Modelling of Continuous casting of steel…

… from virtual calculations to industrial reality

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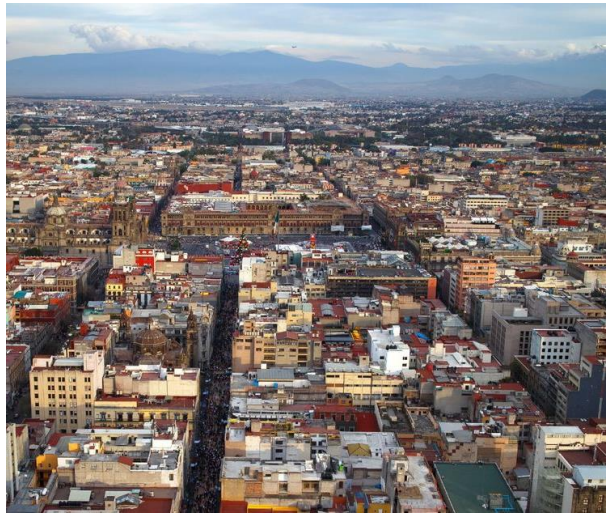
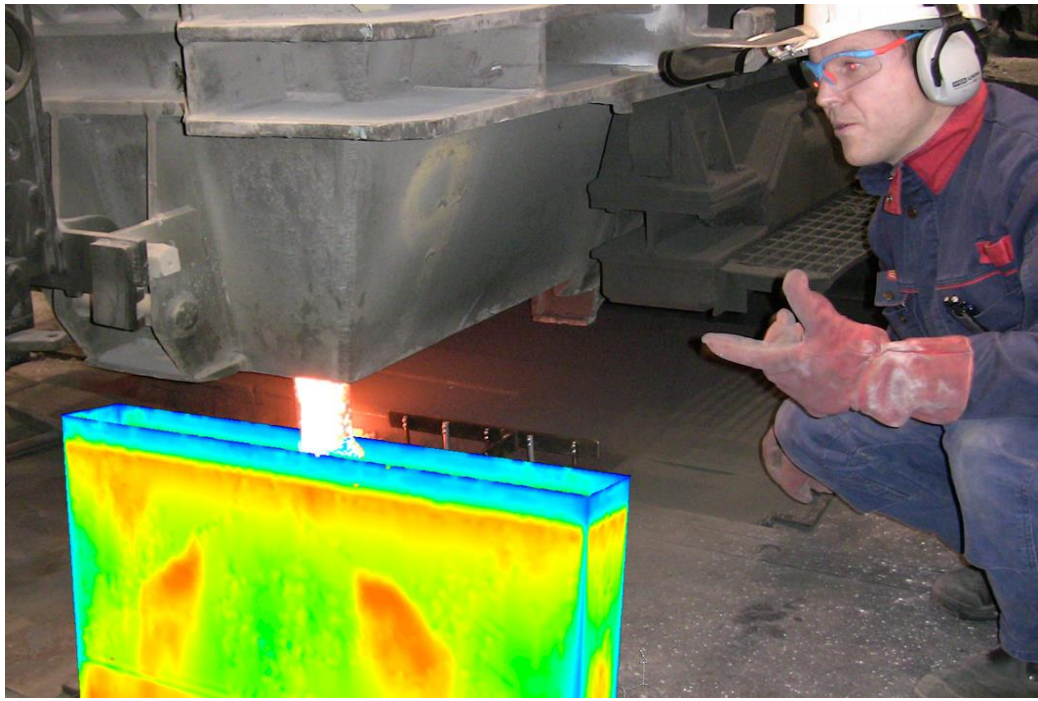


Modelling of Continuous casting of steel:

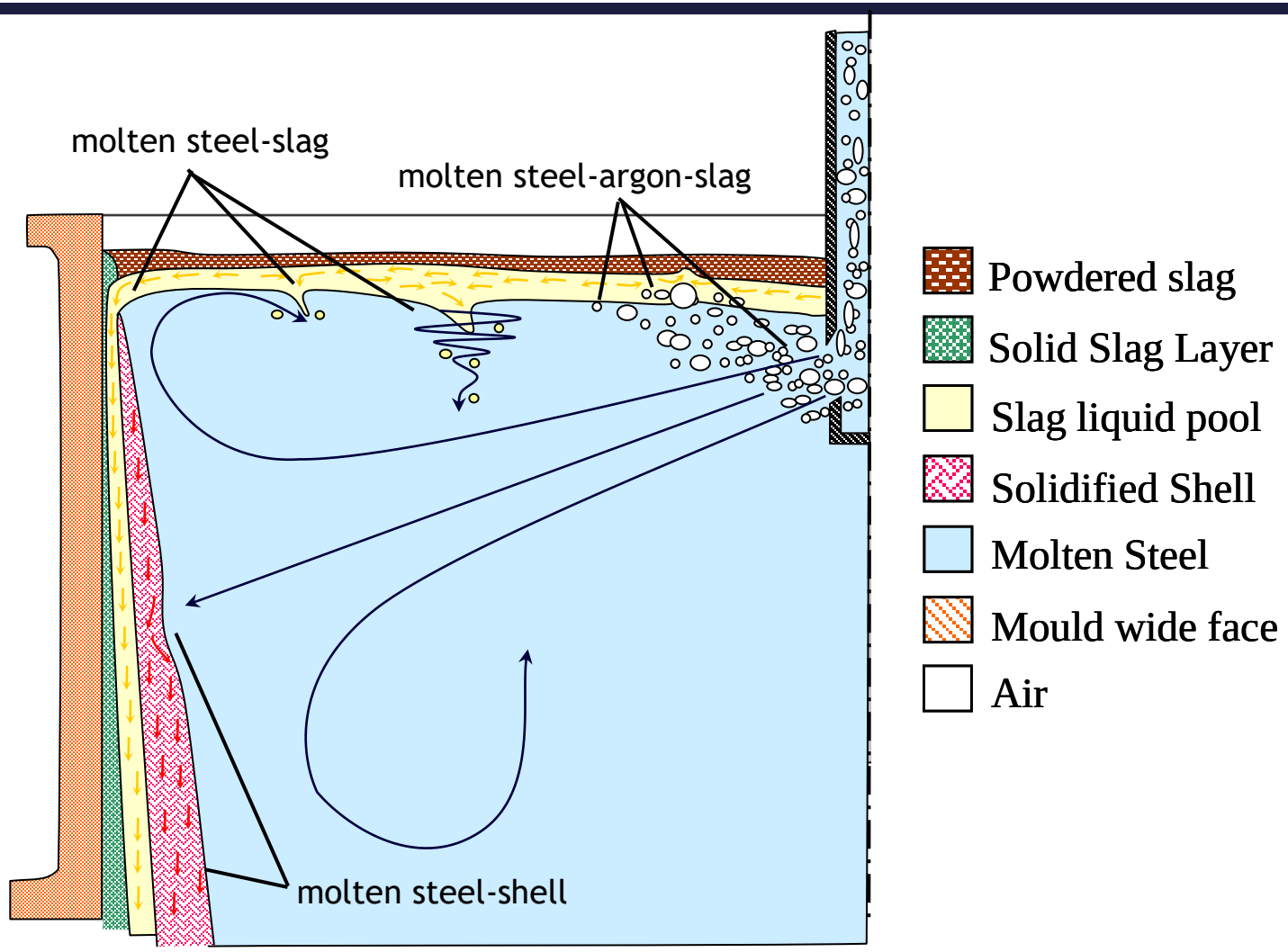
from virtual calculations to industrial reality

