Something a bit different: NNEWFLUX and OPTILOCALHT

Dr Bridget Stewart (née Harris)
Materials Processing Institute
Eston Road, Middlesbrough , TS6 6US
United Kingdom

Research Fund for Coal & Steel

Why the need for something different?

- Mould flux selection requires compromise between the conflicting property requirements for the various functions these materials perform.
- What if selection could be simplified by introducing another layer of choice for steel manufacturers?
- This was my aim in setting up the NNEWFLUX and OPTILOCALHT projects.
- NNEWFLUX is concerned with viscosity of the liquid flux.
- OPTILOCALHT is concerned with varying the rate of heat transfer in the mould-strand gap.

NNEWFLUX:

Non-Newtonian mould fluxes - a smart viscosity response to enhancing production flexibility of steel grades prone to entrapment

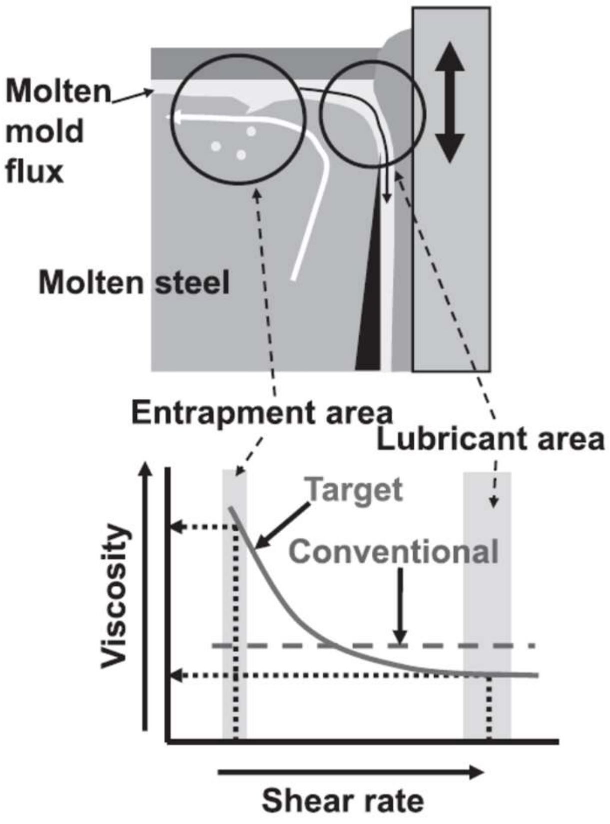
Coordinator: Bridget Stewart

Co-Authors: Maïté Cornille, Pavel Ramierez Lopez, Hyunjin Yang, Diana Mier Vasallo, Klaus Schulz, Adam Hunt, Maria Ferrer Prieto

Duration: 1 July 2016 – 31 December 2020

Problem addressed by NNEWFLUX

Slag entrapment in the mould



【Entrapment area】

Shear rate is small.
(Molten steel velocity)

Target

High viscosity
to prevent flux entrapment

【Lubricant area】

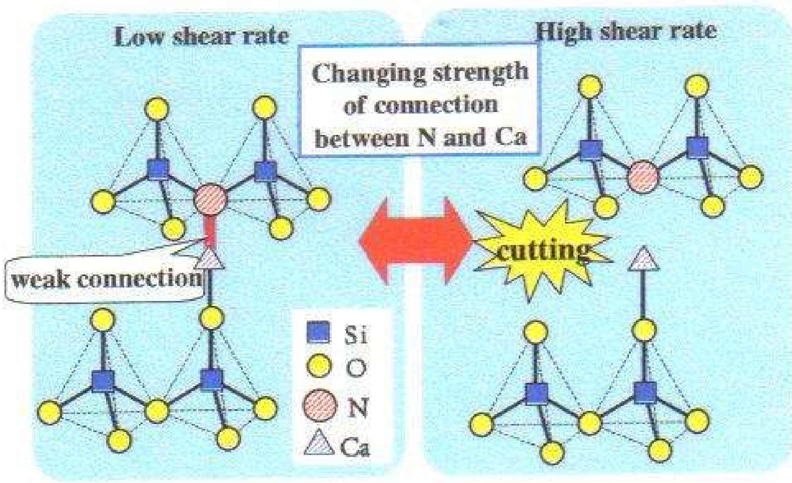
Shear rate is large.
(Mold oscillation)

Target

Low viscosity
to reduce friction

Watanabe et al. (2014)

- Proposed introducing weak bonds to the silicate network
- Si_3N_4 most promising but expensive



Approach

Organisation of Work Packages

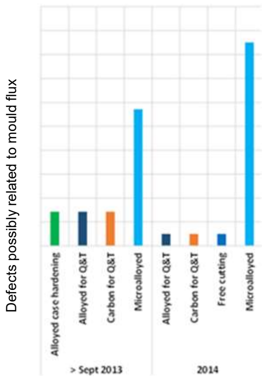
WP1
- Identification of grades to study
- Mapping of current casting operations
- Benchmarking current quality
- Model setup for reference case (e.g. current situation)

WP2
- Predict target viscosities
- Recommend powder properties
- Recommend casting parameters

WP3
- Production of non-Newtonian fluxes
- Laboratory characterisation of conventional and new fluxes

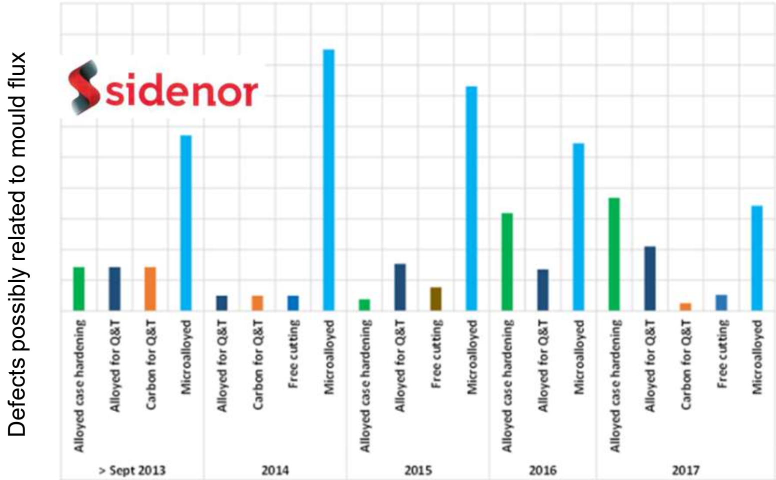
WP4
- Pilot and industrial casting trials to validate non-Newtonian flux concepts

WP5
- Evaluation of non-Newtonian fluxes and models
- Provide model interface for operators.
- Definition of operating windows for best quality



Grades selected

- Statistical evaluation of the influence of slag entrapment on the billet quality at Sidenor and slab quality at ArcelorMittal over the past 5 years
- Shown that several steel families and grades that seem prone to entrapments.
- Identified "challenging" and "easy to cast" grades, validated by economic assessment.



