Continuous Casting modelling: An Overview

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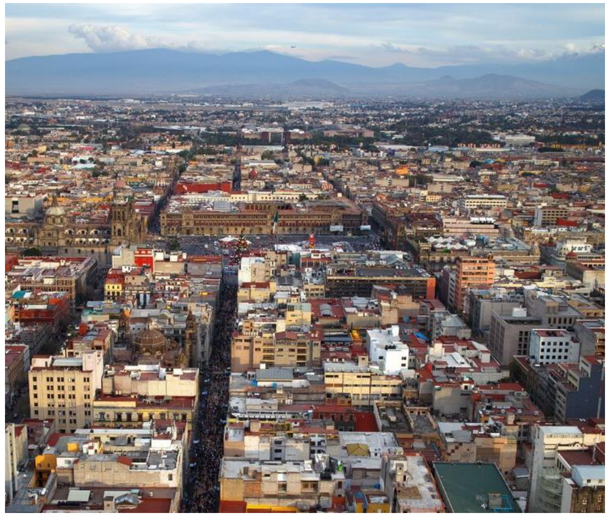
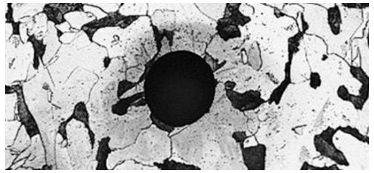
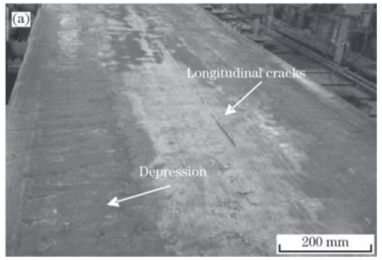
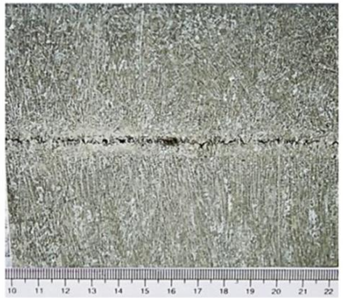


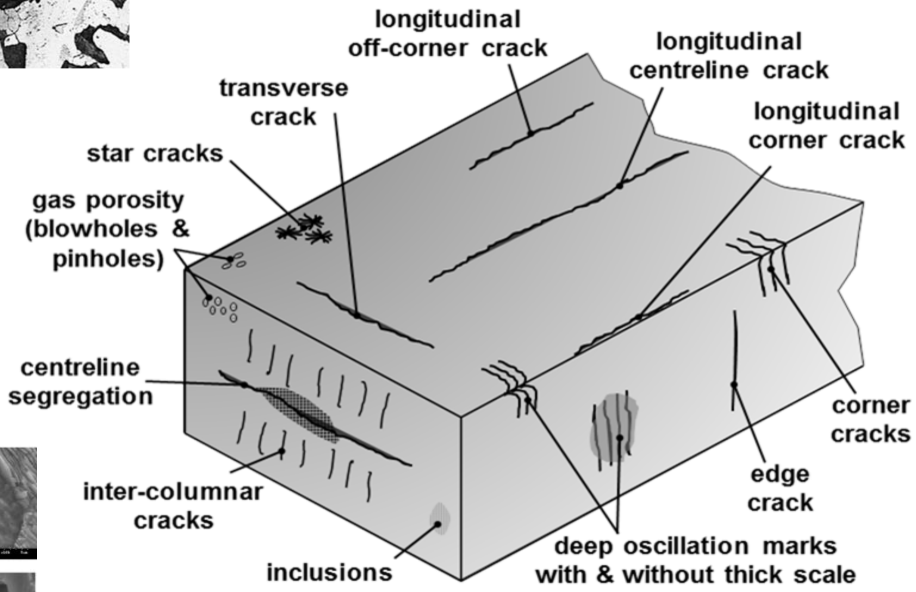
Motivation

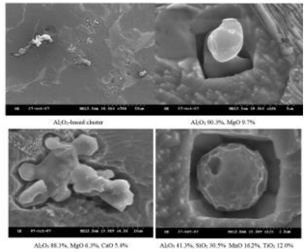
Common CC defects

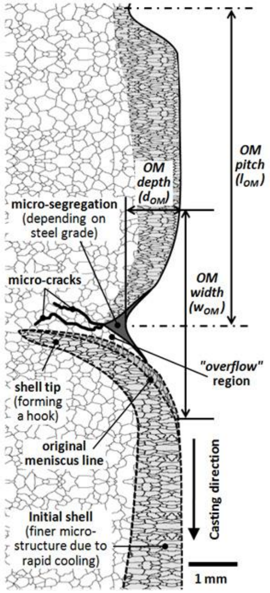












Q1) What kind of ”events” you observe more frequently?

a) Castability issues due to clogging & poor flow control?

b) Surface defects from cast product to plate?

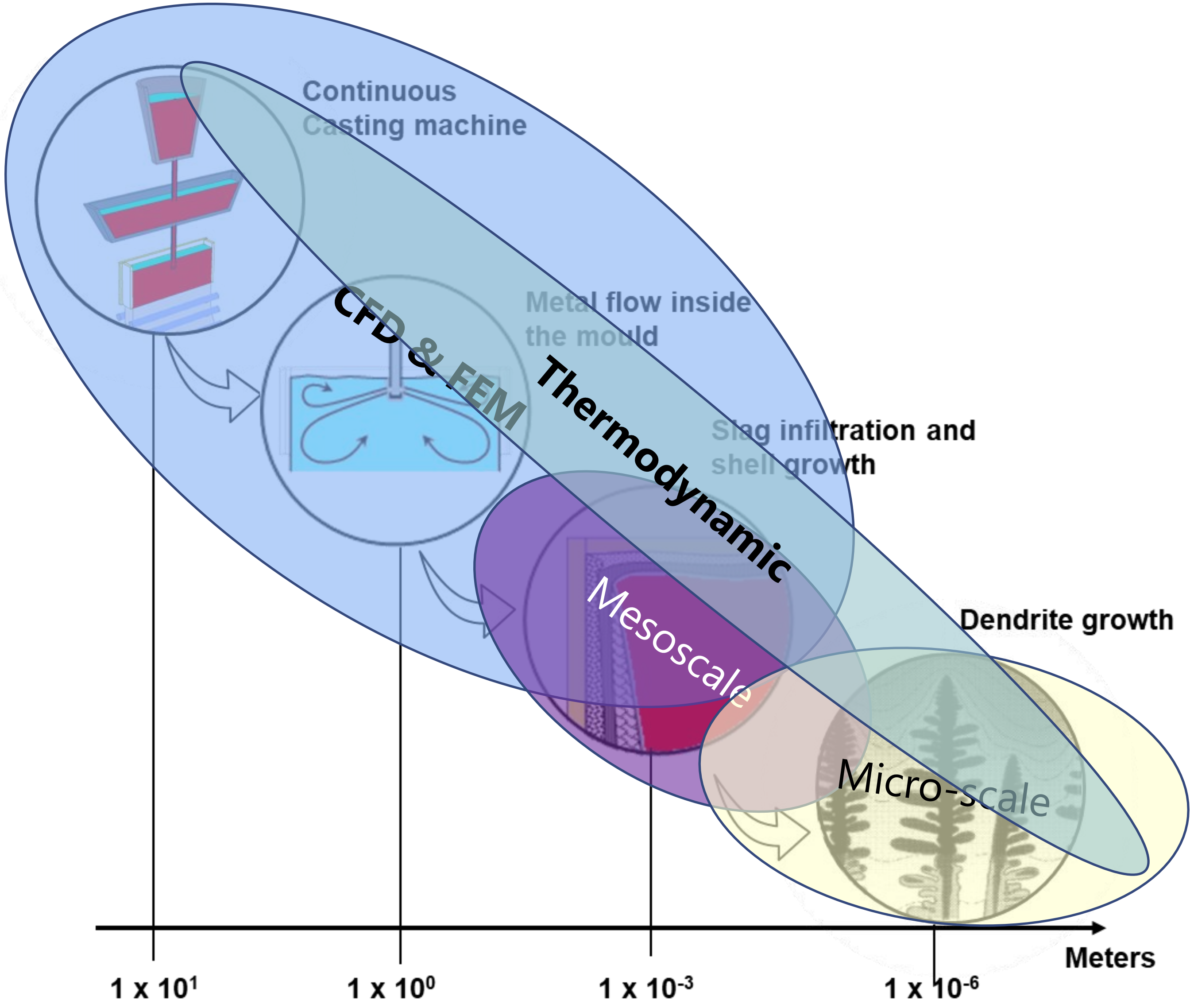
c) Internal quality issues (e.g. segregation, macro-porosities, internal cracks?

