Numeric Modelling of the Heat Transfer in the Continuous Casting Mould

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- **Introduction**
  - **The System Strand-Mould**
  - **Objectives**
- Modelling Boundary Conditions
  - Model View
  - General Parameters
  - Mechanical Analysis of the Strand Shell
  - Mould Flux Consumption Model
- Results
  - Variation of Steel Grades
  - Comparison with Plant Trials
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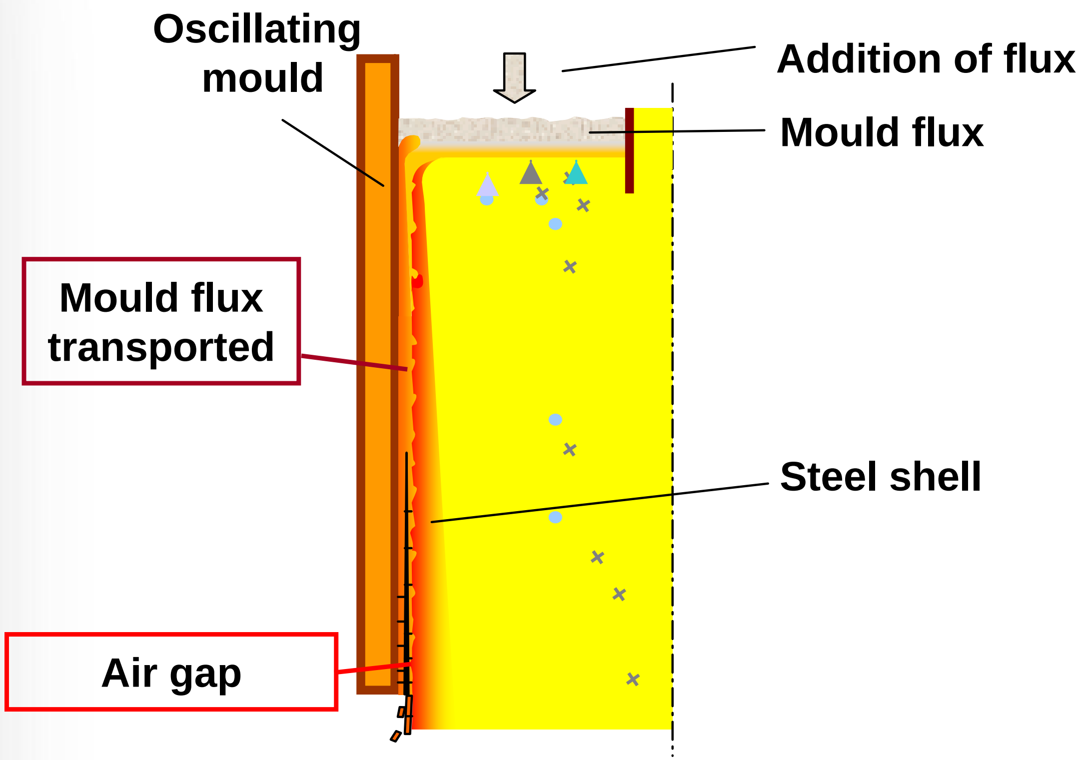
Continuous Casting – The System Strand / Mould



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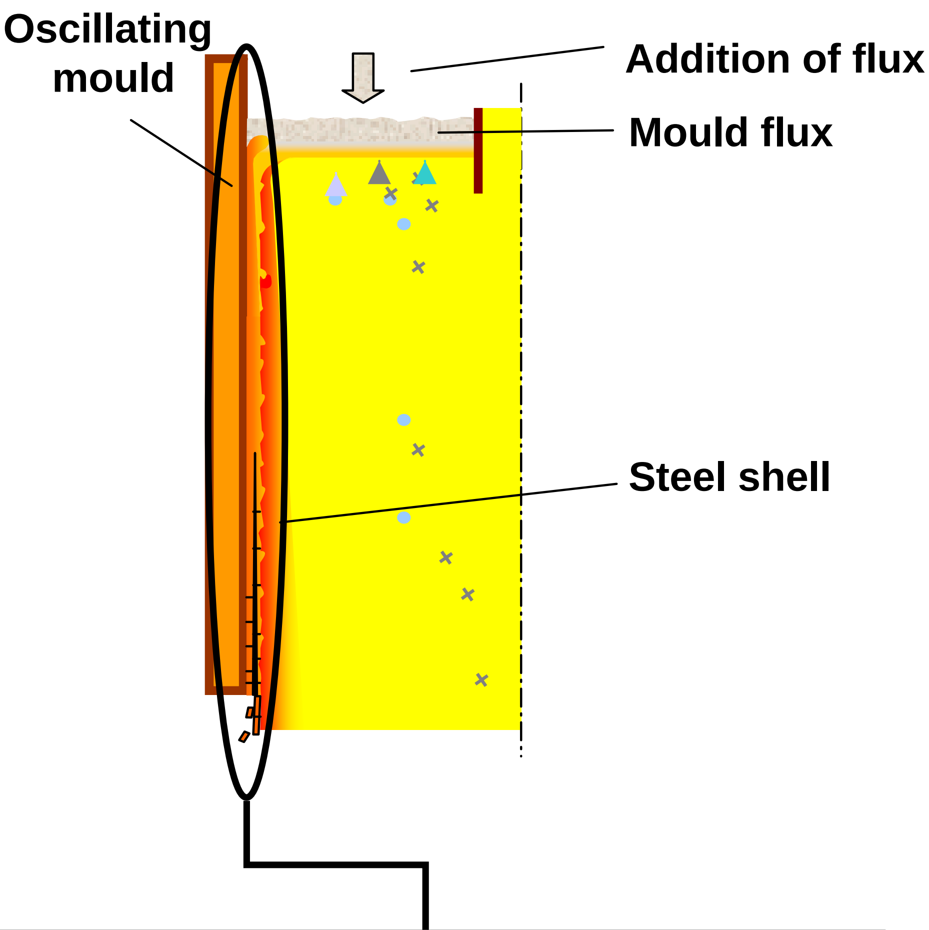