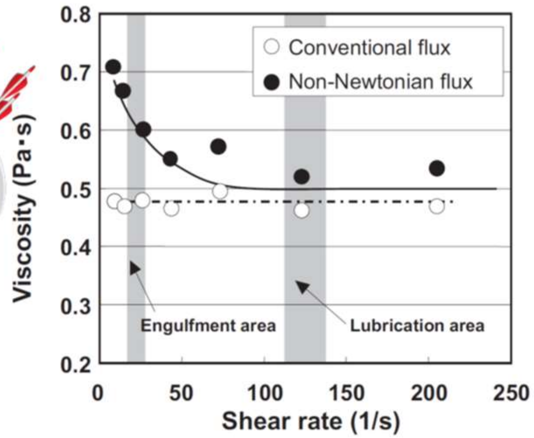
ArcelorMittal	Challenging	Easy to Cast	Total
% Production in 2017	11.5	3.7	240 000t
Powder slivers	4.09%	0%	3.72%
Cracks	4.78%	1.51%	4.61%

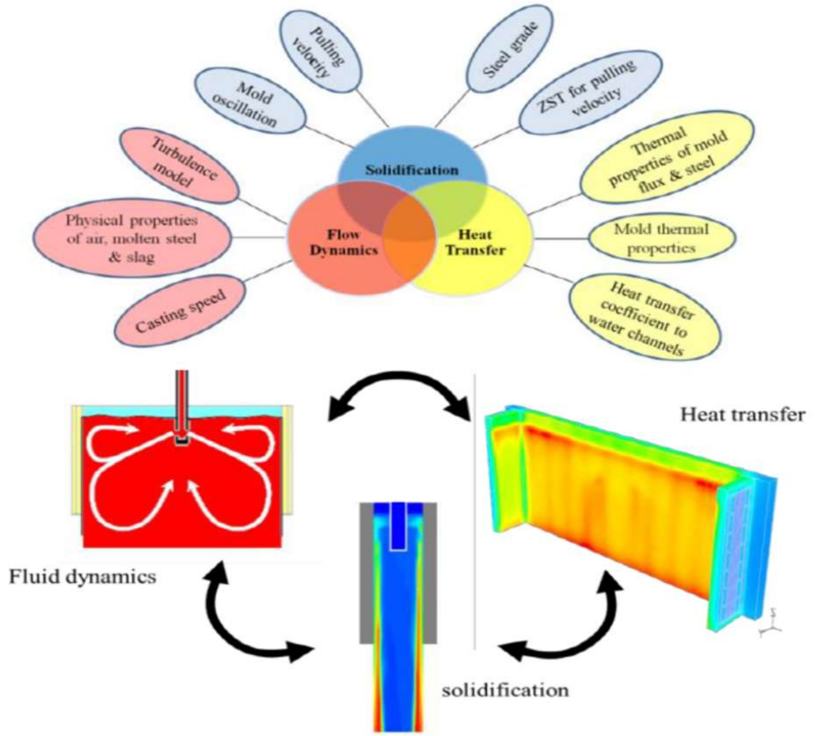
Potential savings of 150k€ per annum for Arcelor 'Challenging'

Steel Grade sidenor	Cost of rejection associated with entrapment type cracks (€/month)	Cost of rework associated with entrapment type cracks (€/month)
Sidenor 'Challenging'	5000	1700
Sidenor 'Easy to Cast'	1000	200

Modelling

- Aim to identify target properties for non-Newtonian flux for the grades studied in this project through understanding of lubrication mechanisms.
- Advanced numerical modelling by Swerim MEFOS for explicit slag infiltration predictions.
- Looked at why more entrapment occurs in the 'challenging' cases.

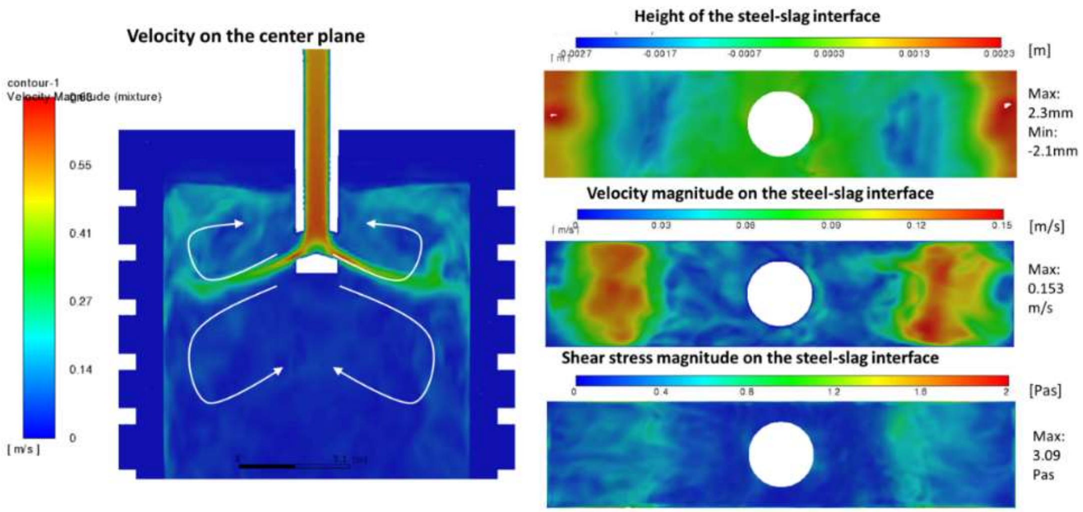




Modelling for ArcelorMittal Caster

- For ArcelorMittal cases, entrapment is not caused by high interfacial velocity.
- No slag entrapment was predicted from the numerical simulations of fluid flow.
- It is suspected that the entrapment mechanisms are related to heat transfer and solidification, such as entrapment by hook formation.

Critical velocity for entrapment = 0.298 m/s



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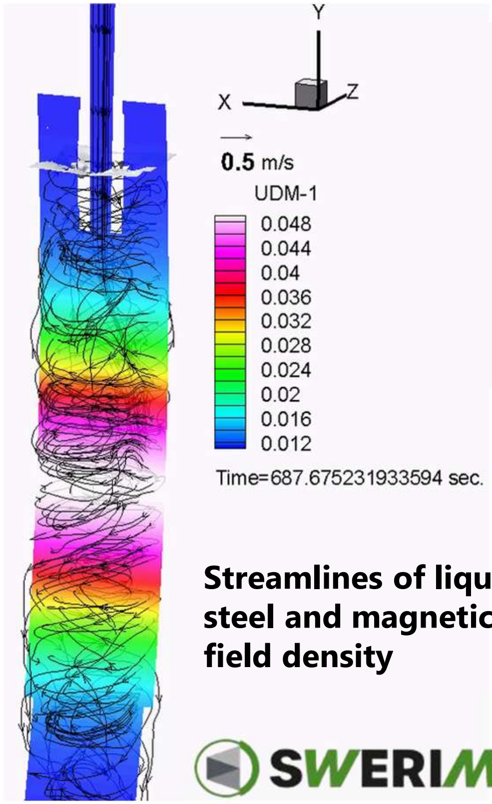
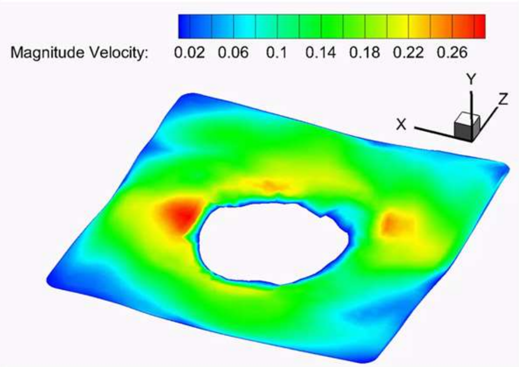
Modelling for Sidenor Billet Caster