d) Problems derived from testing and/or implementing new casting technologies?

e) Issues with challenging/new steels (e.g. High Si, Peritectics, etc.)

Classification of models

Multi-scale & Multi-phenomena



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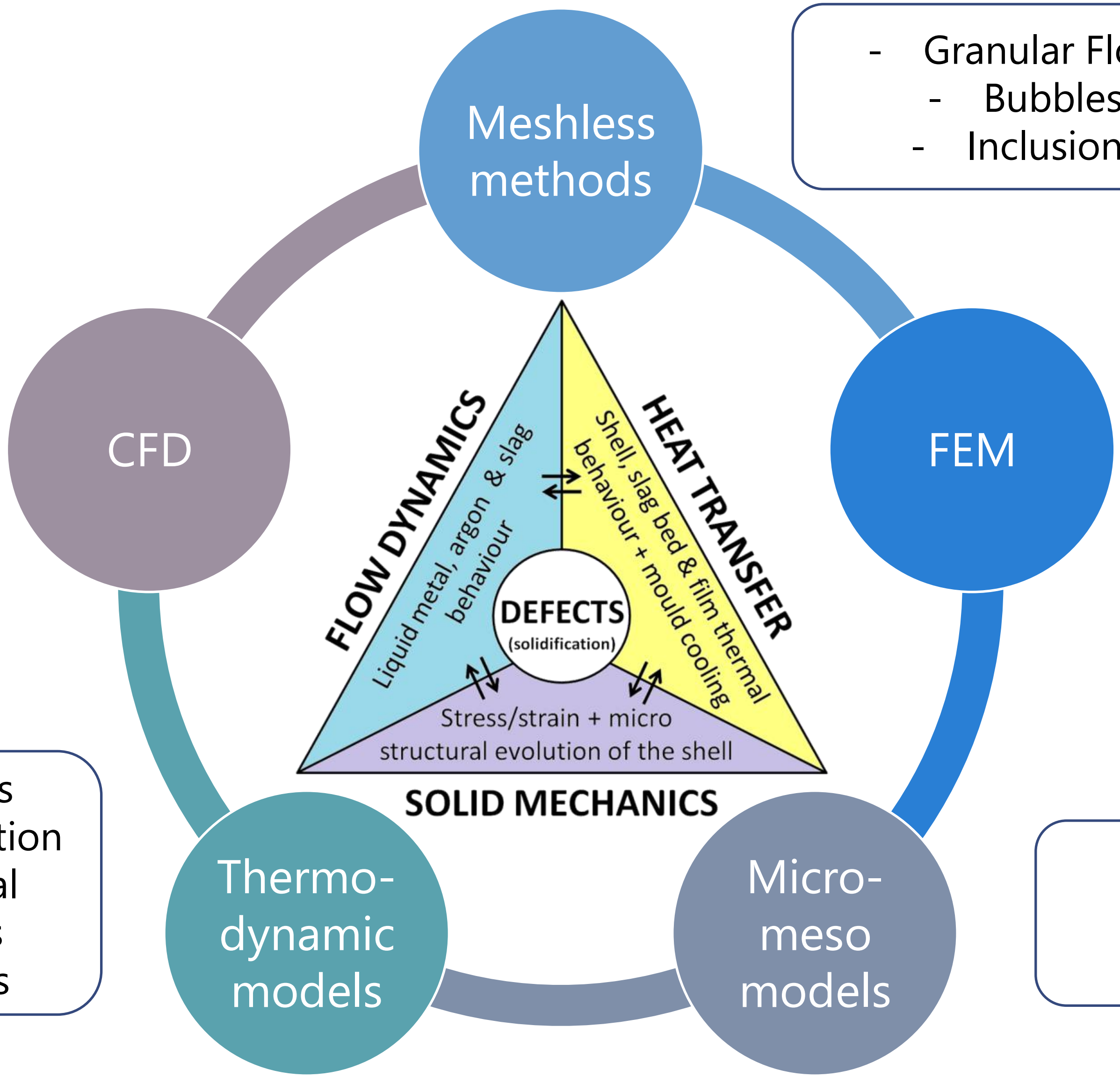
Classification

- Metal level stability
- Argon Injection
- Stopper/nozzle design

- Granular Flows
- Bubbles
- Inclusions



- Stress-strain
- Cracking
- Mould distorsions

- Mat props
- Phase evolution
- Slag/metal reactions
- Inclusions

- Solidification
- Phase evolution
- Segregation

Typical modelling applications in CC

Thermodynamic models

Typical applications include:

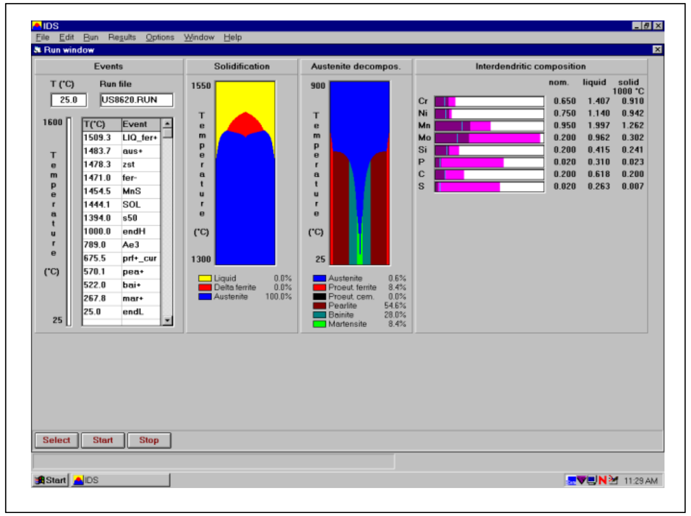
- Determination of thermo-physical properties for simulations
- Phase Evolution during solidification
- Slag-metal reactions
- Formation of inclusions, intermetallics, carbides, nitrides, etc…
- Inputs for micro-mesoscale models
- Design of steels

Example 1: Steel properties for simulations

IDS

- Steel composition
- Cooling rates

INPUT



OUTPUT

Solidification phenomena
Phase transformations
Microsegregations
Microstructure evolution
Inclusions
Precipitates
Pore formation, etc.