"Steelmakers are increasingly using simulations to find optimal settings for their casting processes that avoid expensive and time-consuming trial-error tests during production..."



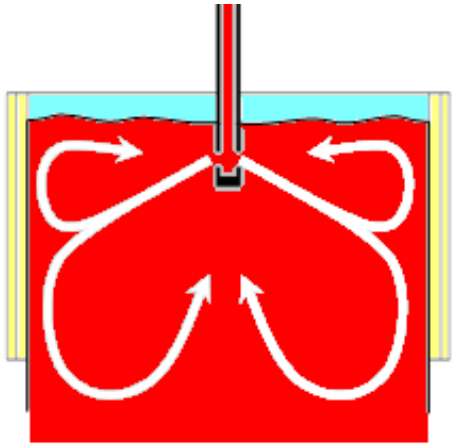
BACKGROUND

Multiphase interactions in CC

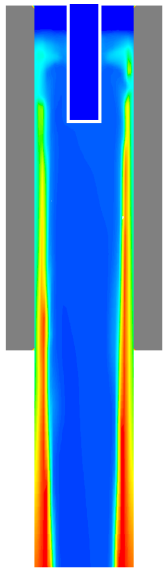


Coupled physical phenomena in CC

CONTINUOUS CASTING → MULTIPLE PHENOMENA

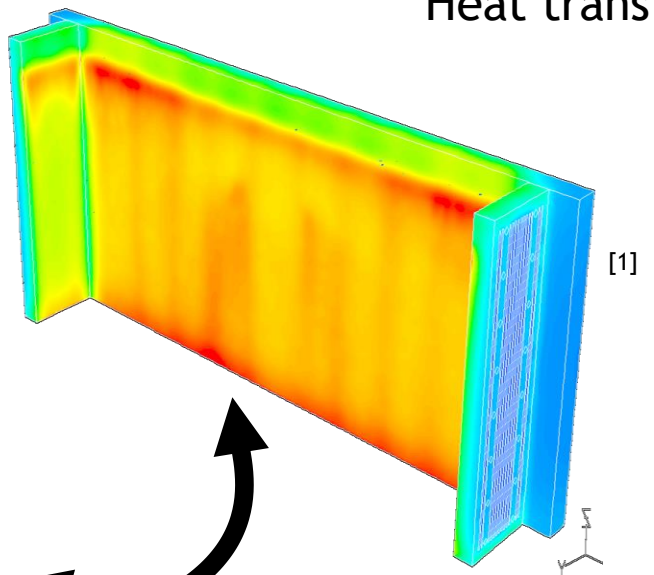


Fluid dynamics



solidification

Heat transfer

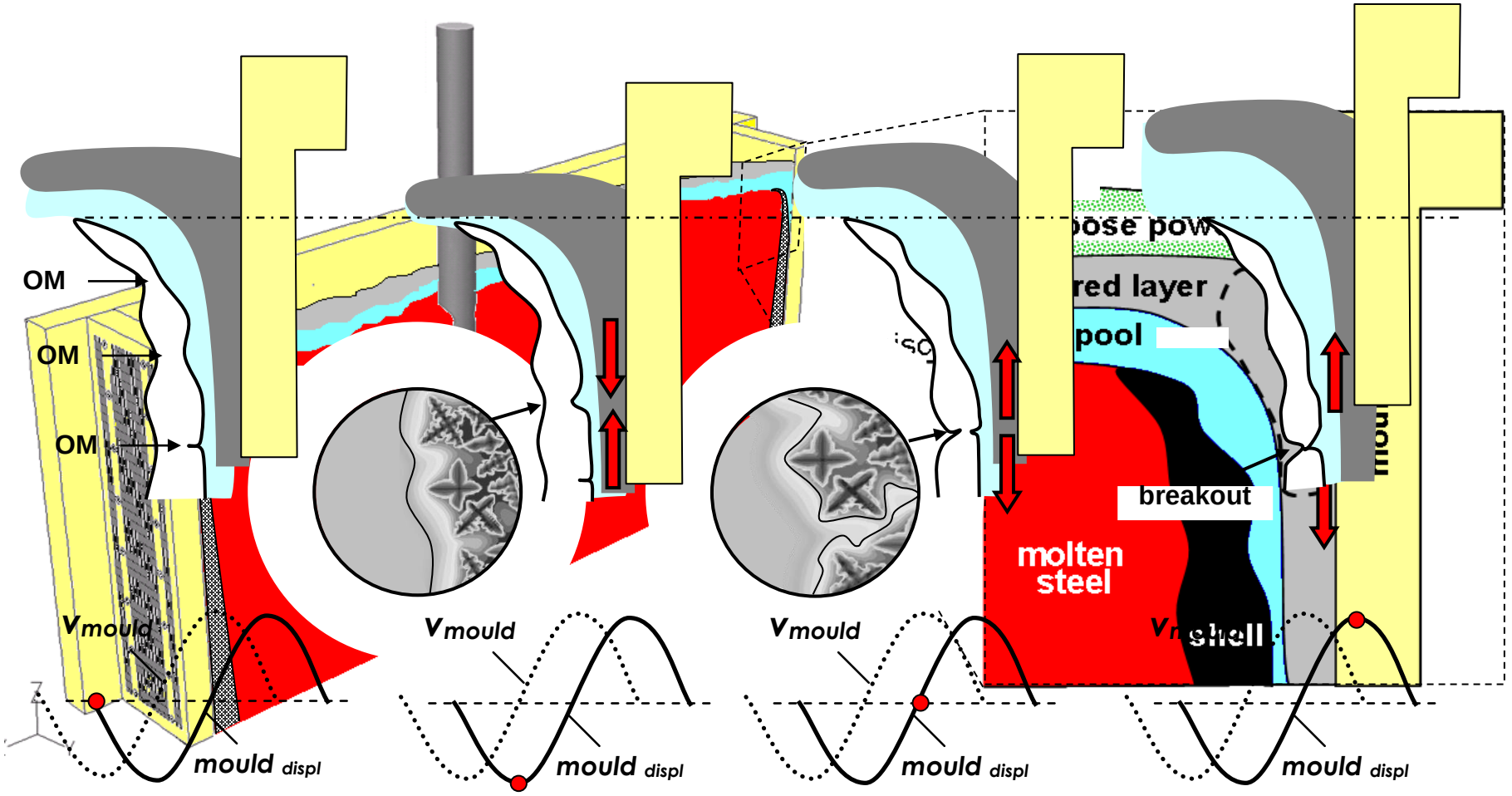


[1]

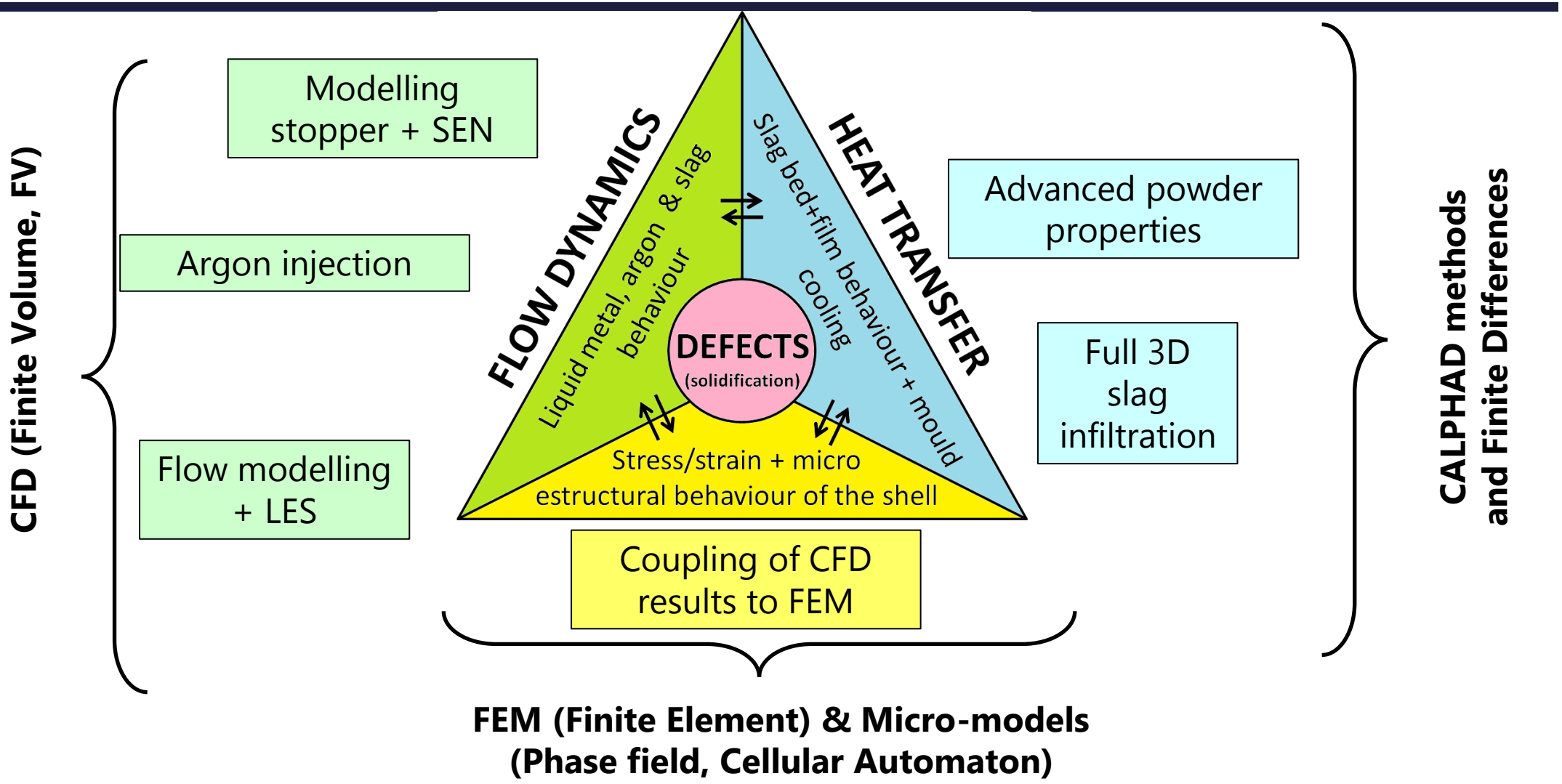
[1] R. D. Morales and P.E. Ramirez-Lopez, AISTech Conference Proceedings 2006, 20.

Crack formation in the CC mould

Most defects originate in the mould during initial solidification…



Modelling approaches



