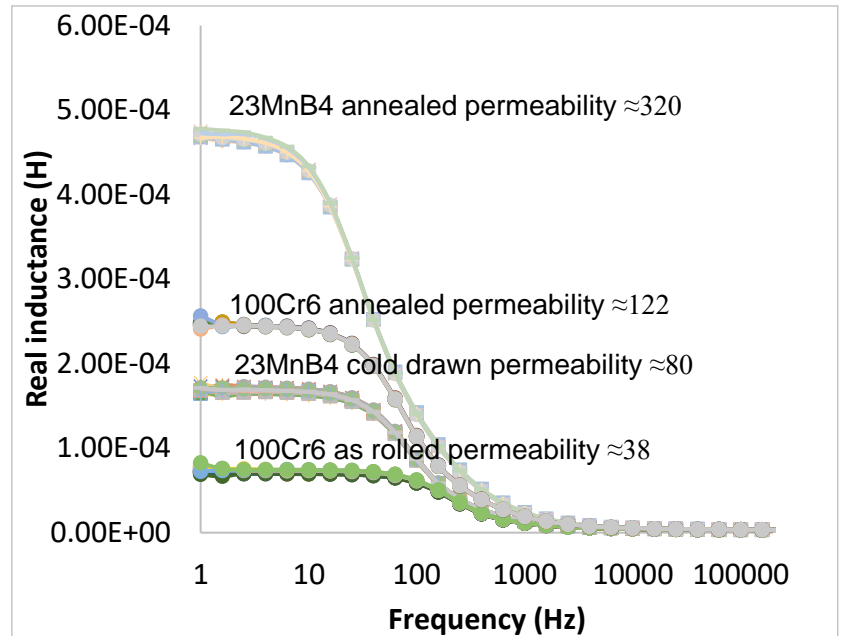
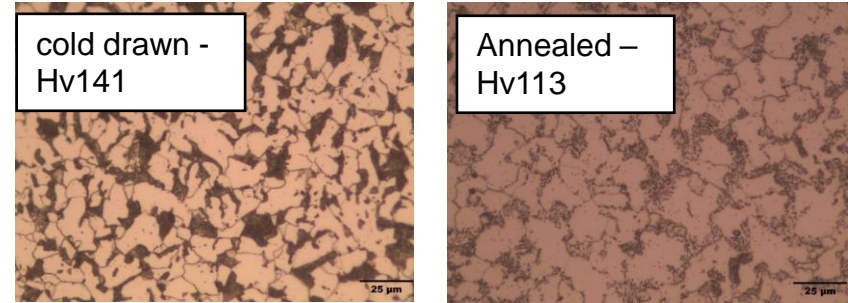


# Progress to Date

## In-situ annealing study

- Two grades of samples were provided by British Steel:
  - 100Cr6 bearing steel
  - 23MnB4 Cold heading grade
- A cylindrical EM sensor has been used to test the samples in different microstructure states:
  - Results shows that the inductance value can clearly separate the samples.
  - This suggests that in-situ testing at annealing temperatures should detect microstructure development. Annealing heat treatments using a new laboratory in-situ EM sensor are planned.
  - FE model is being used to allow an initial prediction of the low field permeability values.

23MnB4 Cold heading grade





# Additionality

- High Value Manufacturing Catapult funding to upgrade the furnace-roller system at WMG. Currently has EMspec system installed and plan to include new sensor array when built. Enhanced water cooling system and roller table / sensor control systems.
- Innovate UK bid with Primetals Technology Ltd, British Steel, Liberty Steel, University of Manchester, WMG for mill installation trials.

# Outputs

- Quarterly review meetings with industry partners (Tata Steel, Liberty Steel, British Steel, Primetals Technology limited) as part of WMG-University of Manchester EM sensors review meetings.
- Feasibility trials for microstructure monitoring during annealing of rod samples (samples provided by British Steel) – on-going.
- Invited presentation “Advanced Sensors for Microstructure Control” at IoM3 50 Years of Alloy Development, Sheffield, 7-8 Nov 2019
- Planned conference presentation (postponed due to Covid-19): L Zhou, C Davis, “*Measured and modelled low field relative permeability for dual phase steels at high temperature*” 20<sup>th</sup> WCNDT 2020, Coex, Seoul, South Korea, 8-12<sup>th</sup> June 2020



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