Thermophysical material properties (H, k, C_p, L,..)
Thermal contraction
Density
Liquid viscosity
Liquid/air surface tension
Solid/liquid interface energy
Hardness, etc.

- **Alloying elements included**: Fe, C, Si, Mn , P, S, Cr, Mo, Ni, Nb, Ti, V, B, Al, Ca, Cu, N, Ce, Mg, O, H. (note: not all elements in all modules)
- **Phases**: α-ferrite, Δ-ferrite, eutectic ferrite, austenite, cementite, pearlite, bainite, α-martensite (bct structure), ε-martensite (hcp structure)
- **Inclusions/precipitates:** Stoichiometric binaries: AlN, BN, B_2O_3(l), CaO, CaS, CO(g), H_2(g), MgO, N_2(g), SiO_2, TiB_2, TiO_2, Ti_2O_3,VO; stoichiometric ternaries: $Fe_{26}Al_9C_5$, $FeMo_2B_2$, FeNbB, $Fe_2Mo_3O_8$, $Fe_4Nb_2O_9$, Ti_2CS; semistoichiometric ternaries: (Mn,Fe)S, (Mn,Cr)S, (C,N)Nb, (C,N)Ti, (C,N)V, $(Cr,Fe)_2B$, $(Ni,Fe)_3B$, $(Nb,Fe)O_2$, $(Fe,X)_2B$ (X=Cr,Mn,Ni,V), $(Fe,X)_3O_4$ (X=Al,Cr,Mo,V), $(Fe,X)_2O_3$ (X=Al,Cr,V), $(Fe,X)_{0.947}O$ (X=Cr,Mn,V), Ce_2O_3,..

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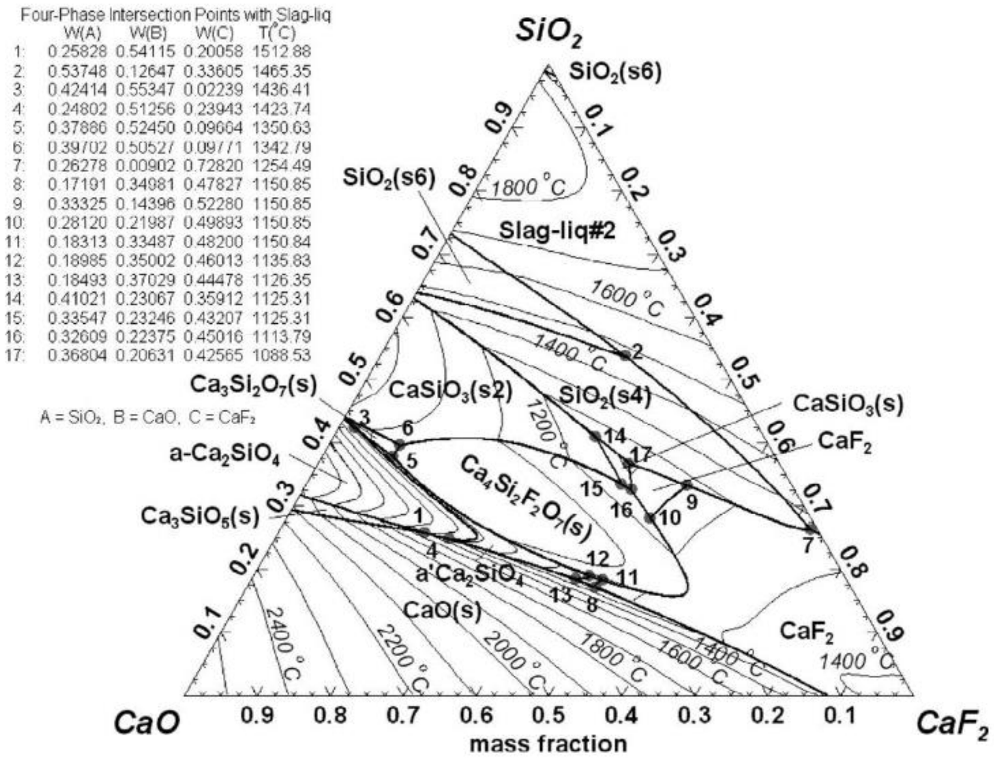
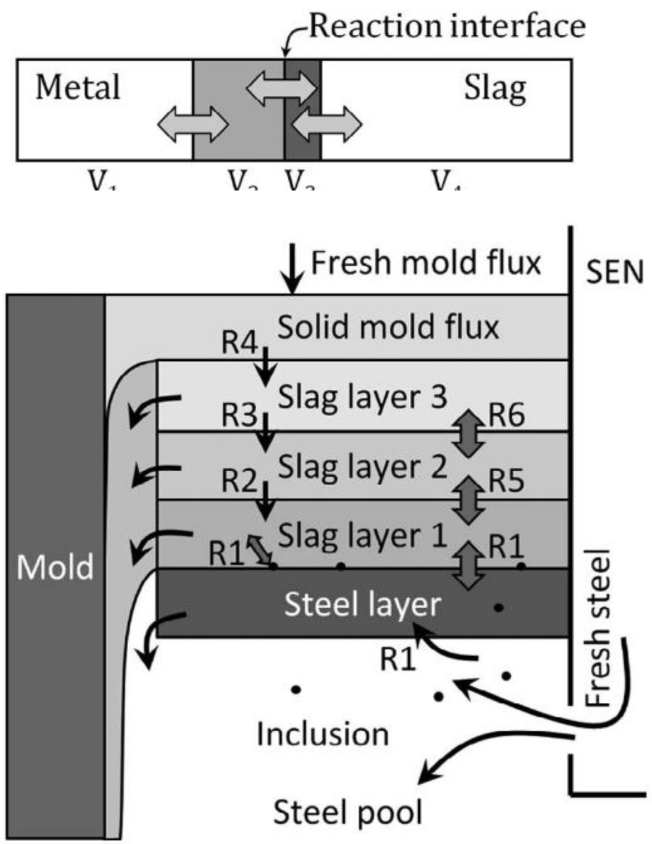
Factsage



Four-Phase Intersection Points with Slag-liq

	W(A)	W(B)	W(C)	T(°C)
1:	0.25828	0.54115	0.20058	1512.88
2:	0.53748	0.12647	0.33605	1465.35
3:	0.42414	0.55347	0.02239	1436.41
4:	0.24802	0.51256	0.23943	1423.74
5:	0.37886	0.52450	0.09664	1350.63
6:	0.39702	0.50527	0.09771	1342.79
7:	0.26278	0.00902	0.72820	1254.49
8:	0.17191	0.34981	0.47827	1150.85
9:	0.33325	0.14396	0.52280	1150.85
10:	0.28120	0.21987	0.49893	1150.85
11:	0.18313	0.33487	0.48200	1150.84
12:	0.18985	0.35002	0.46013	1135.83
13:	0.18493	0.37029	0.44478	1126.35
14:	0.41021	0.23067	0.35912	1125.31
15:	0.33547	0.23246	0.43207	1125.31
16:	0.32609	0.22375	0.45016	1113.79
17:	0.36804	0.20631	0.42565	1088.53