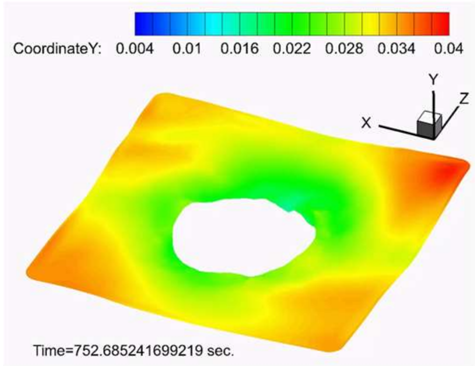
Streamlines of liquid steel and magnetic field density

SWERIM

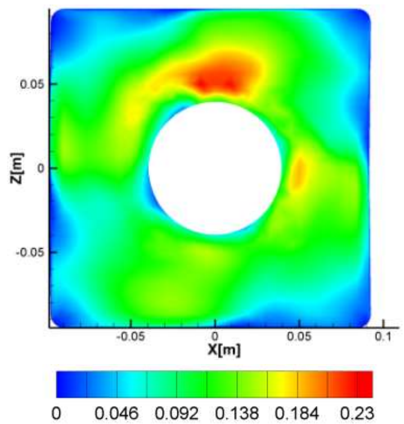
Velocity magnitude of metal level



Height contour of metal level



Time-averaged interface velocity [m/s]



Critical velocity = 0.264 m/s

- For Sidenor cases, slag entrapment is predicted in both cases due to the slightly higher interface velocity than the critical velocities
- High oxygen activity might be one explanation of more inclusions in the ‘challenging’ case. (Interfacial tension can drop from ~1.3 to ~0.5N/m.)

Viscosities of non-Newtonian fluxes

New characterisation method needed

Shear thinning of fluxes up to 40 s^{-1}

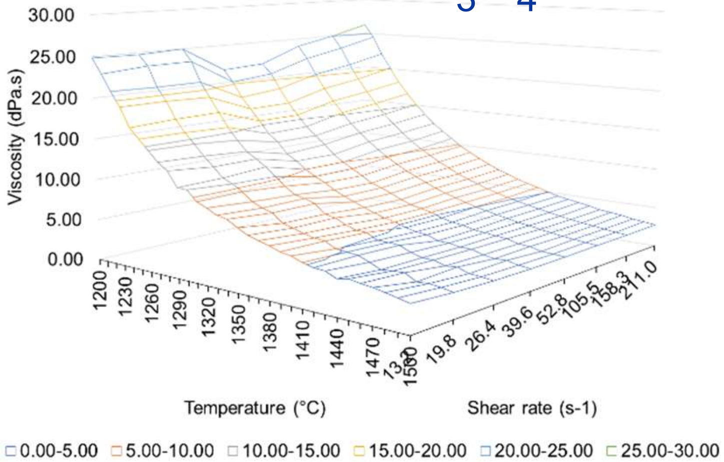
	n
MPI	0.8207
MPI-NNEW	0.8094
Sidenor B	0.8939
Sidenor B-NNEW	0.8158
Powder 8	0.7697
Powder 8-NNEW	0.5847

- Shear thinning behaviour expressed by the power law: $\tau = K.\gamma^n$
- n is flow behaviour index
- n <1 is shear thinning
- Strongest shear-thinning effect observed in Powder 8