- **Heat flux as a characteristic process quantity**
  - ⇒ **Integral heat flux (global quantity)**
  - ⇒ **Local heat flux (exact)**

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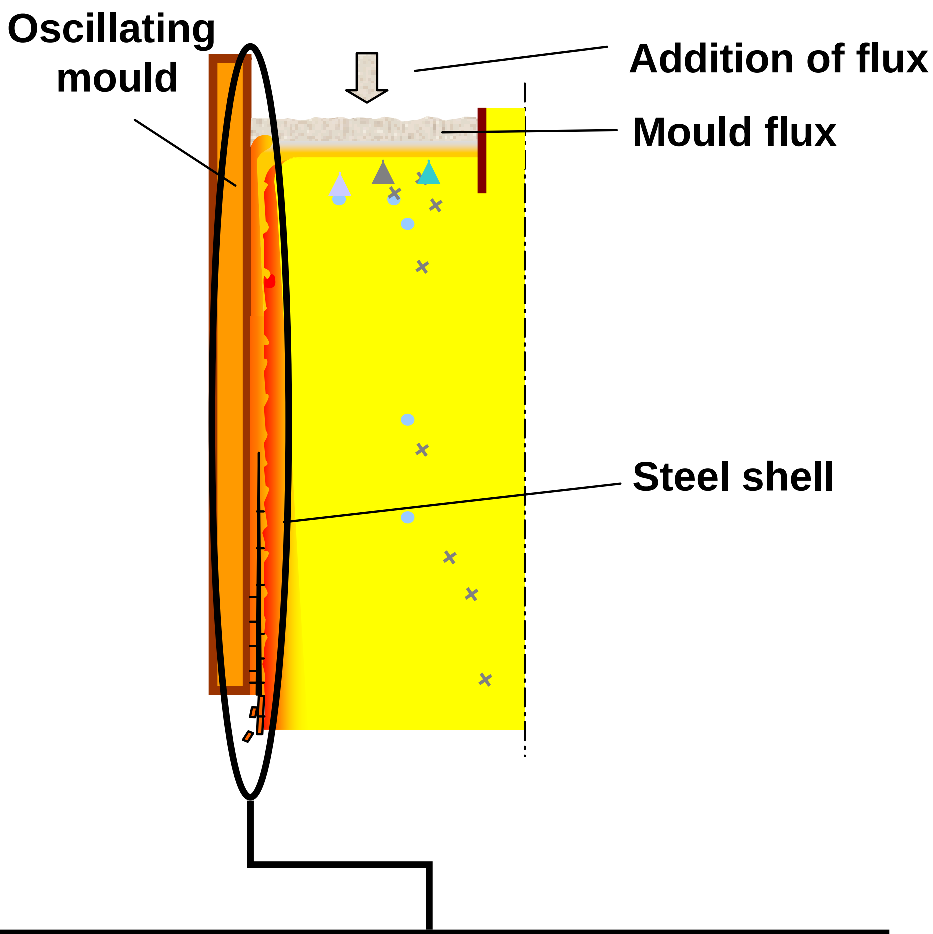

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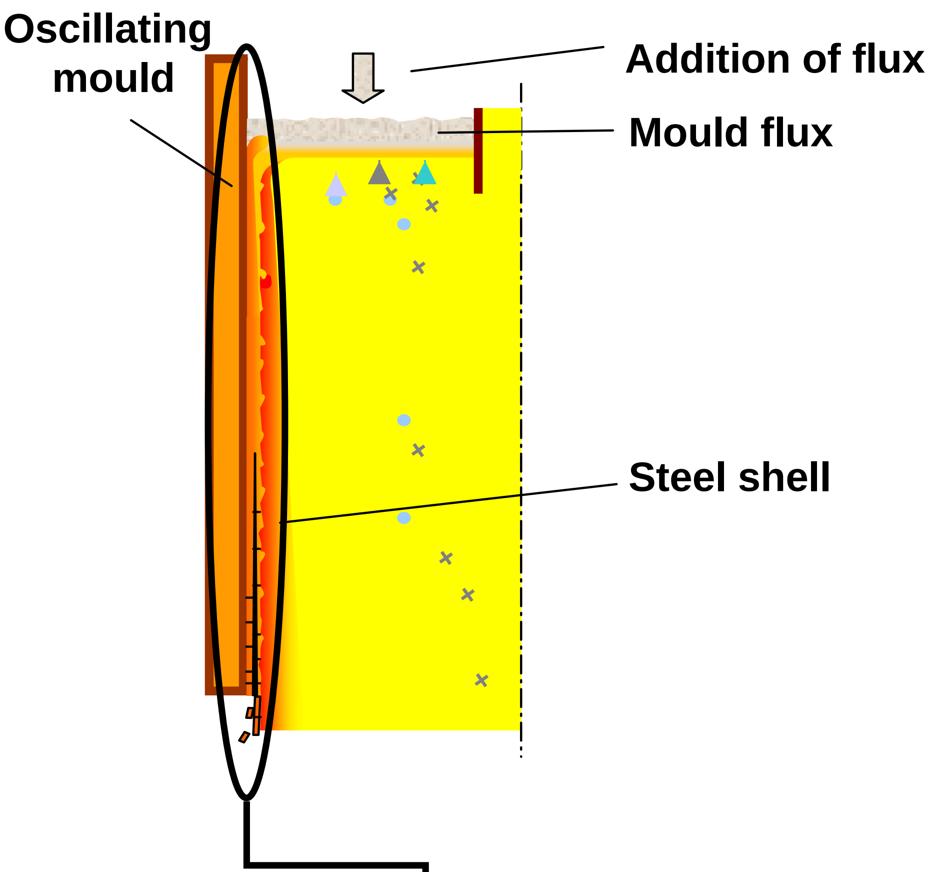