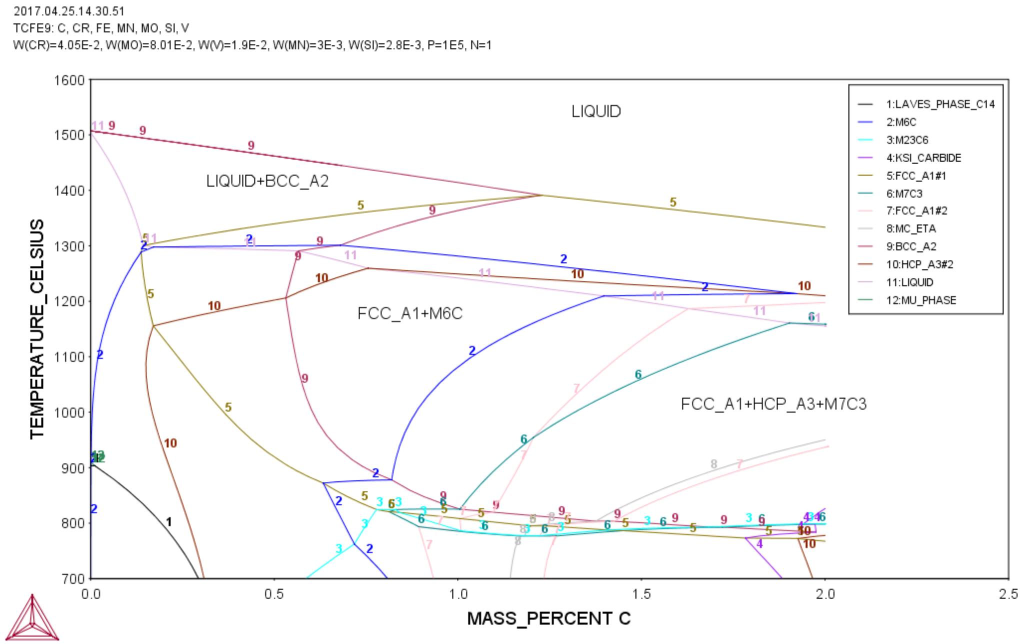


Van Ende and Jung, ISIJ International, Vol. 54 (2014), No. 3, pp. 489–495

Example 3: Design of new steels

Thermocalc

- Calculating stable and meta-stable heterogeneous phase equilibrium
- Amount of composition of phases
- Transformation temperatures, e.g. liquidus and solidus temperature
- Predicting driving forces for phase transformation
- Phase diagrams
- Molar volume, density and thermal expansion
- Scheil-Gulliver (non-equilibrium) solidification simulations
- Thermo-chemical data (enthalpies, heat capacity, activities, etc.)
- Design and optimization of alloys and processes

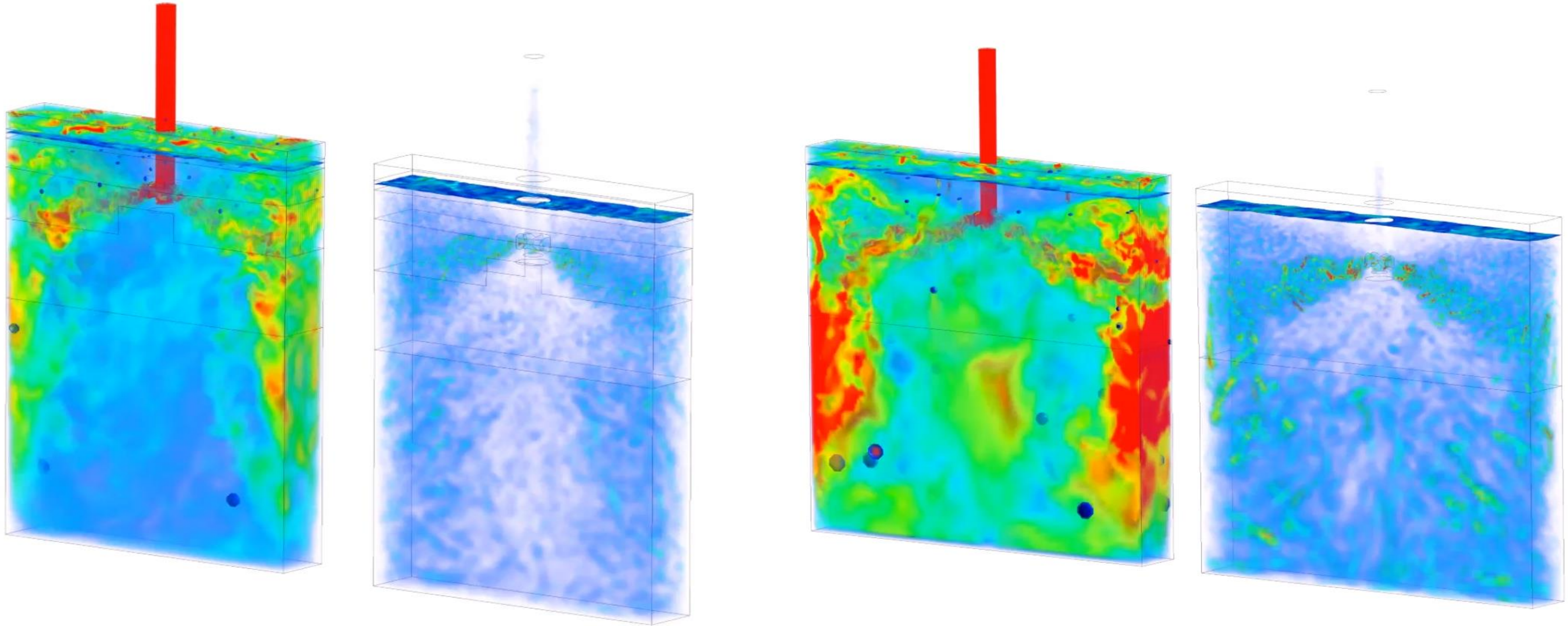


Computational Fluid Dynamics (CFD)

Typical applications include:

- Design, test and optimization of Flow Control devices
- Analysis of flow pattern in the mould (with or without external fields such as Electro-magnetics)
- Mixing (e.g. steel grade changes, residence time)
- Optimization of casting conditions
- Heat transfer & Solidification