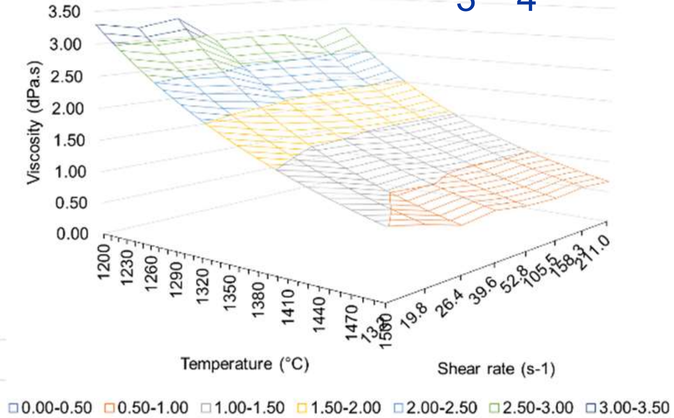
Viscosities of non-Newtonian fluxes

Both temperature and shear rate needed for modelling

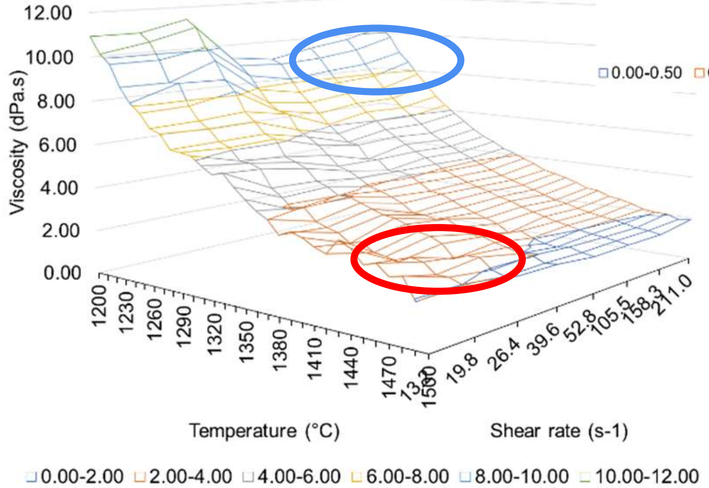
Sidenor B + Si_3N_4



Powder 8 + Si_3N_4



MPI + Si_3N_4



Entrapment area

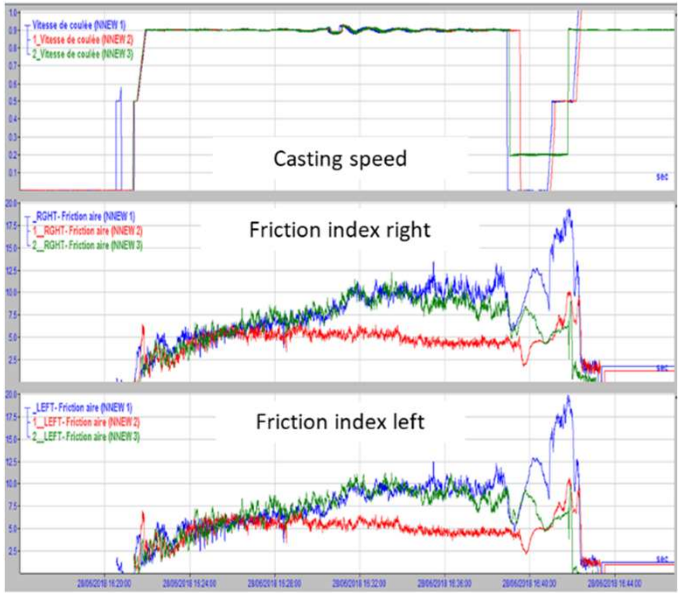
Lubrication area

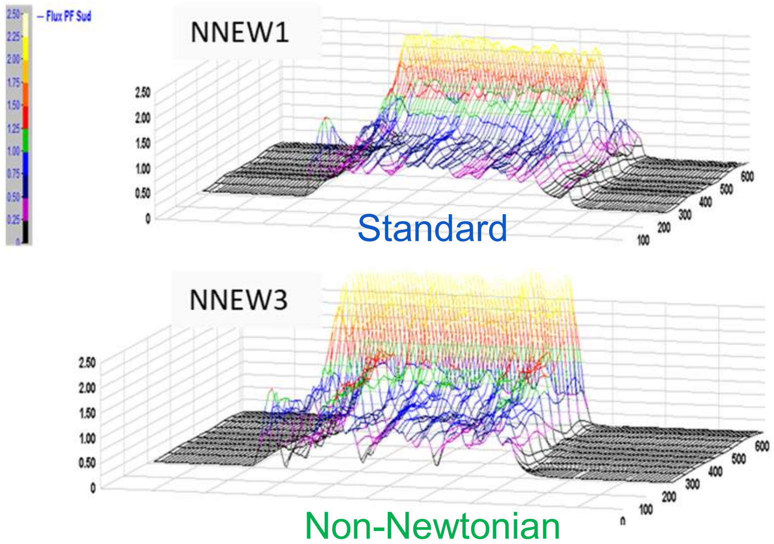
Pilot trials

	NNEW1	NNEW3
Date	28/06/2018	13/02/2020
Grade	MAMA#1	MAMA#1
Powder	#8	#8 + 2-3% Si_3N_4
Dimension	100x450	100x450
Casting speed	0,9m/min	0,9m/min
Ar injection flow-rate	0,13NL/min	0,2NL/min
Immersion depth from top of the port	130mm then reduction every 5min of 5mm	130mm then reduction every 5min of 5mm
Mold level position from TOC	80mm	80mm
Taper	0.9%/m per face	0.9%/m per face
Frequency	203cpm	203cpm
Stoke	6mm	6mm
Water flow BF	1560L/min	1560L/min
Water flow BF	180L/min	180L/min

Trial parameters

Friction similar with NN flux





Heat extraction slightly higher with NN flux

Pilot trials

Pictures & Handyscan after sand blasting

	NNEW1	NNEW3
Date	28/06/2018	13/02/2020
Grade	MAMA#1	MAMA#1
Powder	#8	#8 + 2-3% Si3N4
Dimension	100x450	100x450
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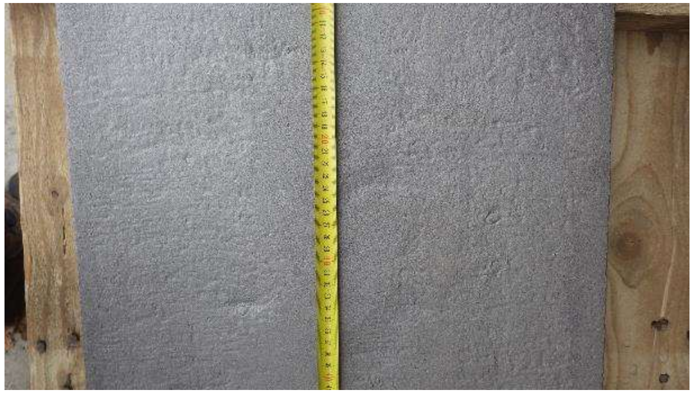
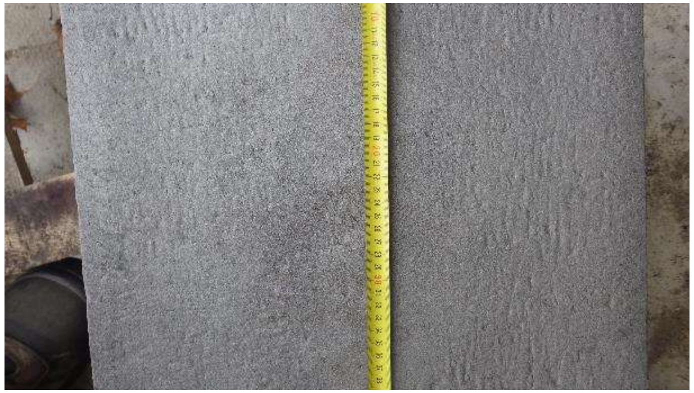
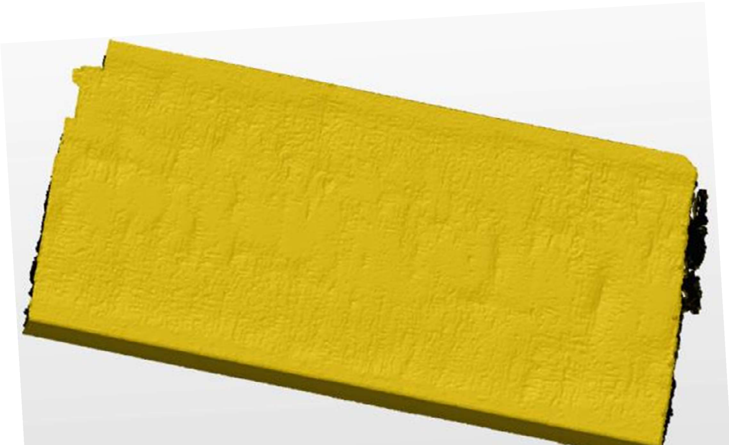
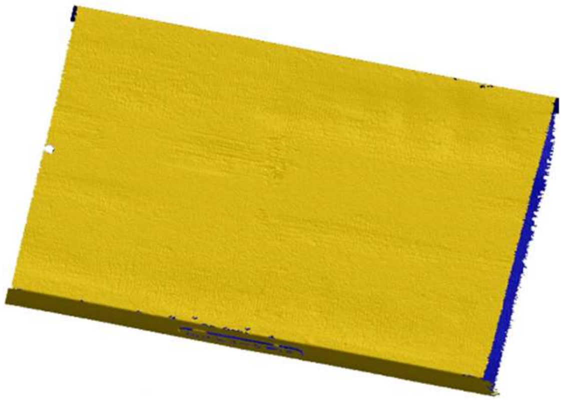
Trial parameters







Standard Powder



Non-Newtonian Powder

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sidenor
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ArcelorMittal