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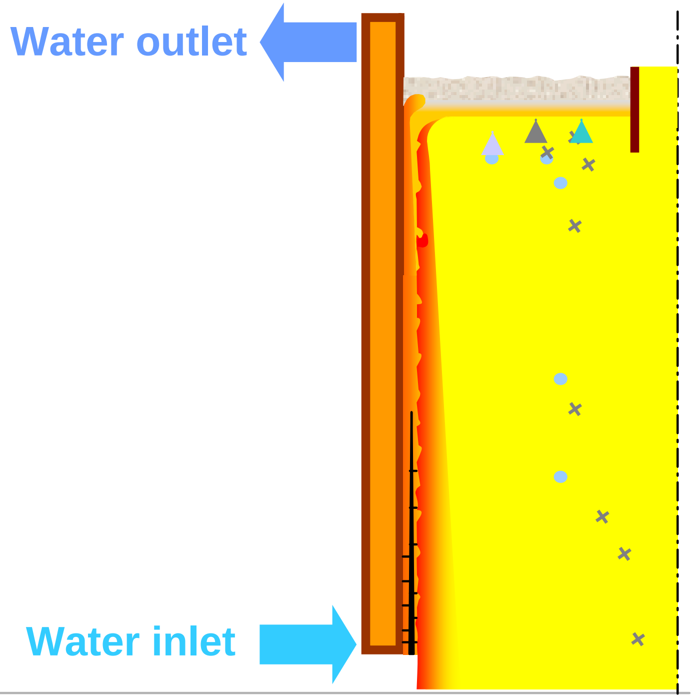

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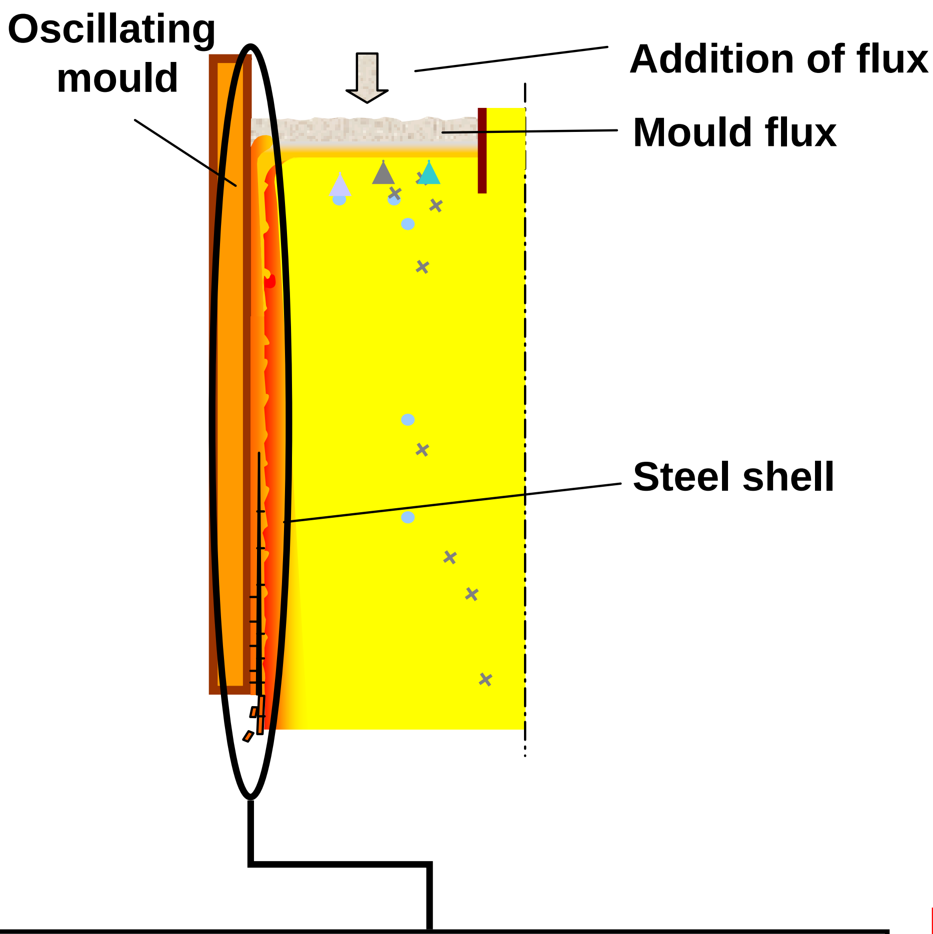

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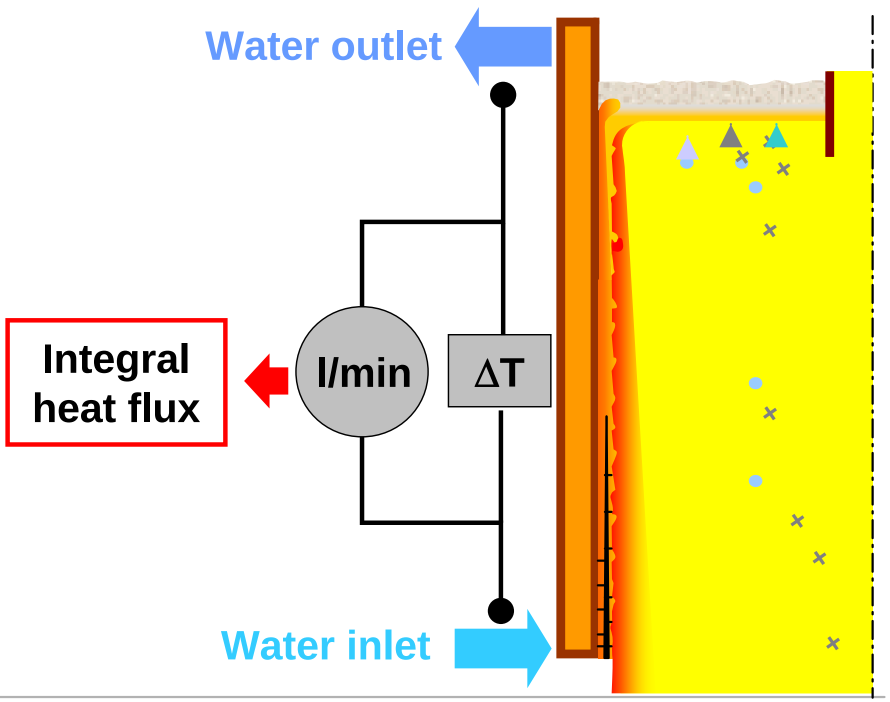