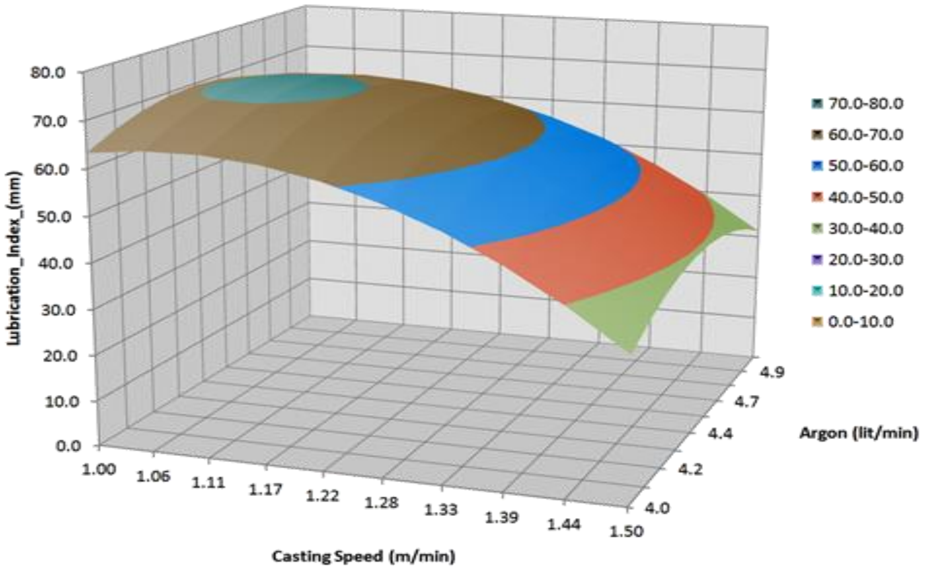
Example 1: SEN performance vs width

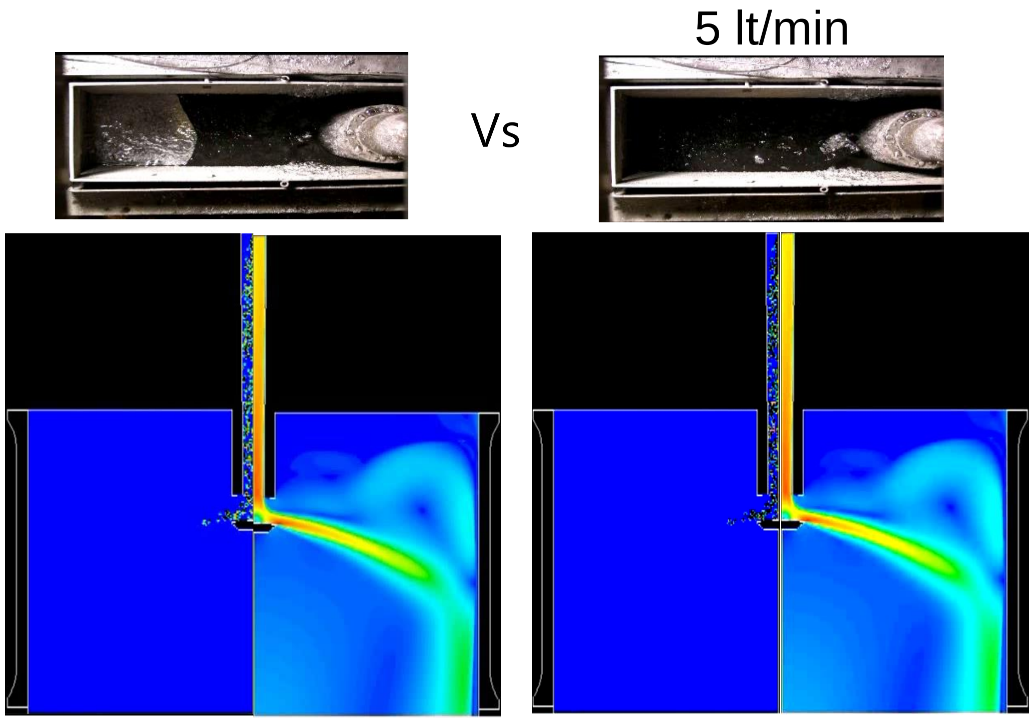


1200x220 1680x220

Example 2: Parametric studies to optimize casting operations

Models built included: argon injection praxis, immersion depth, powder performance and mould oscillation to obtain optimal lubrication in the mould as a function of all casting conditions





Stable casting (double roll)

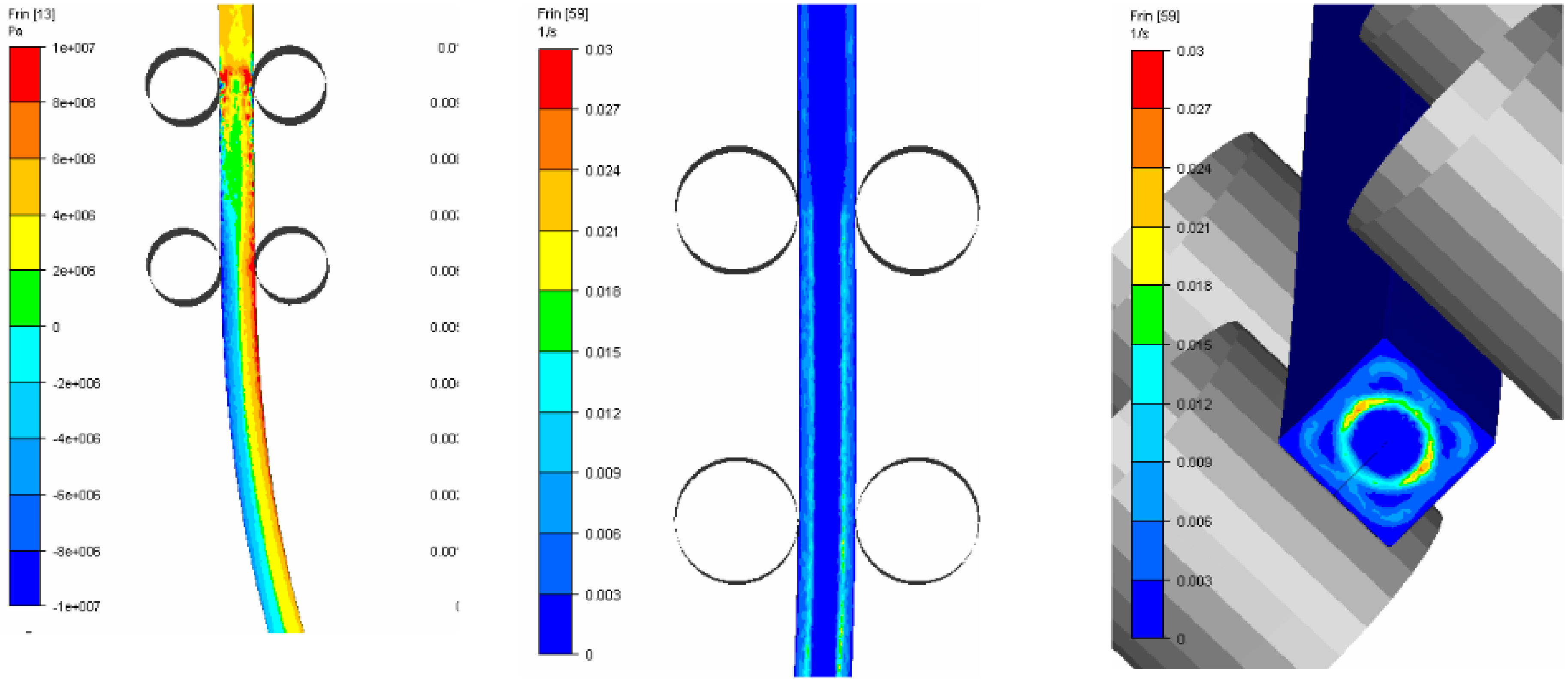
Unstable casting (single roll)

Finite Element Methods (FEM)

Typical applications include:

- Mould design
- Analysis of Stress-Strains in the shell and mould (e.g. residual stresses)
- Prediction of failure (more recently cracking)
- Heat transfer and solidification
- Flow dynamics

Example 1: Thermo-mechanical simulation in 3D



a) Pressure field

b) Yamanaka et al. criterion (vertical section plane)

c) Yamanaka et al. [18] criterion (transverse section plane)