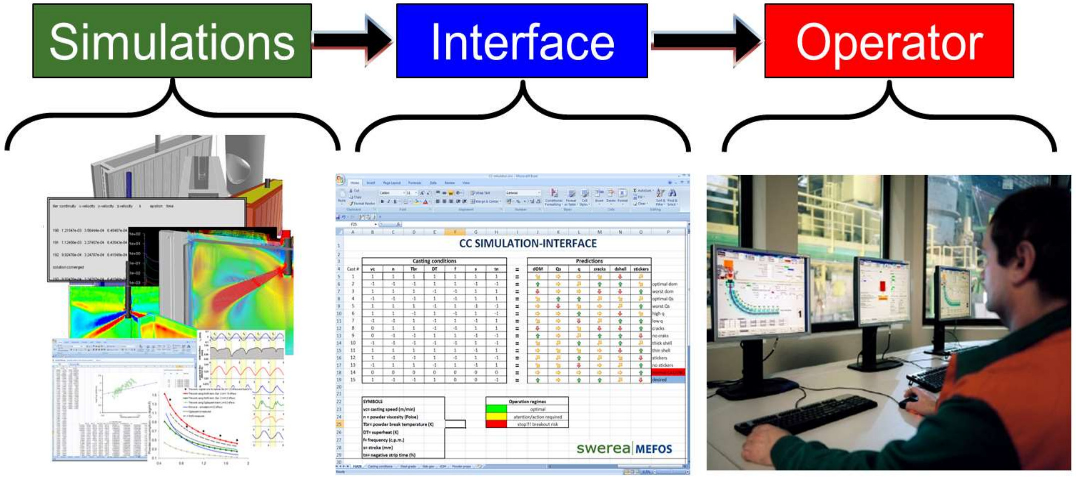
Industrial trials - Sidenor

Four trials with challenging microalloyed grades

Trial Nº	Data	Heat	Steel grade	Size, mm	Mould Powder	Main defect as-cast material	Rejection, %	Rework, %	Main defect rolled material
1	Jun-20	211066	A	240	B – 5 billets	--	13.70%	11%	**MP entrampment**
	Jun-20	211066	A	240	**NN - 1 billet**	--	0%	0%	--
2	Jun-20	211095	B	240	**NN - 3 billets**	Crack into OM Blows into OM Pinholes	5.00%	47.50%	Pore or pinhole
	Jun-20	211095	B	240	B – 2 billets	Longitudinal crack Pinholes	11.50%	25.00%	Rolling defect
3	Jul-20	211308	C	185	B		2.20%	12%	--
	Jul-20	211309	C	185	**NN**		0%	0%	--
4	Jul-20	211386	B	185	**NN**	Blows into OM	7.40%	16%	Rolling defect
	Jul-20	211387	B	185	B	Longitudinal crack	2.1	15	--

Next Steps

- Define operating windows to achieve best product quality with new fluxes
- Parametric studies ongoing
- Results will form basis of Casting Simulation Interface (CSI) for operators who might use the new powders
- Final report



OPTILOCALHT:
Optimisation of Local Heat Transfer in the CC Mould for Casting Challenging and Innovative Steel Grades

Coordinator: Bridget Stewart

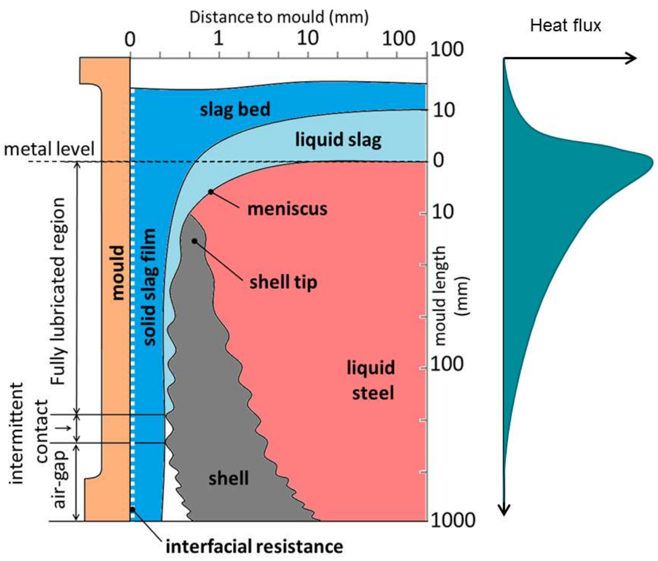
Co-Authors: Pavel Ramierez Lopez, Hyunjin Yang, Pooria Nazem Jalali, Peter Andersson, Sailesh Kesavan, Diana Mier Vasallo, Maria Ferrer Prieto, Maïté Cornille, Ben Yao, Adam Hunt, Chris Oswin, Alan Taylor, Rongshan Qin, Ashutosh Bhagurkar, Zushu Li, Rahul Sarkar, Karin Hansson-Antonsson, Frederik A Axelsson, Paavo Hooli & Johan Pejnefors

Duration: 1 July 2019 – 30 June 2023

Hoopa Metallurgy

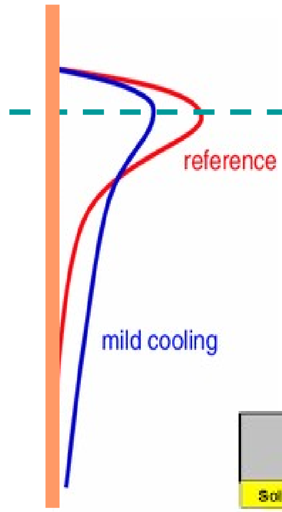
Definition of the problem

Creating more flexibility for steel producers

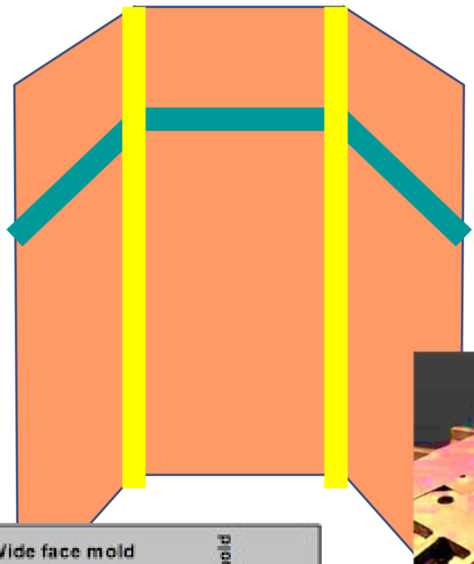


Hanao & Kawamoto, 2008

Influence of mould flux



After Kromhout, PhD Thesis 2011



Meniscus

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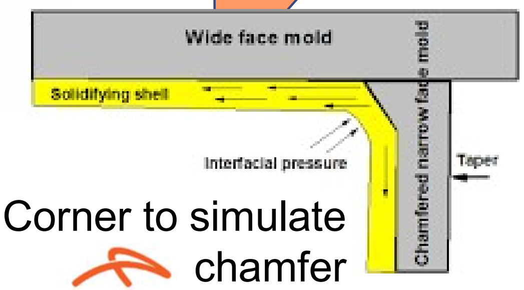
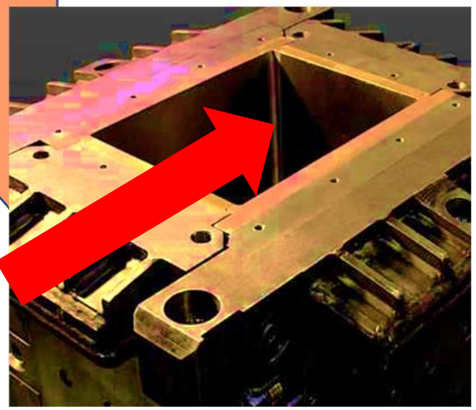