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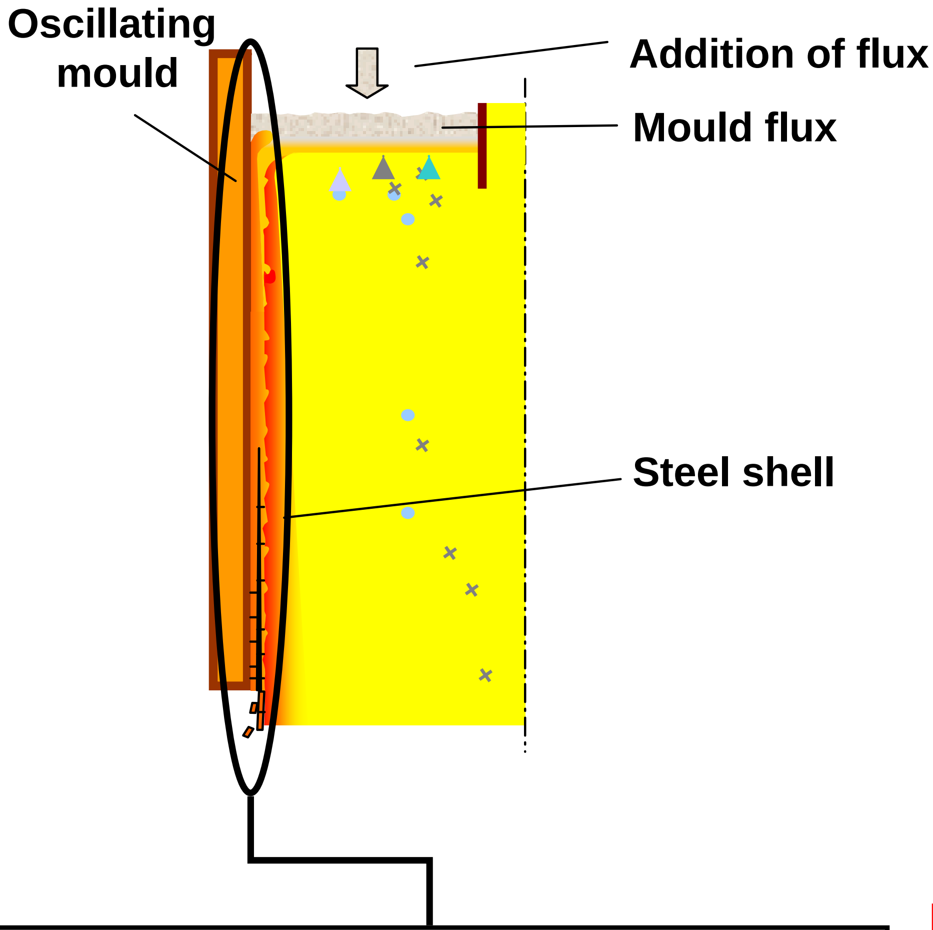
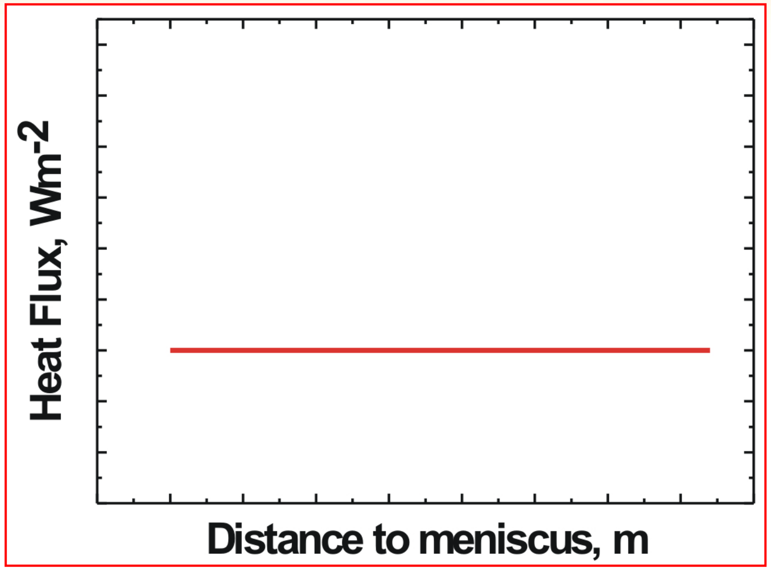
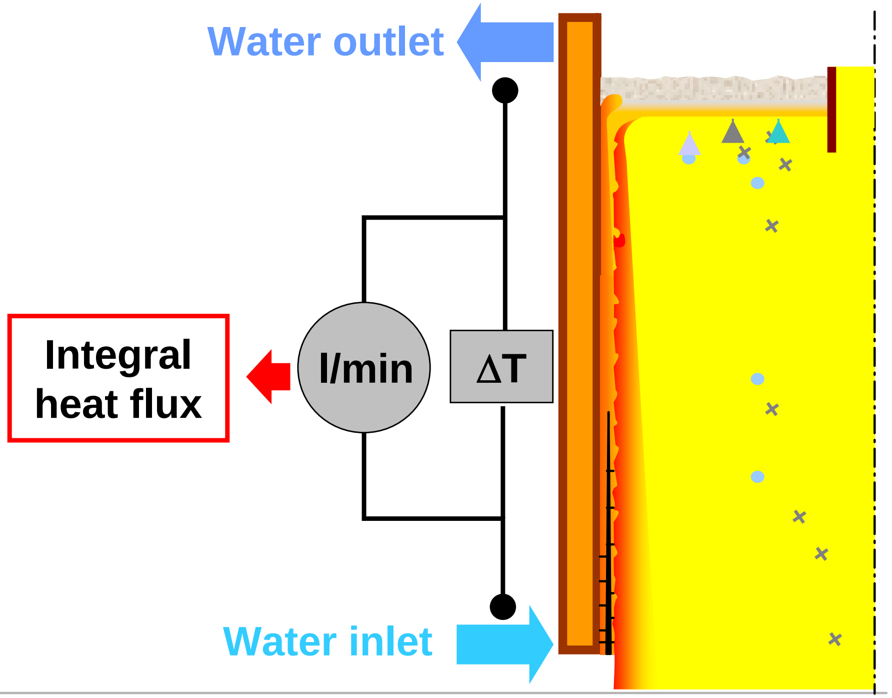