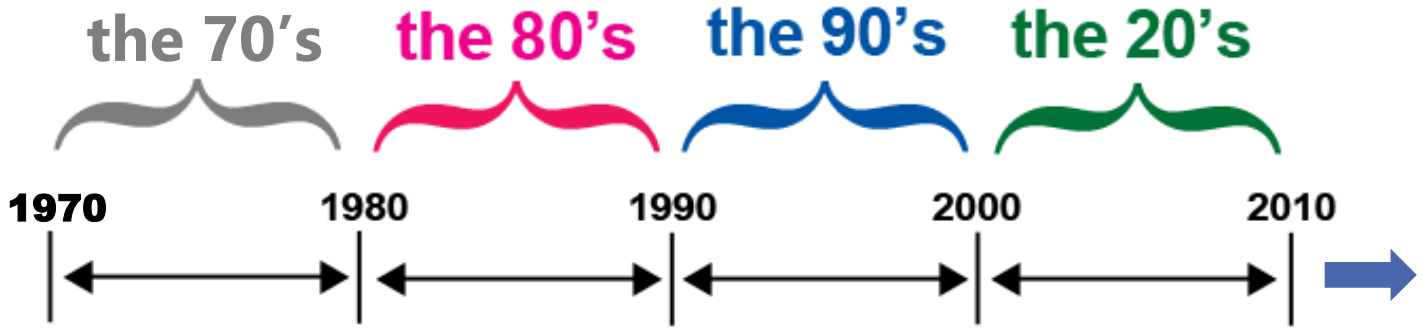
Quick modelling timeline…

Starting in the 70's and 80's with the advent of personal computers, the first generation of models managed to predict the overall behaviour of the caster based on empirical data. (see Brimacombe & Pritchard)

Models in the 90's saw the addition of Computational Fluid Dynamics (CFD) and solidification to casting simulations. (B.G. Thomas, Sekely, Hasan and Others)

Faster computers and improved codes allowed huge progress regarding multi-phase applications (e.g. bubbles and inclusions) combined with calculations of flow and solidification in the past decade. (Thomas, Ludwig, Louhenkilpi, etc)

Currently, a wide variety of commercial and in-house codes are available for CC such as PROCAST, COMSOL, TEMPSIMU, CON1D/2D, etc.