Figure 11. Pressure field and Yamanaka et al. criterion after bending

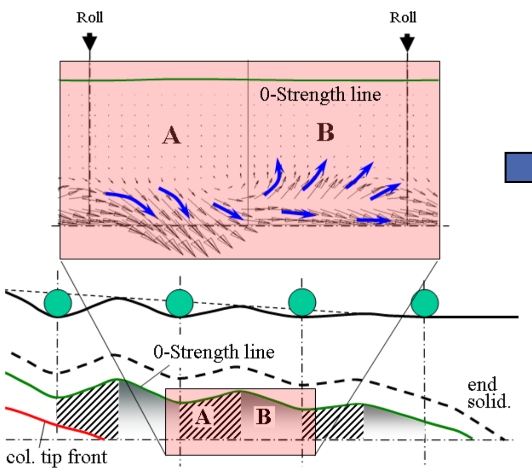
Bellet et al. Proc. MCWASP XII, 12th Int. Conf. on Modeling of Casting, Welding and Advanced Solidification Processes, Vancouver & Alaska, June 7-13

Example 2: Mechanical Soft Reduction

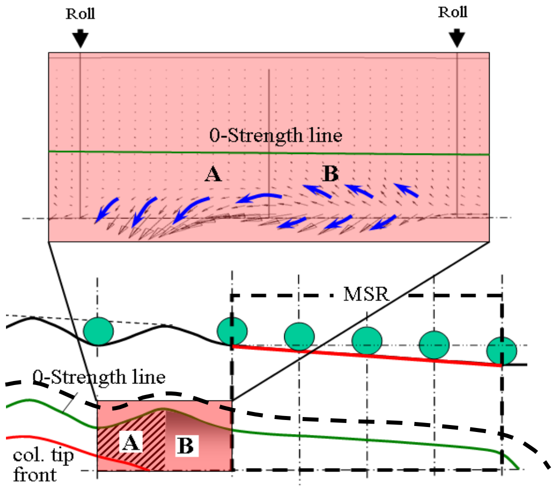
The principle of MSR (mechanical soft-reduction) is to modify the centerline segregation by adapting the interdendritic flow through a mechanical deformation of the dendritic skeleton in the mushy zone (controlling the MSR factor γ).

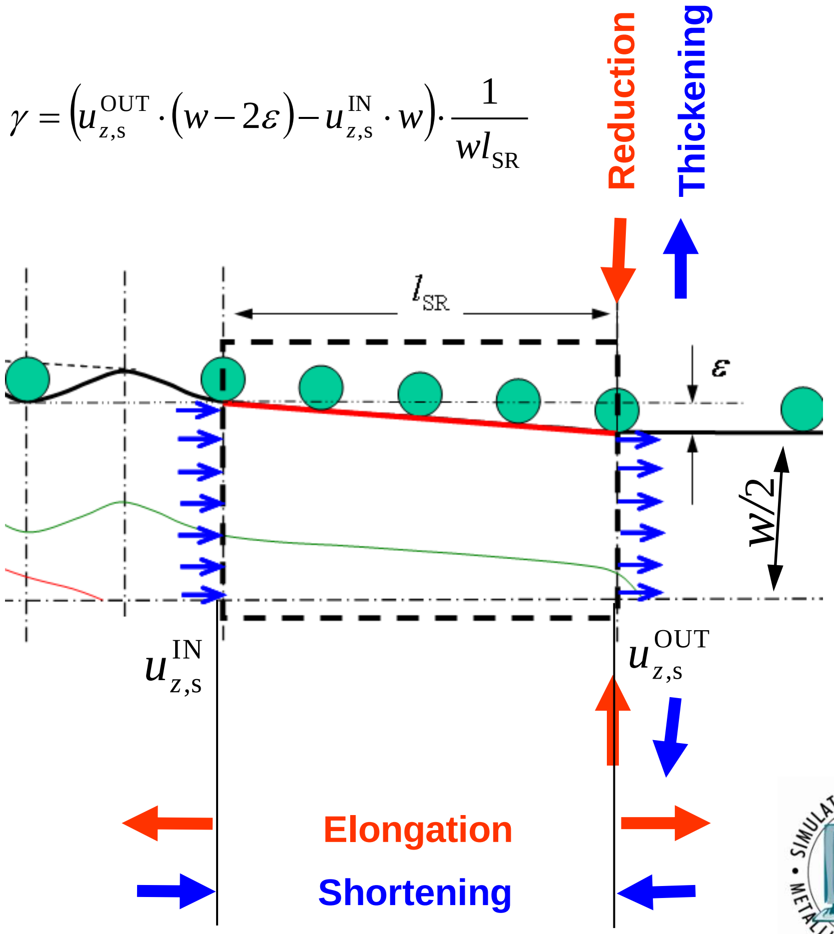
$$\gamma = \left(u_{z,s}^{\mathrm{OUT}} \cdot (w - 2\varepsilon) - u_{z,s}^{\mathrm{IN}} \cdot w\right) \cdot \frac{1}{w l_{\mathrm{SR}}}$$