Integral heat flux (schematic)



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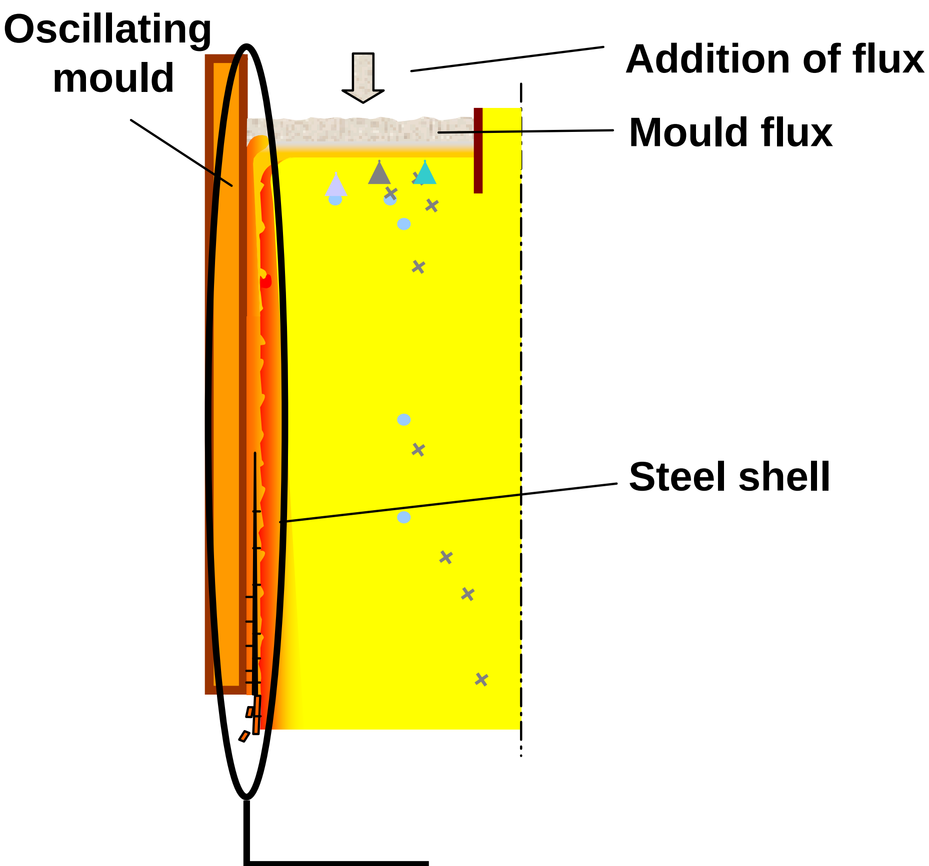

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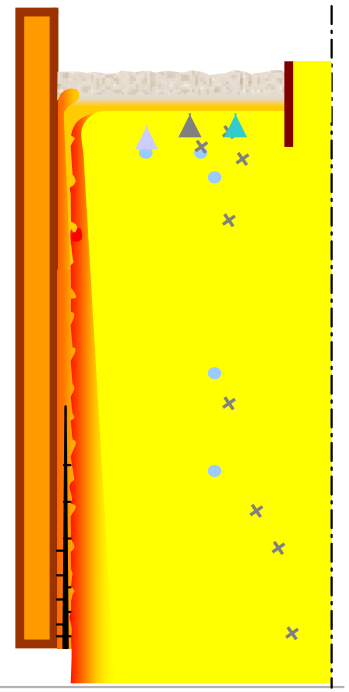