A recent trend is the development of thermo-mechanical models coupled to flow dynamics for solving the combined flow, solidification and stress-strain during casting. Of all these, PHYSICA and THERCAST seem to be two of the most promising approaches…

Research trends

FEM is ubiquitous

Despite all the progress, the actual simulation of cracking during CC has remained elusive from modelling efforts. This is partly due to the Multiphysics nature of the problem (e.g. dependent on heat transfer, solidification and stress-strain) as well as the high temperatures at which the process occurs (which limits possible measurements and data acquisition).

Process models are typically based on macro-scale FEM methods that aim at predicting the total strain and stress coming from the elastic, thermal and plastic strains by means of thermo-mechanical models

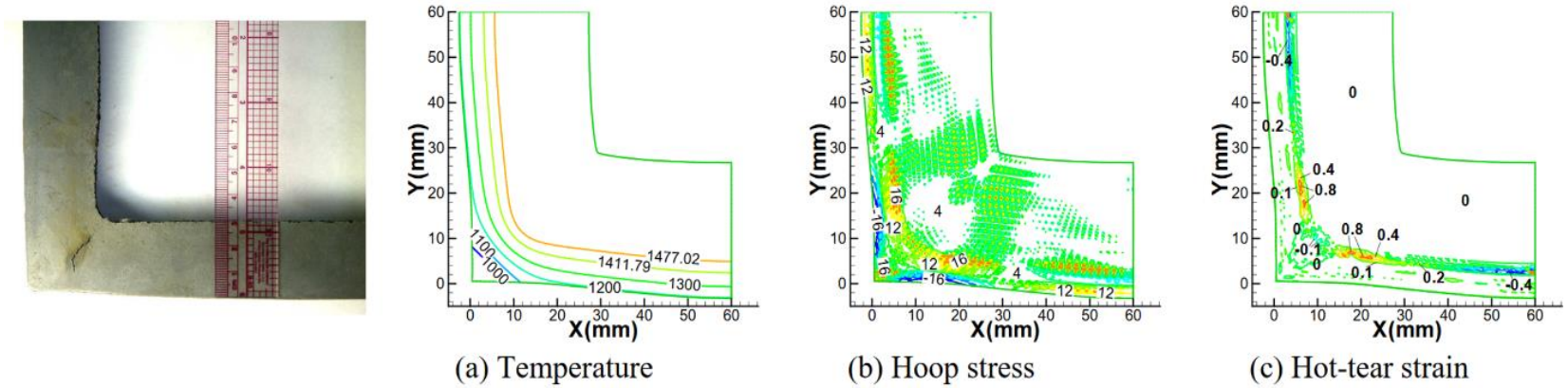


Fig: Sub surface Corner cracking in CC (extreme left) and thermo-mechanical modelling by Bellet & Thomas [1]

[1] Brian G. Thomas, Michel Bellet. Modeling of Stress, Distortion, and Hot Tearing. Edited by S. Viswanathan and E. DeGuire. ASM Handbook, Volume 15: Casting, ASM International, pp.Pages 449-461, 2008, ASM Handbooks, 978-0-87170-711-6. <hal-00509529>]

EU-RFCS Research Highlights

Modelling of Continuous casting of steel:

The aim of EU-RFCS research is…

- to reduce or even eliminate the number of defects and process problems during casting by combining **numerical simulations** with **plant trials** and **physical experiments**; providing at the same time, a more fundamental understanding of the mechanisms responsible for their formation.

- The expertise acquired is used to **enhance the processing window** or even test the introduction of new/different grades and casting powders; providing the steelmakers with a new set of tools to **improve their casting practices.**

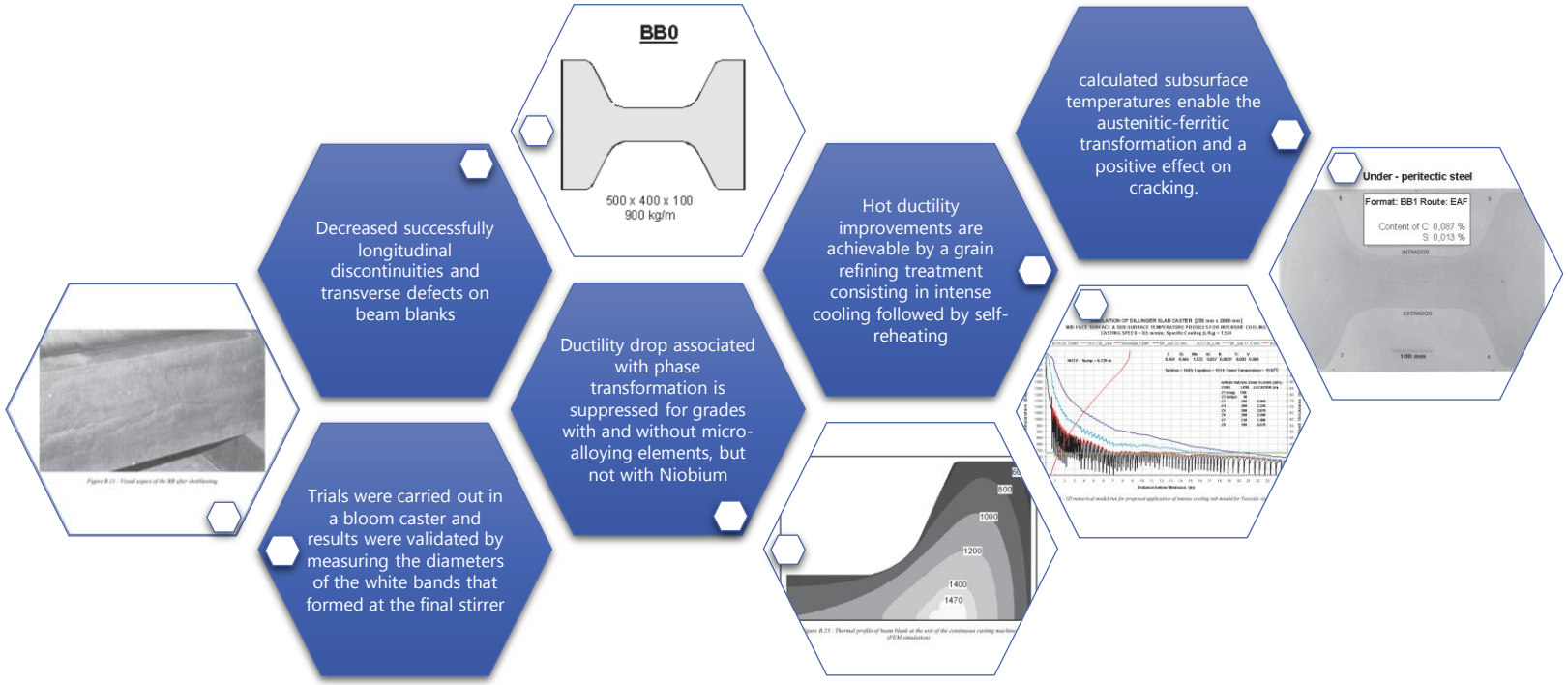
Projects focused or related to modelling