Without MSR



With MSR

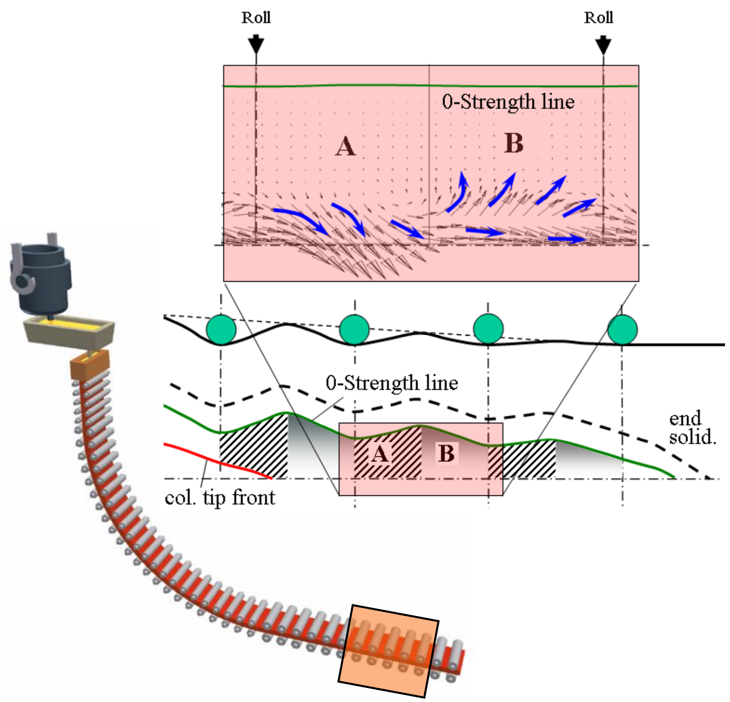


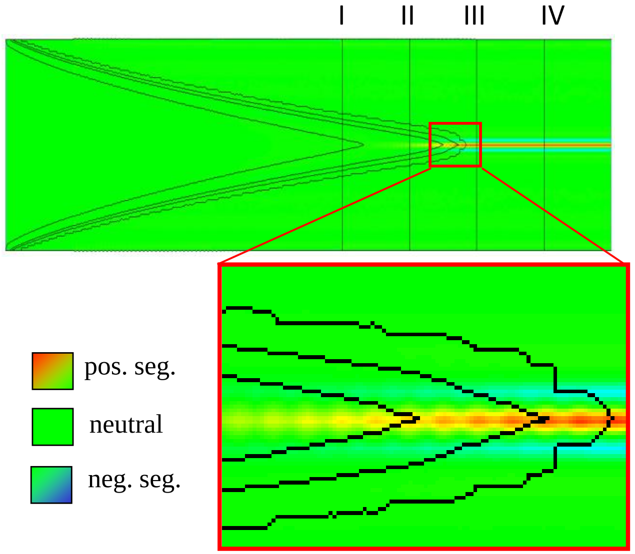


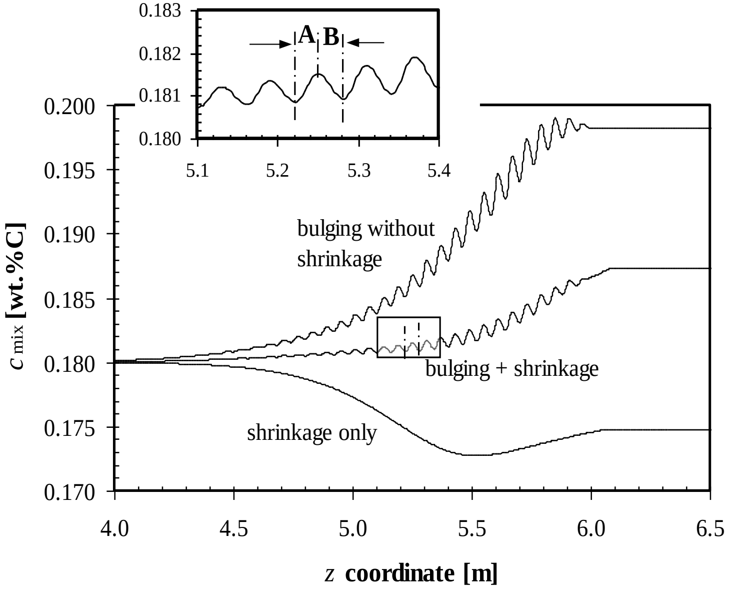
Wu M., Domitner J., Ludwig A., MMTB, 2012.

Example 2 (Cont.): Mechanical Soft Reduction

Surface bulging induced interdendritic flow is a dominant factor for centerline positive segregation

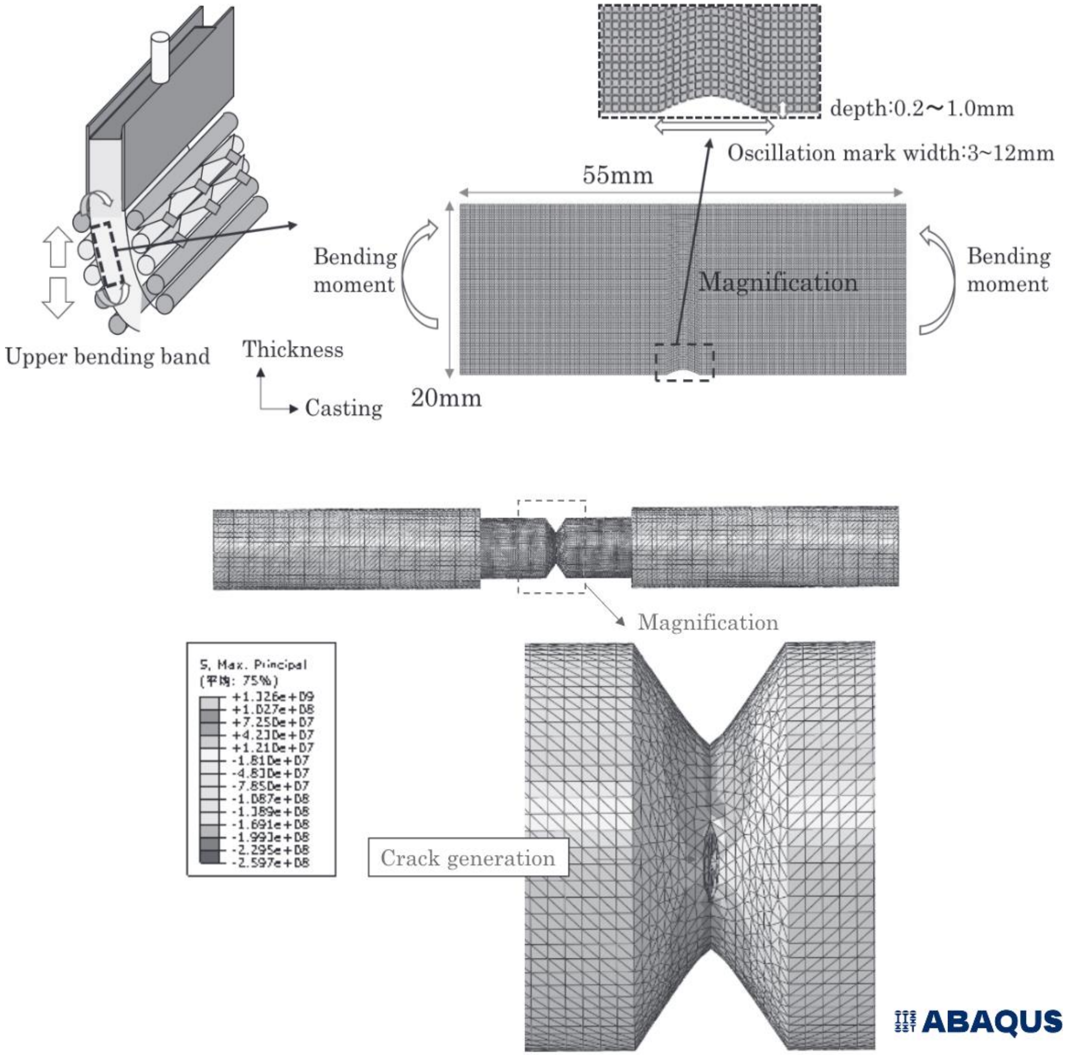






Wu M., Domitner J., Ludwig A., MMTB, 2012.

Example 3: Crack Initiation in FEM



Toishi, Miki & Kikuchi, SIJ International, Vol. 59 (2019), No.5, pp. 865–871

https://www.youtube.com/watch?v=LBKs_P-dadk

Micro and Meso scale modelling

Typical applications include:

- Predicition of solidification structures (PDAS,SDAS, grain size, etc.)
- Formation of inclusions, intermetallics, carbides, nitrides, etc…
- Inputs for solidification models in FEM or CFD
- Design of steels

Q2) Which modelling technique are you more familiar with?

a) Computational Fluid Dynamics (CFD)

b) Finite Element Methods (FEM)

c) Thermodynamic models

d) Micro-Meso scale modelling

e) None

Caveat emptor

Before pressing any button !!!...