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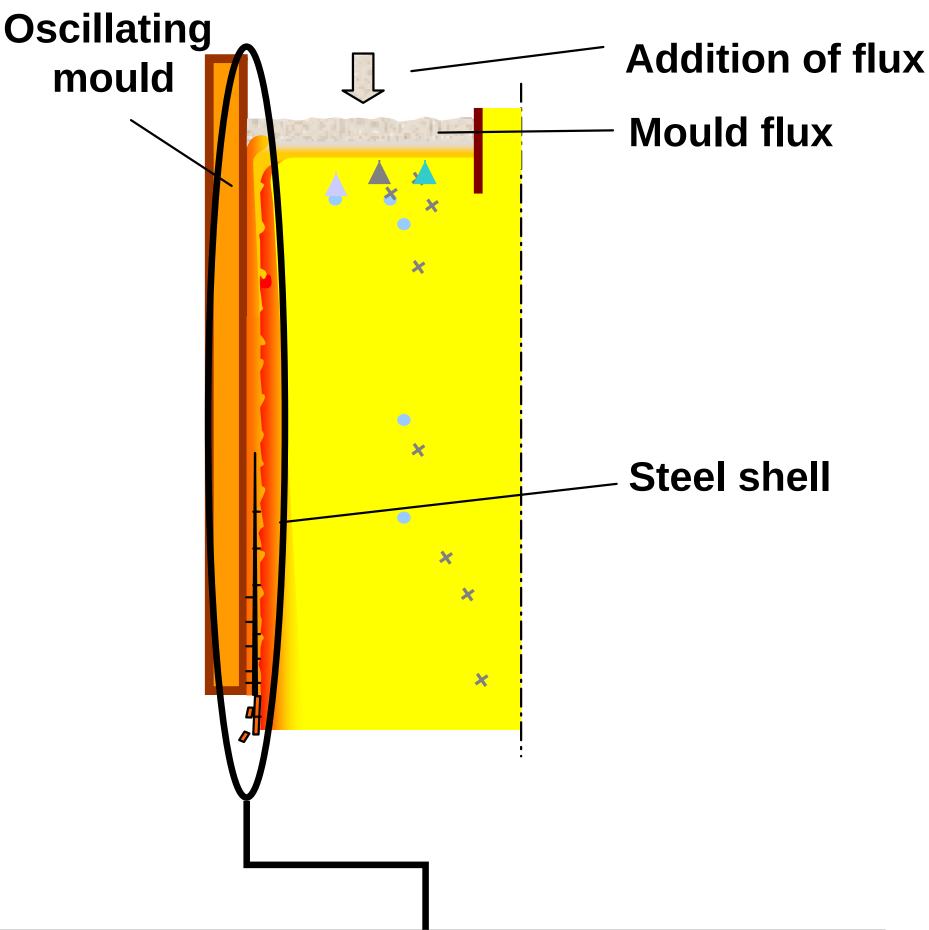

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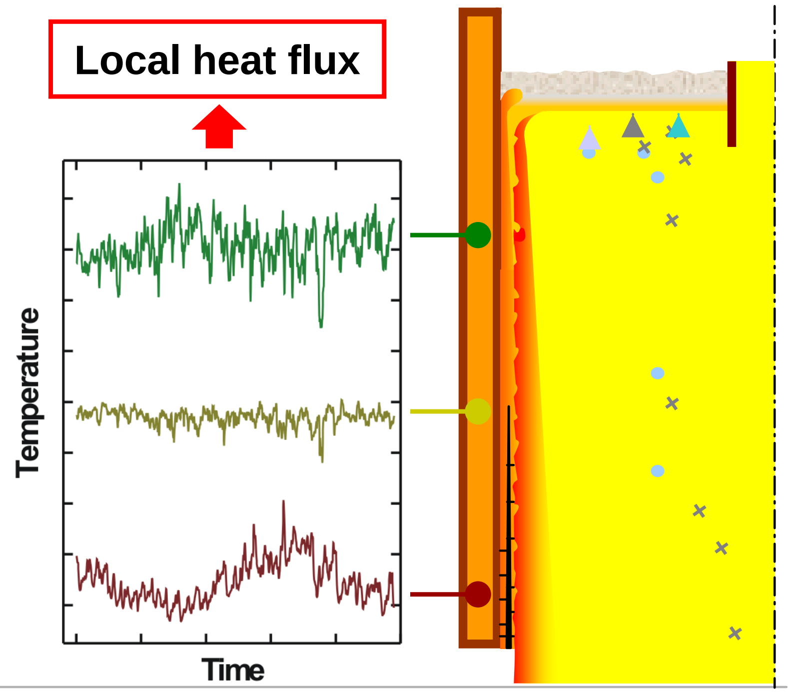

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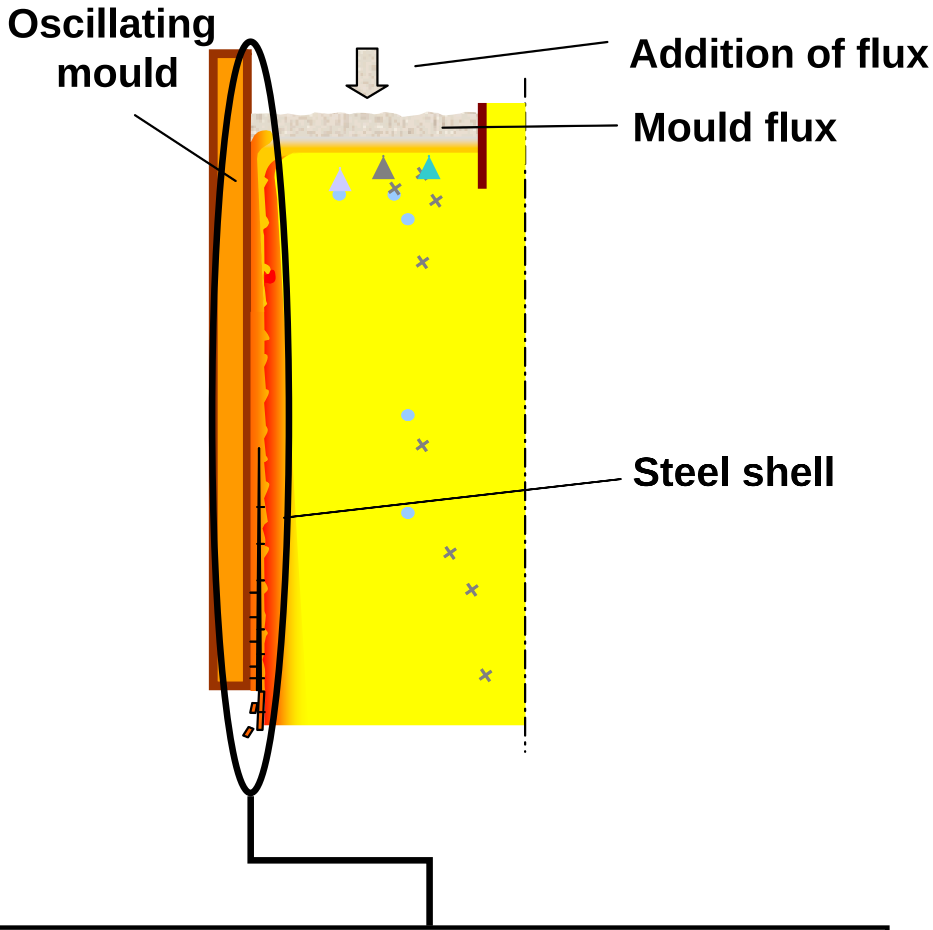