Corner to simulate chamfer

ArcelorMittal



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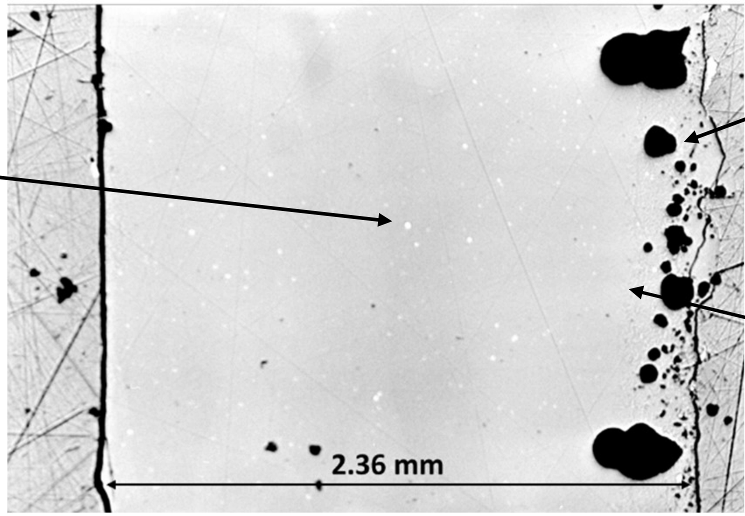
What reduces heat transfer in slag films?