Period	Acronym	Title	Topic 1 - Basic knowledge	Topic 2 – Modelling	Topic 3 – Process Optimisation	Topic 4 - Mould powders	Topic 5 – Process control & sensoring	Topic 6 - New Casting Technology/Demonstration projects	POSSIBLE SUBTOPICS
01/07/1999 - 31/12/2002	N/a	Castability & surface quality of steels microalloyed with Ti or TiNb in continuous casting of slabs, thin slabs and beam balnks			Main topic T3.3: Improved steel compositions		Secondary topic T5.2 Secondary cooling control		T1.2 Hot ductility
01/07/2005 - 30/06/2009	BEAM-BLANK MFC	Direct casting of small sections beam-blanks thanks to meniscus free casting technology.		Secondary topic T2.1: mould modelling				Main topic T6.1 - Near net-shape (beam blanks)	T2.1 Mould modelling
01/07/2005 - 31/12/2008	SLAGFILMOWL	Optimising slag film properties and determination of operational windows for lubrication, mould heat transfer and shell formation.			Main topic T3.1: Operating Conditions	Secondary topic T4.2: Slag film characterization			T2.2 Secondary cooling modelling
01/07/2011 - 31/12/2014	DIRECT DEFECT TOOLBOX-DDT	Development of a toolbox for direct defect prediction and reduction through the characterisation of the meniscus slag bed behaviour and initial shell solidification in CC.		Secondary topic T2.1: mould modelling	Main topic T3.1: Operating Conditions				T3.1 Layout design
01/07/2009 - 31/12/2012	LUBRIMOULD	Identification of optimal mould lubrication conditions through an innovative hot and cold simulation method.		Main topic T2.1: mould modelling		Secondary topic T4.1: Casting Powder properties			T3.2 Operating conditions
01/07/1995 – 30/06/1999	N/a	Optimisation of the straightening process in continuous casting.		Main topic T2.2 Secondary cooling modelling			Secondary topic T5.1 Measuring systems (roll forces)		T3.3 Improved steel compositions
01/07/1995 - 31/12/1998		Influence of mould metallurgy on concast surface quality.		Main topic T2.1: mould modelling			Secondary topic T5.1: measuring systems		
01/07/2005 - 31/12/2008	SOLIMOULD	Enhanced as-cast product quality by optimised mould taper design.							T2.1 Mould modelling
01/07/2006 30/06/2009	GRAINCONT	Grain size control in steel by means of dispersed non metallic inclusions							
01/07/2007 - 31/12/2010	NDTCASTING	Innovative non contact non destructive sensors for automatic detection of surface and internal defects in hot continuously cast products							T2.2 Secondary cooling modelling
01/09/2003 - 28/02/2007	FLUXFLOW	Enhanced steel product quality & productivity by improved flux performance in the mould through optimising the multiphase flow conditions & special regard to melting & entrapment.							T2.1 Mould modelling
01/07/2004 - 30/06/2007	EDDYCAST	Multiplexed eddy current arrays for the detection of corner cracks on as cast products in the inspection yard & at the exit of continuous casting.							T2.2 Secondary cooling modelling
01/07/2005 31/12/2008	PRECIPITATION	Precipitation behaviour of microalloyed steels during solidification and cooling.							T2.1 Mould modelling
01/07/2006 30/06/2009	GRAINCONT	Grain size control in steel by means of dispersed non metallic inclusions							T2.2 Secondary cooling modelling

PROJECT: EUR 21445 - New secondary cooling patterns for peritectic and micro alloyed steels