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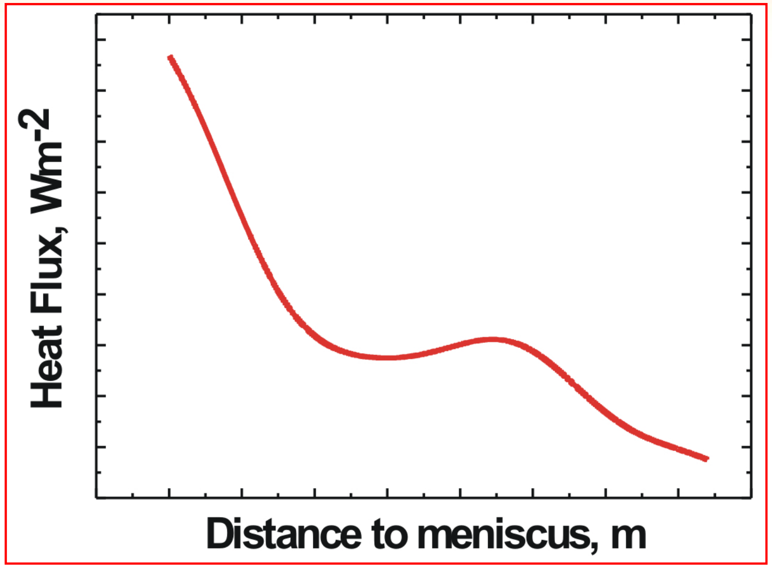
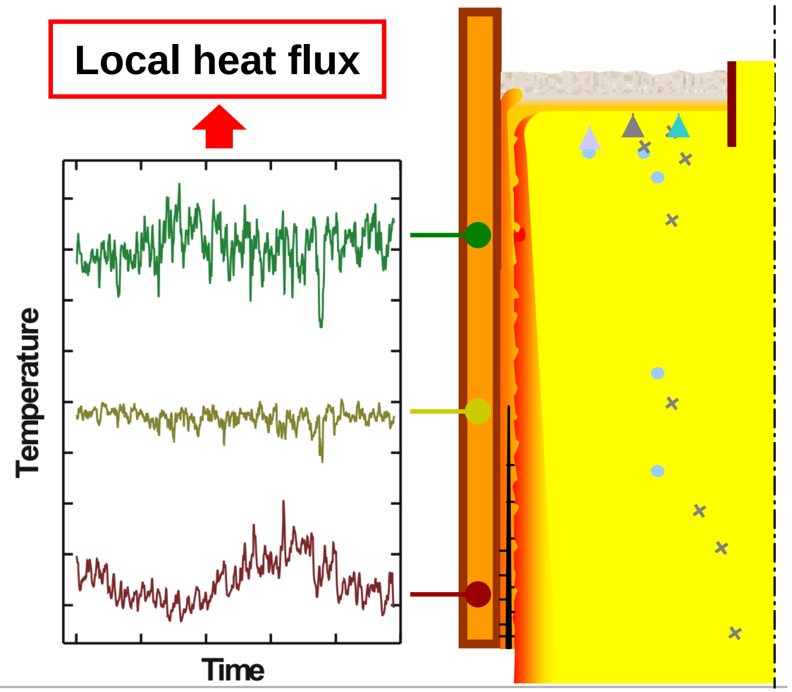


Local heat flux (schematic)



- **Heat flux in the mould is highly variable:**
  - **changes over mould height,**
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  - **columnar to equiaxed transition,**
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⇒ Boundary condition model
- **Predict heat flux with limited measuring work,**
- **Analyse influence of varying casting parameters.**