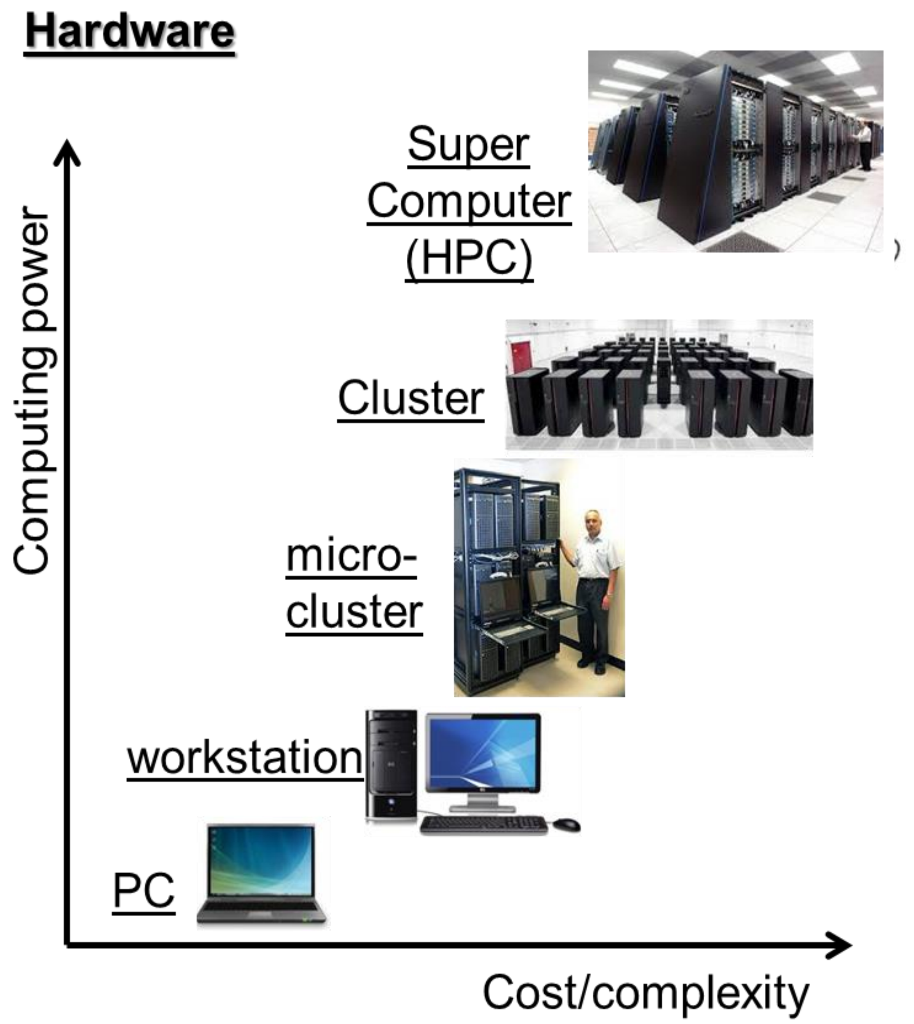
It is necessary to define the outreach, needs and expected outcomes from the analysis, since CFD often demands significant resources (e.g. hardware, software and man power).

Some general questions must be answered:

- Why is the simulation required?

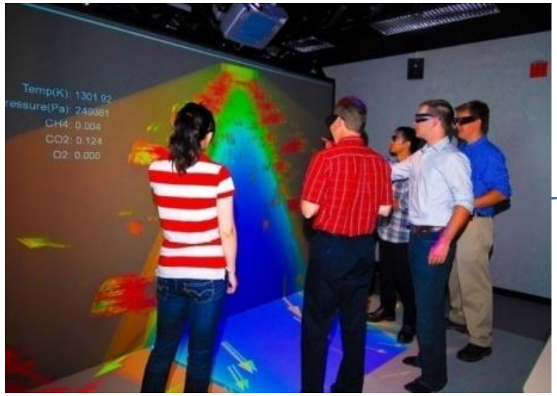
- What are the problem boundaries, size and geometrical constraints?

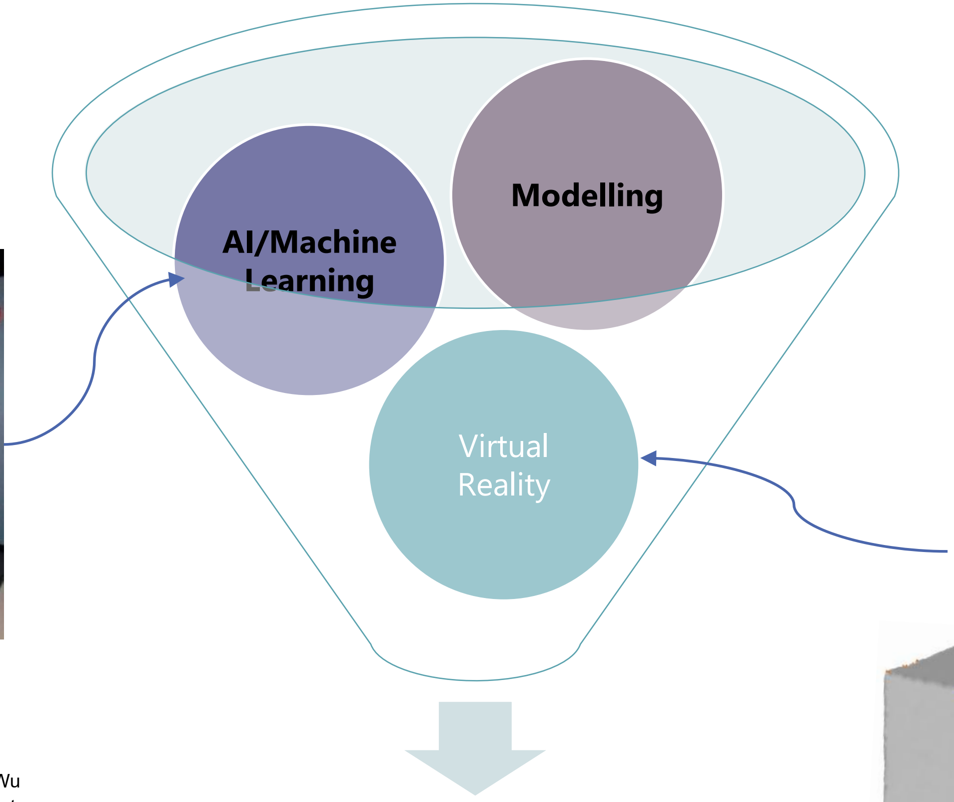
- What is the possible behaviour?

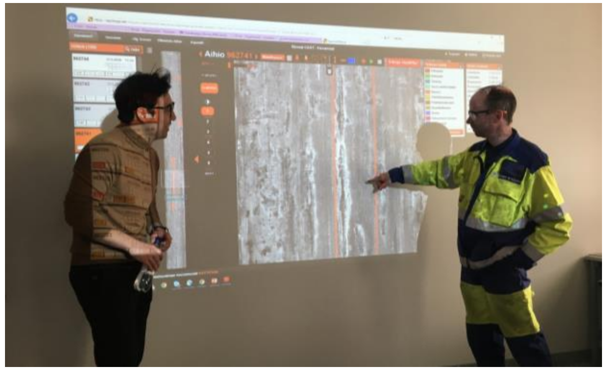


Future perspectives?

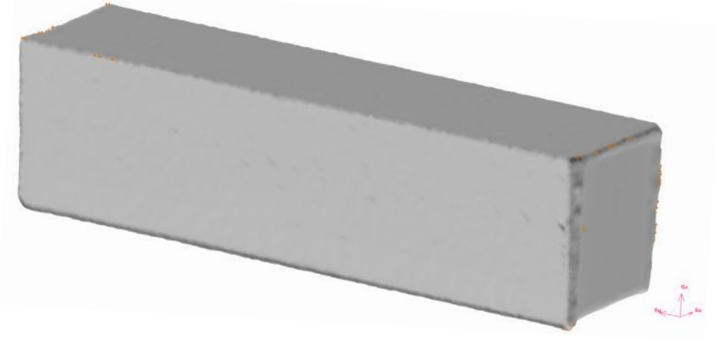
The future?







Digitalization



Chenn Q. Zhou, Pavel E. Ramirez Lopez, John Moreland and Bin Wu
SCANMET IV, 4th International Conference on Process Development in Iron and Steelmaking
10–13 June 2012, Luleå, Sweden

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