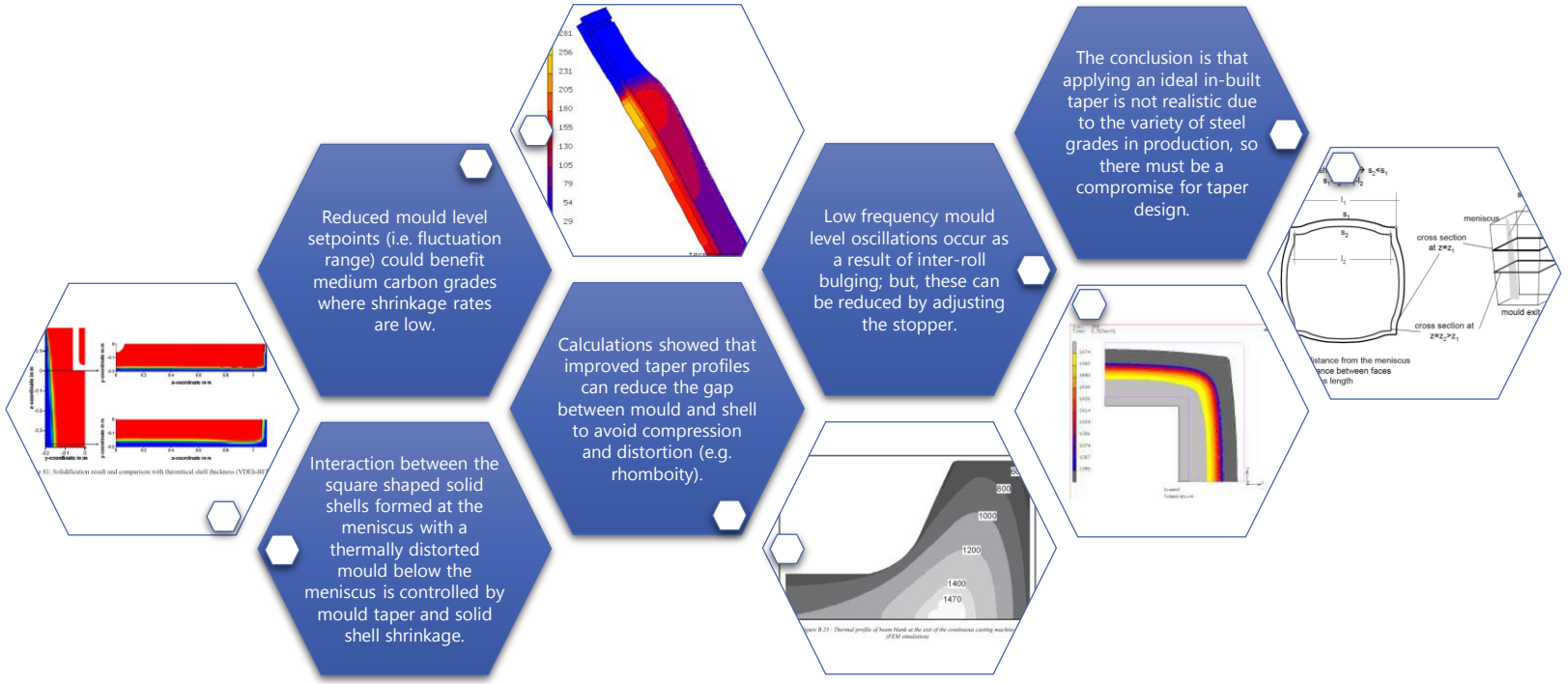
The project developed new cooling strategies based on:

- Numerical modelling of secondary cooling
- Laboratory studies of hot ductility and…
- Evaluation of as–cast microstructure.
- A numerical model for new cooling strategies was successfully developed to calculate the possible use of a quenching box



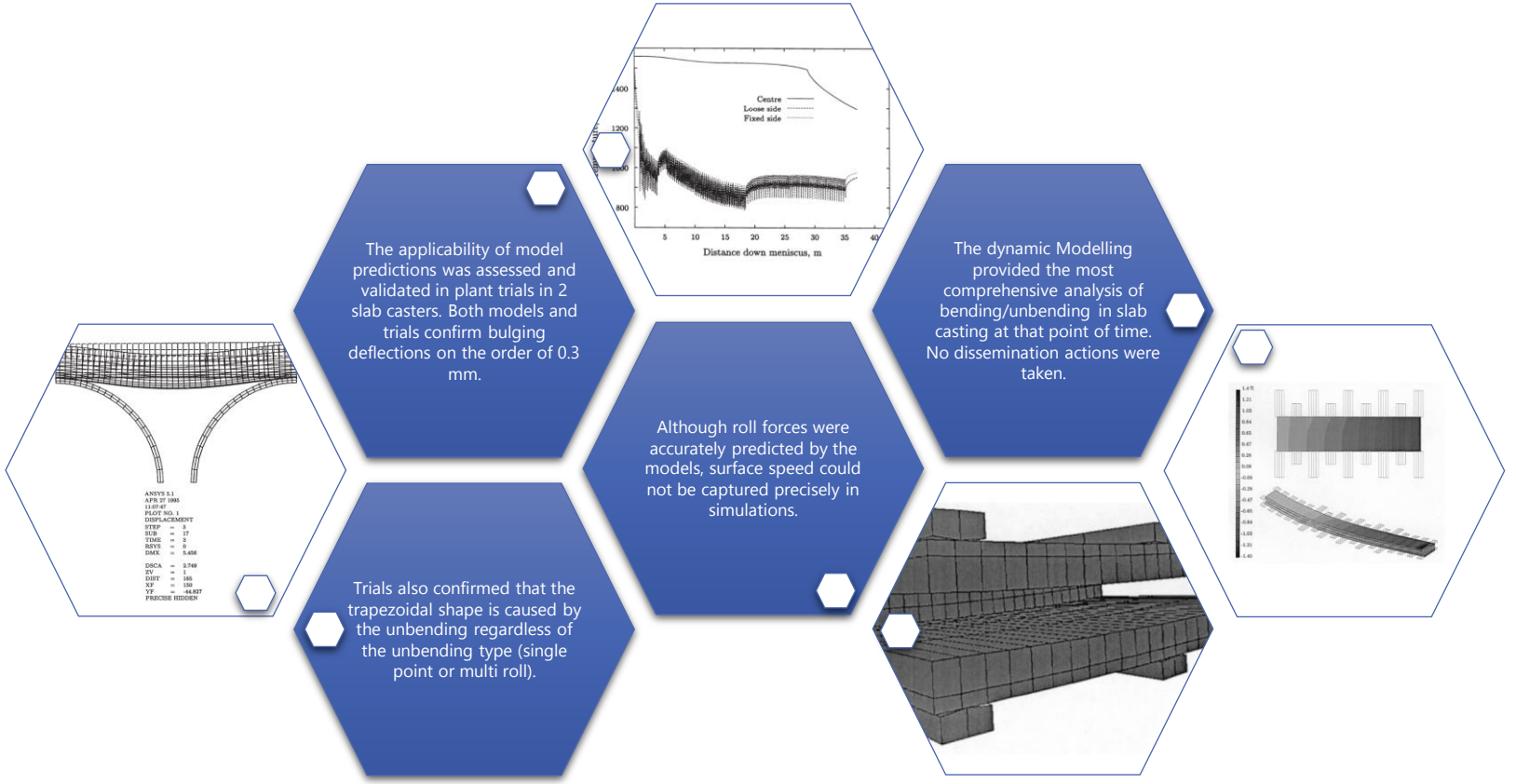
PROJECT: SOLIMOULD KI-NA-24176-EN-C - Enhanced as-cast product quality by optimised mould taper design

- The project could determine how the mould taper in combination with shrinkage, operational parameters and other conditions (wear and distortion) affect the as-cast product quality of carbon and stainless steels.
- A full strand inter-roll bulging model was successfully developed
- Trials with different oscillation settings