Slag film from British Steel Teesside

Mould/slag film interface

Slag film/strand interface



Ludlow, Harris et al, SLAGS 2004

Metal droplets

Susa, MOLTEN 2016

Yoon, Cho et al., MOLTEN 2016

Porosity

Hunt & Stewart, MOLTEN 2016

Crystallisation

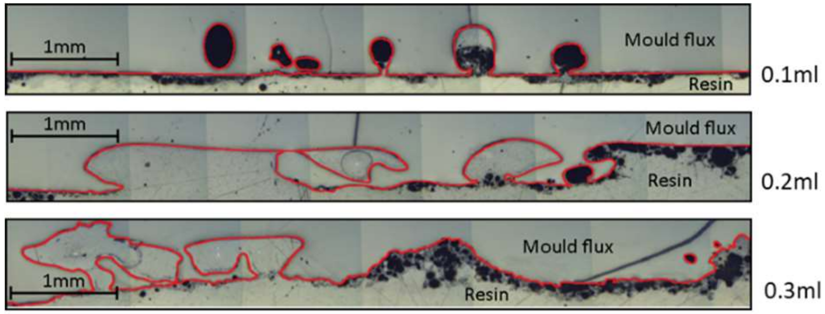
Composition

Electric Potential – *Riaz & Mills*

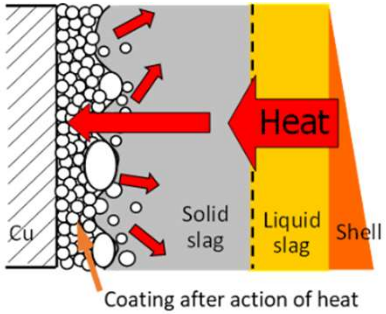
Electropulsing – *Qin*

State of the Art

Possible Methods for Localising Heat Transfer Control

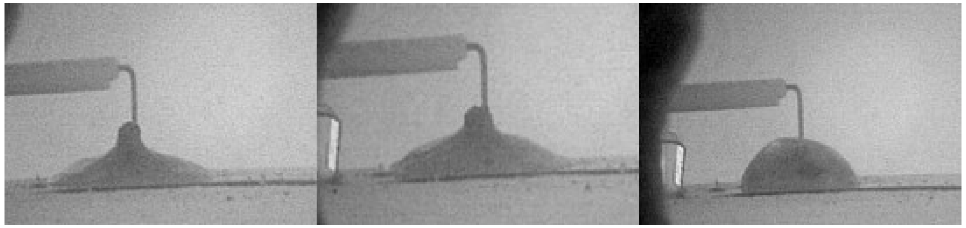


Hunt, PhD Thesis 2017



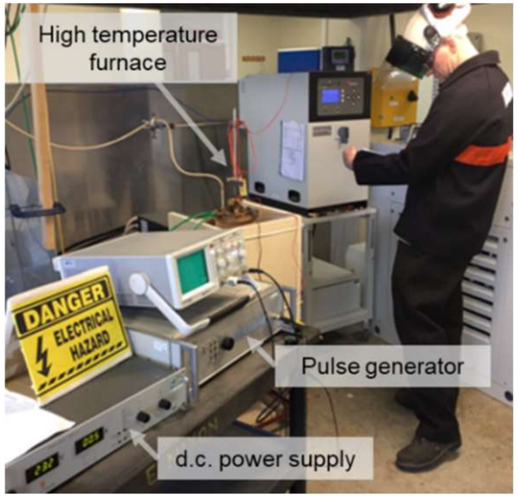
Porosity and scattering effects

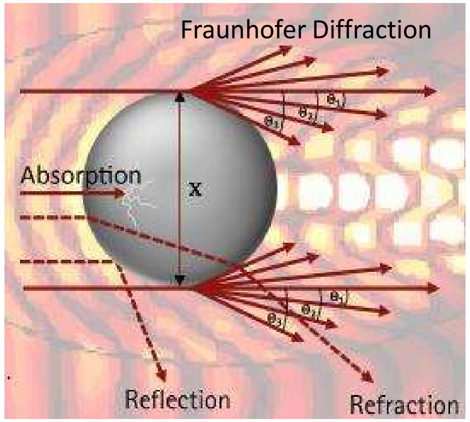
Stewart, Scholes & Hunt, Patent 2016



Slag electrification & electropulsing

Mills & Riaz, Unpublished results, 2001   *Qin, 1998*

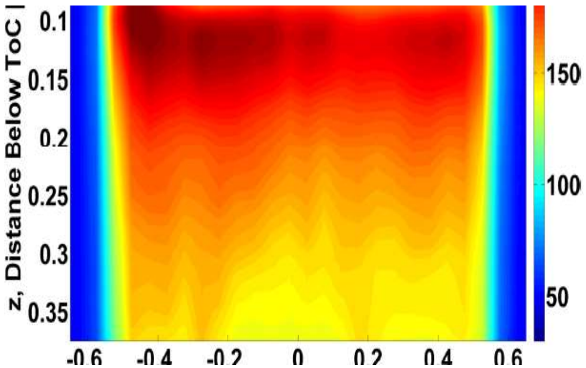




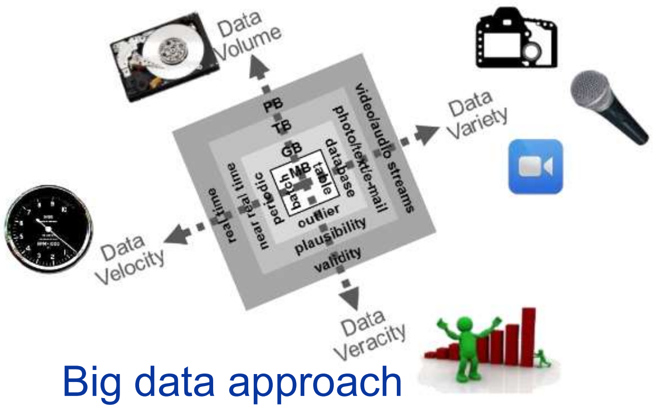
Mie scattering

State of the Art

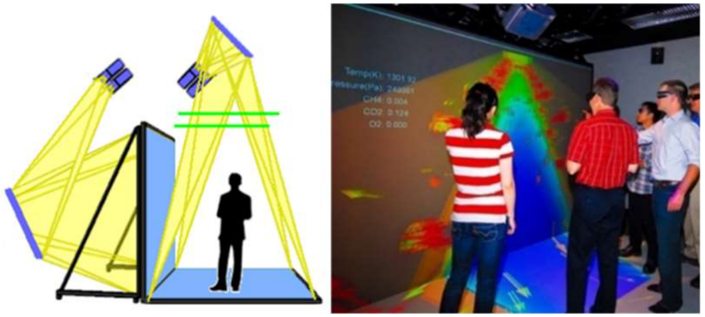
Design and Evaluation



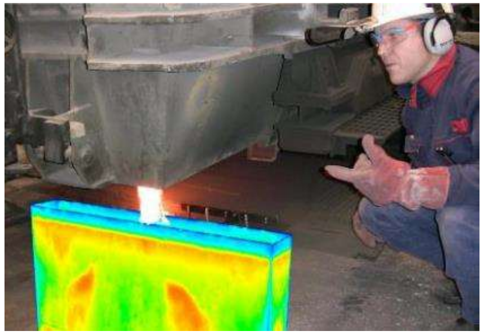
Dense temperature measurements



Big data approach

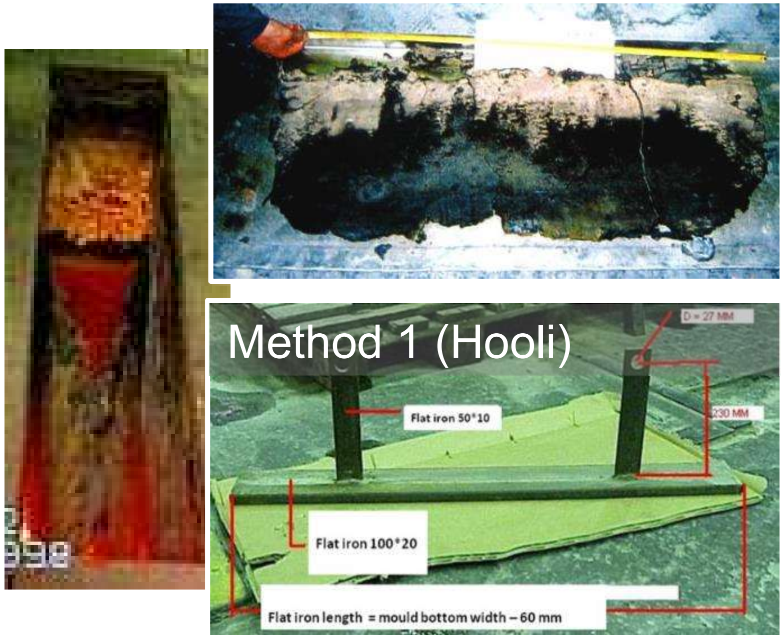


New methods to visualise and interrogate the data

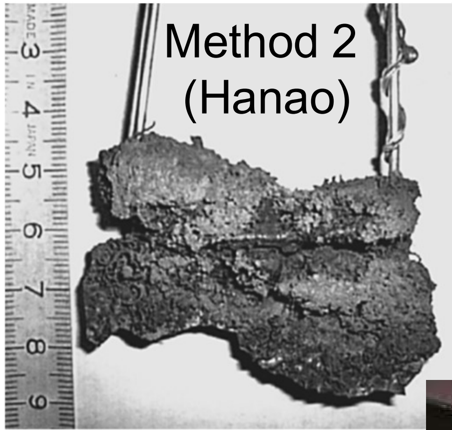


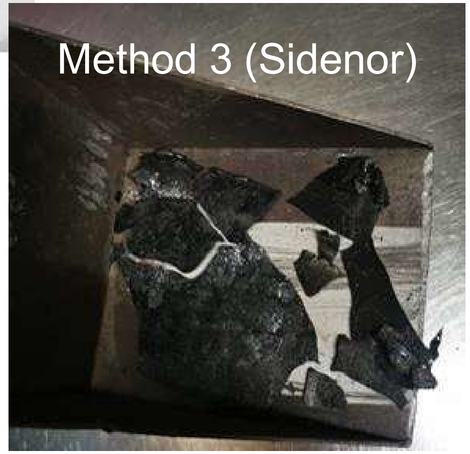
Modelling to predict optimal local heat transfer control