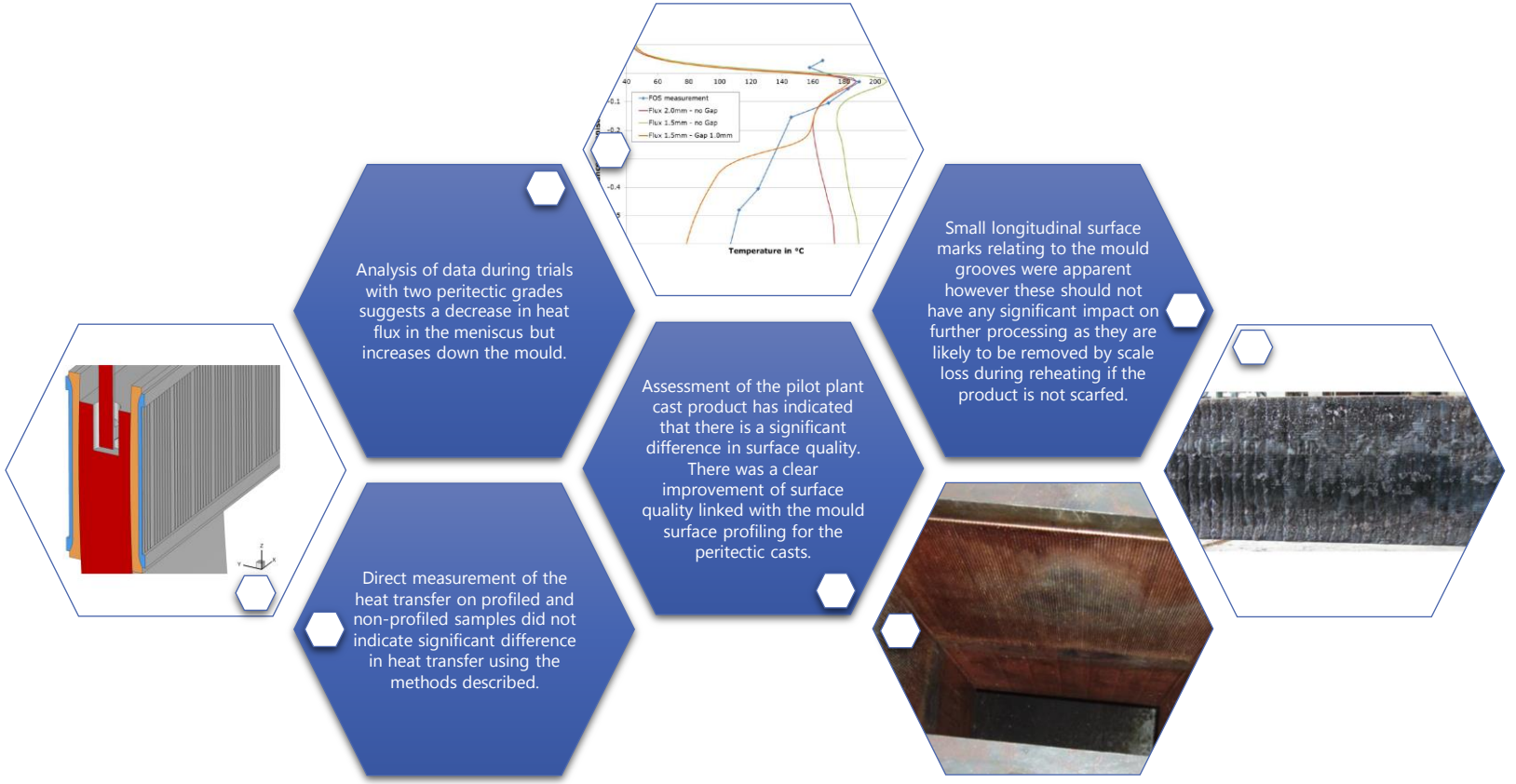
PROJECT: EUR 19850 - Optimisation of the straightening process in continuous casting

- Measurements of strain indicators were carried out both off- and on-line at CORUS Ijmuiden.
- This included successful measurement of strand deflection during inter-roll bulging.
- Roll forces, surface speeds and trapezium shape distortion were also measured successfully.
- MPI successfully developed improved 3D numerical models in FEM to simulate bending.
- Finally, a multi-beam model was developed by CORUS R&D



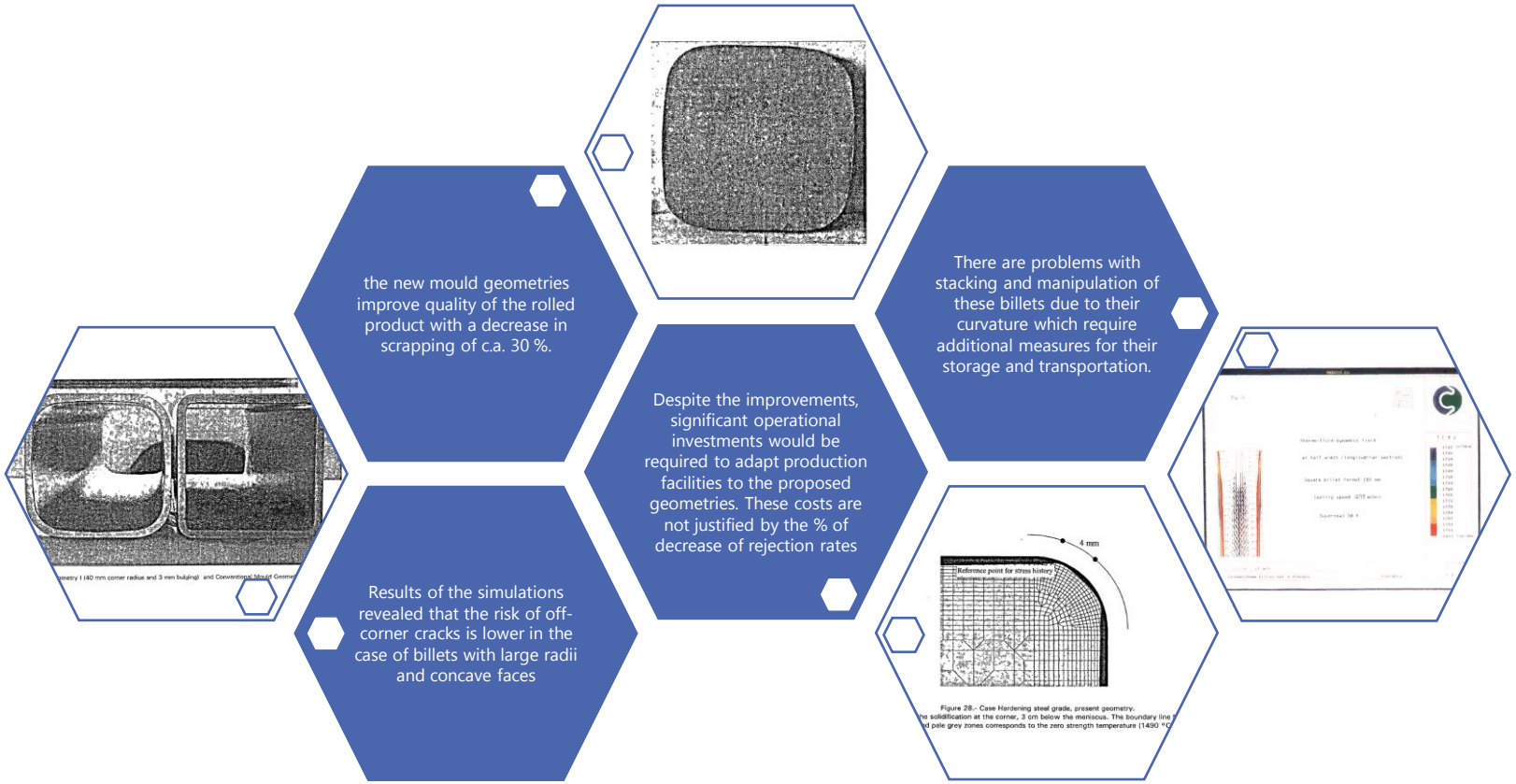
PROJECT: INNOSOLID EUR 29549 - “Investigation of innovative methods for solidification control of liquid steel in the mould”

- Numerical model was developed for slab, but narrow face temperatures were not so accurately predicted, so a simple air gap model was developed to add casting flux effects, coatings or developing a gas gap.
- Numerical model enabled the development of an adjusted design for the cooling circuit in the copper mould plates.
- A FEM model was utilised to compute the resulting heat flux in the copper plates.

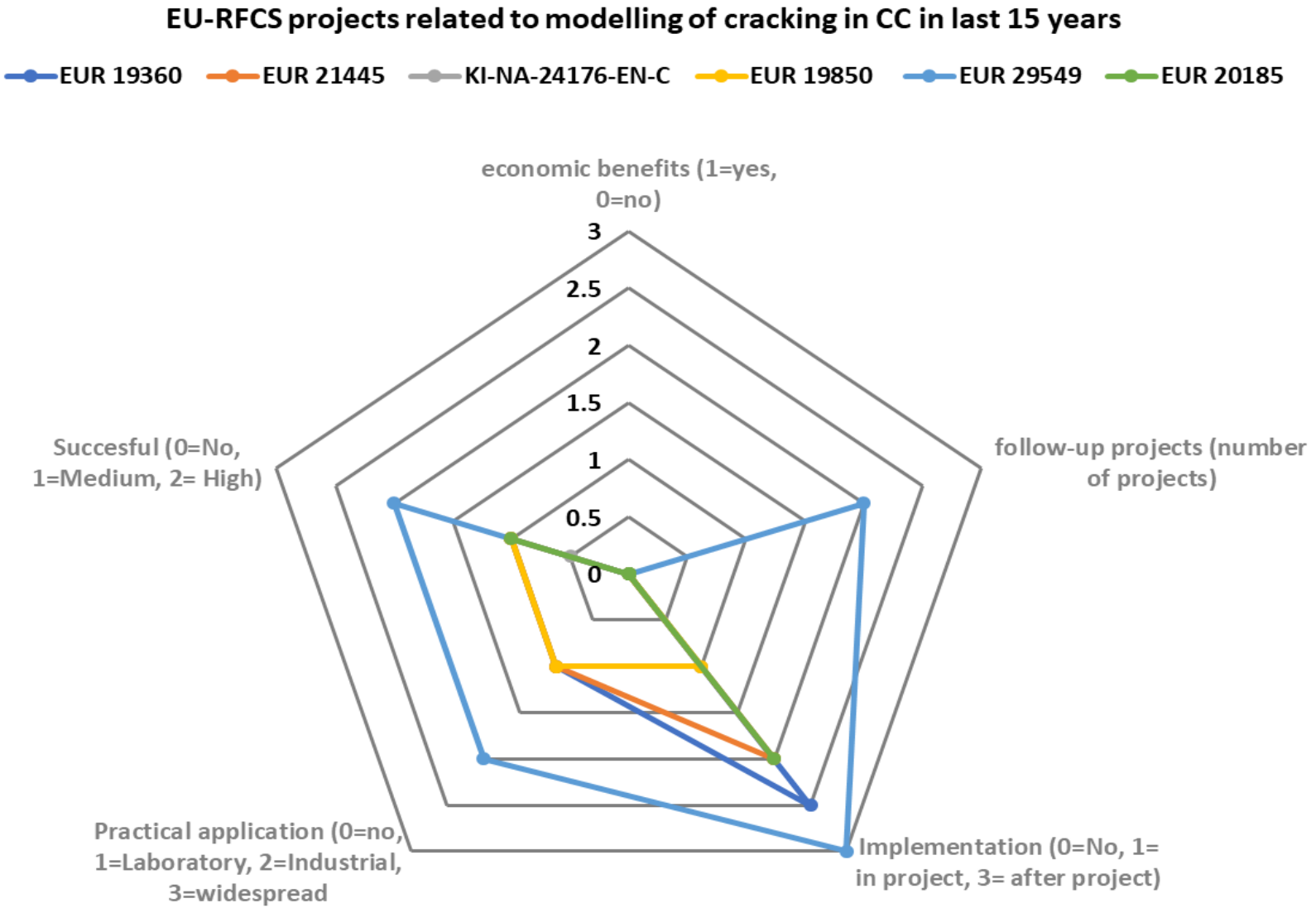


PROJECT: EUR 20185 - Control of the dendritic structure of the initial frozen shell in continuous casting

- The project developed successfully new mould geometries for better control of the dendritic structure of the initial frozen shell in the continuous casting of billets.
- The new moulds include an increased radius at the corners and face bulging (i.e. in-built parabolic taper).
- CSM successfully developed a model to describe solidification of the steel inside the mould.
- The 2D model included the effects of thermal field from the liquid steel and the influence of slag infiltration by means of a 1D model



Example of outcomes analysis



Thanks for the attention!

Stay informed

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