WP1 Slag film extraction methods



Hoopa Metallurgy

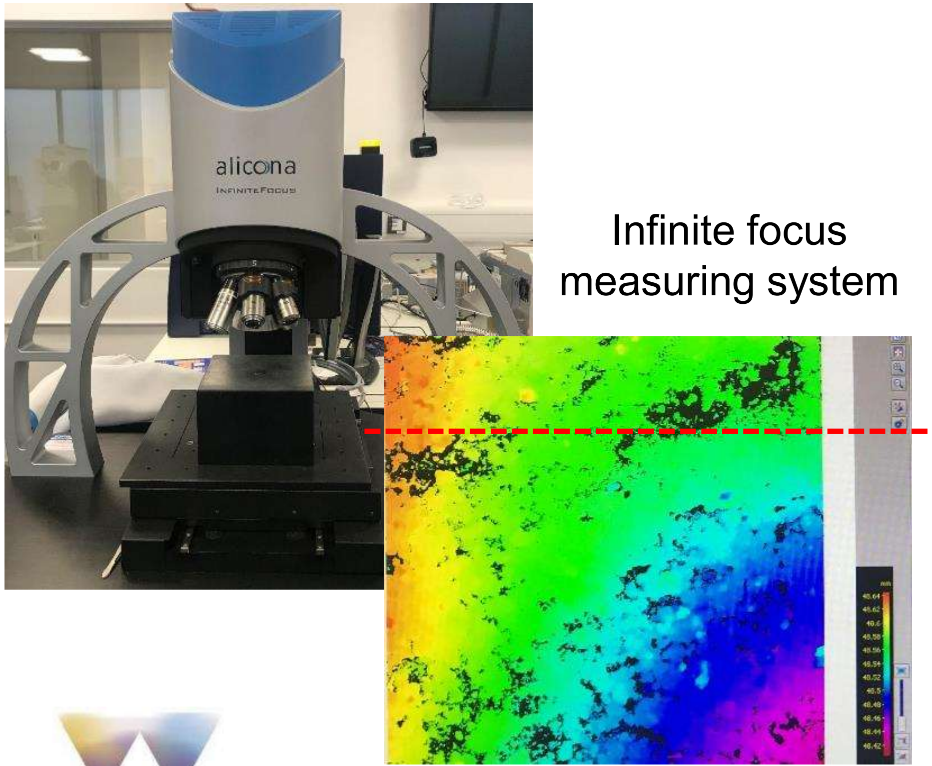




Materials Processing Institute SANDVIK SWERIM ArcelorMittal sidenor

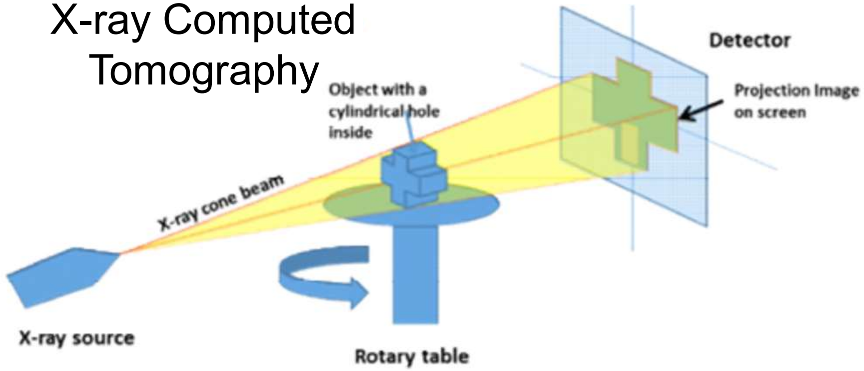
WP2 Slag film characterisation

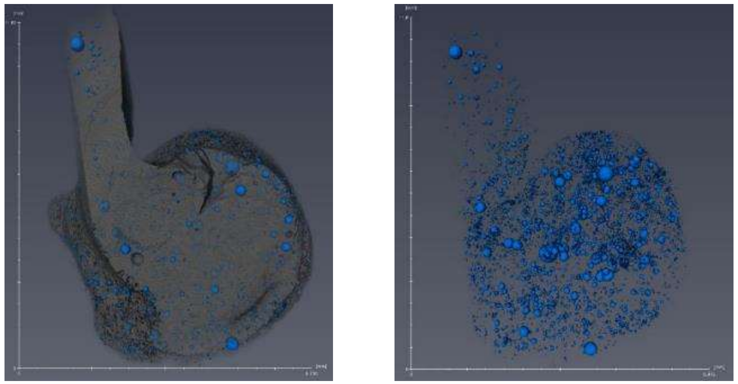
Use of novel techniques e.g. for surface roughness and porosity



Infinite focus measuring system

Measured surface roughness profile of Sidenor slag film



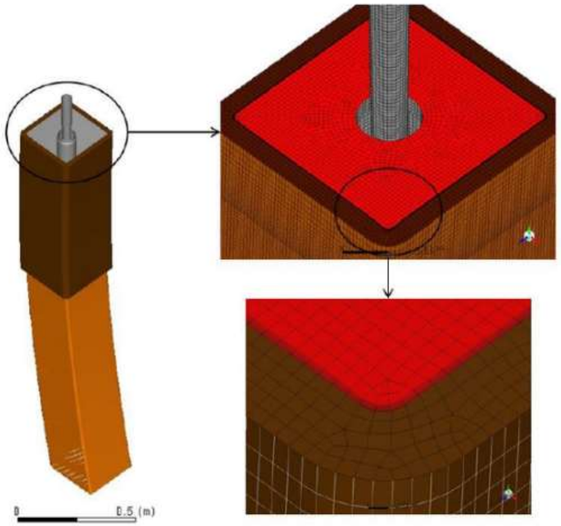


Sidenor slag film with porosity

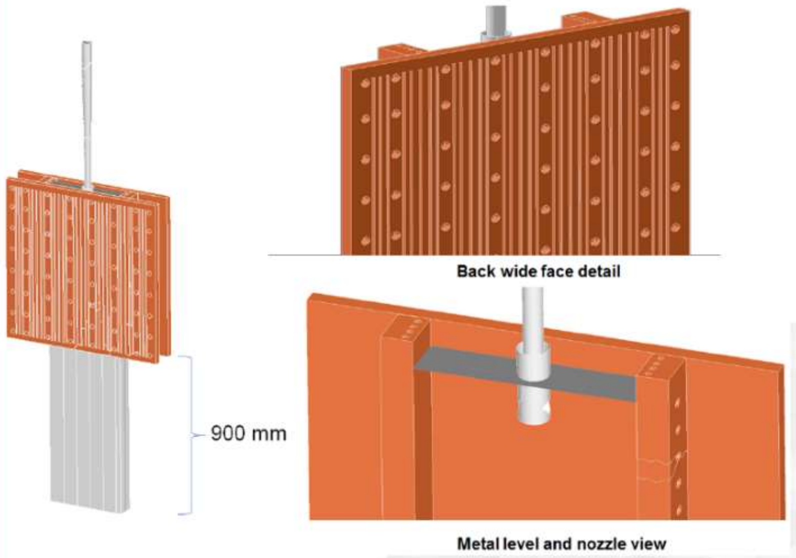
Porosities in 3D

WP3 Modelling

To predict values of q_{hor} and slag infiltration for reference cases



SIDENOR billet caster: 240 x 240 mm



Arcelor Mittal Pilot caster: 100 x 450 mm

sidenor

ArcelorMittal

SANDVIK

SWERIM

WP 6 Pilot trials

Facilities:

7T AC Electric Arc Furnace

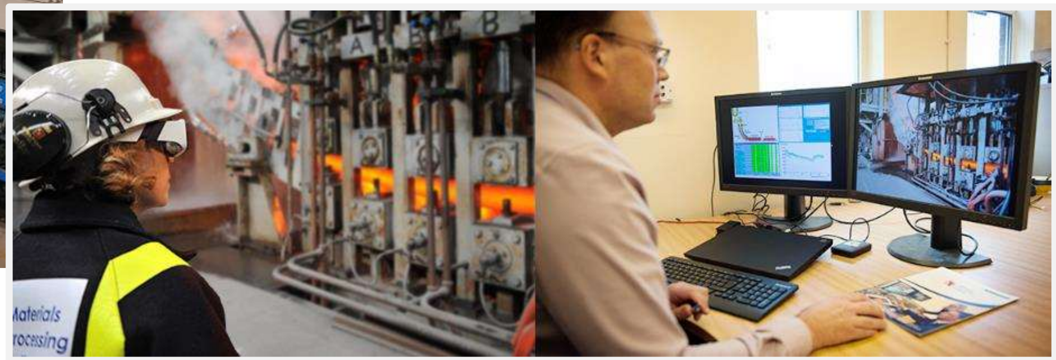
Combined vacuum degassing and ladle furnace

Billets and mini-slab

Up to 20m cast length

SANDVIK

Partners can participate in MPI pilot trials, and access live data by combining remote access through wearable technology (Smart Glasses) with Digital Twin of the caster.



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Next steps

- Publications on electrical methods in press (Open University)
- Install dense temperature measurement sensors in industrial moulds (Proximion, Sidenor, Sandvik)
- Revise plan as Covid-19 response evolves.

Acknowledgements

Thank you to everyone involved!

Research Fund for Coal & Steel

SWERIM
sidenor
RINA
Materials Processing Institute
BFI

VALCRA

VALCRA

SWERIM

sidenor

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BFI

Contact: Bridget Stewart
bridget.stewart@mpiuk.com
https://www.mpiuk.com/

European Commission

Research Fund for Coal & Steel