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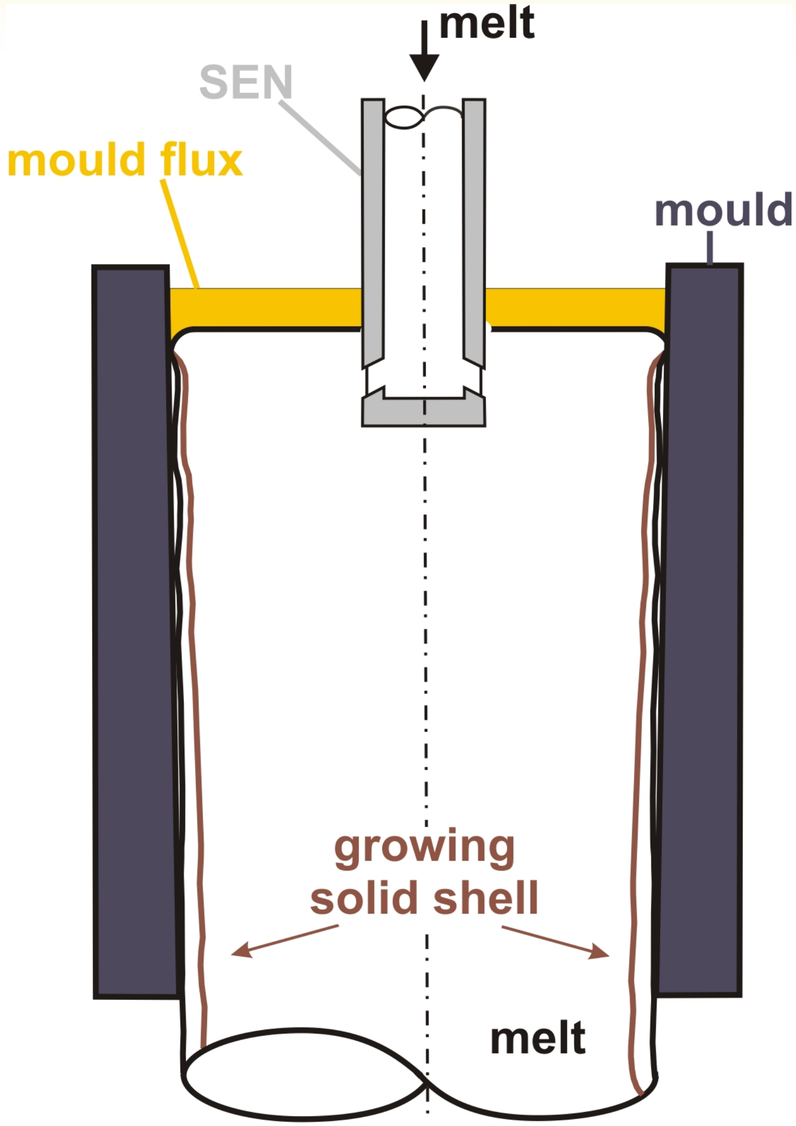
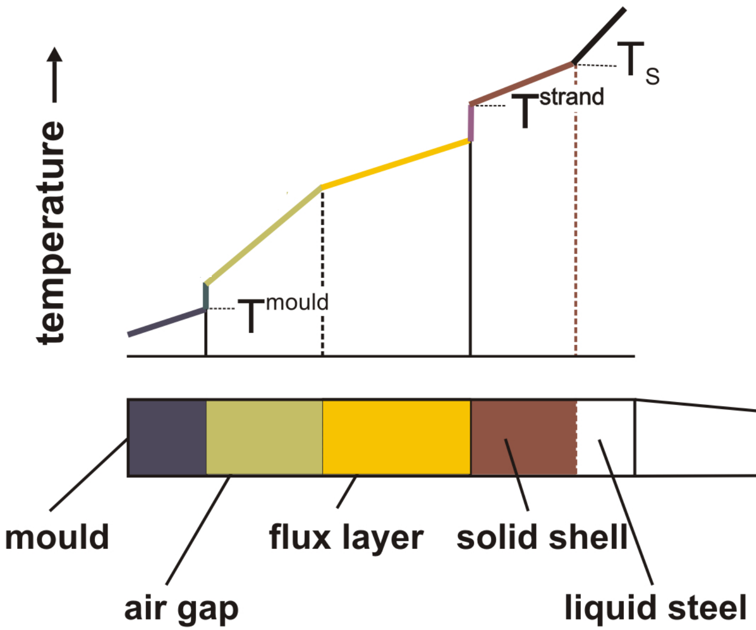
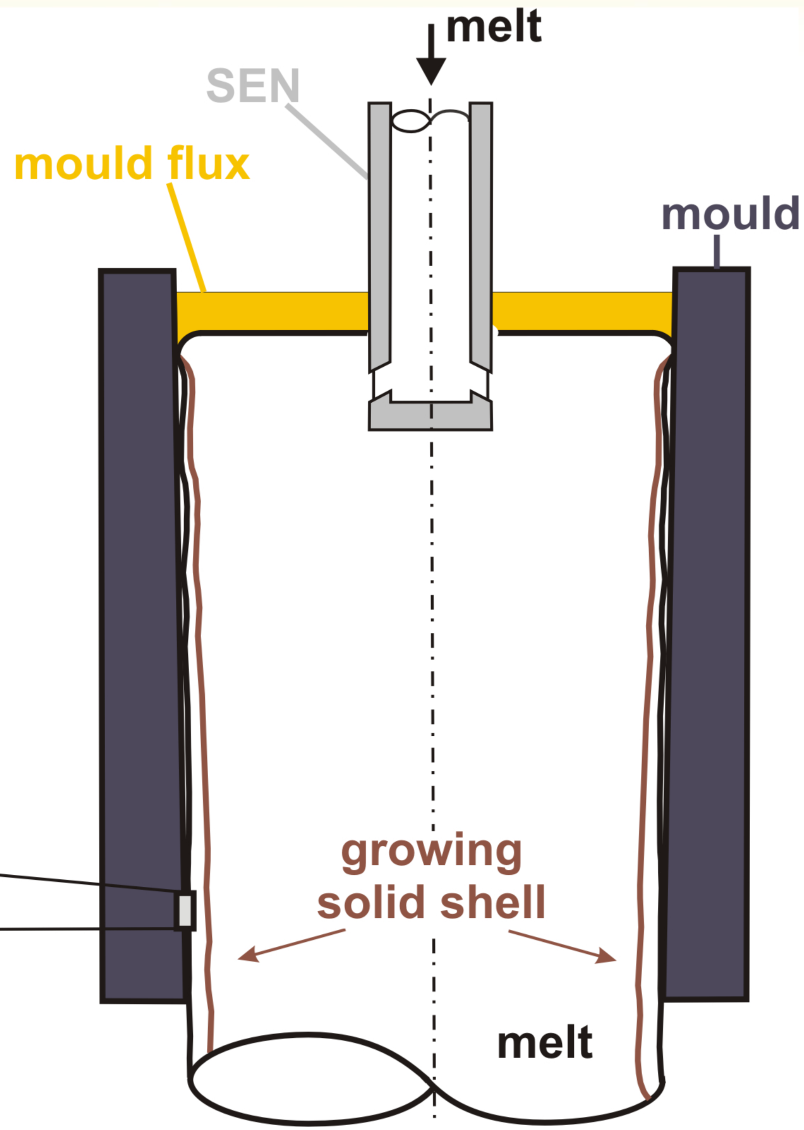
Model View



Cross section of mould and strand for a round bloom caster

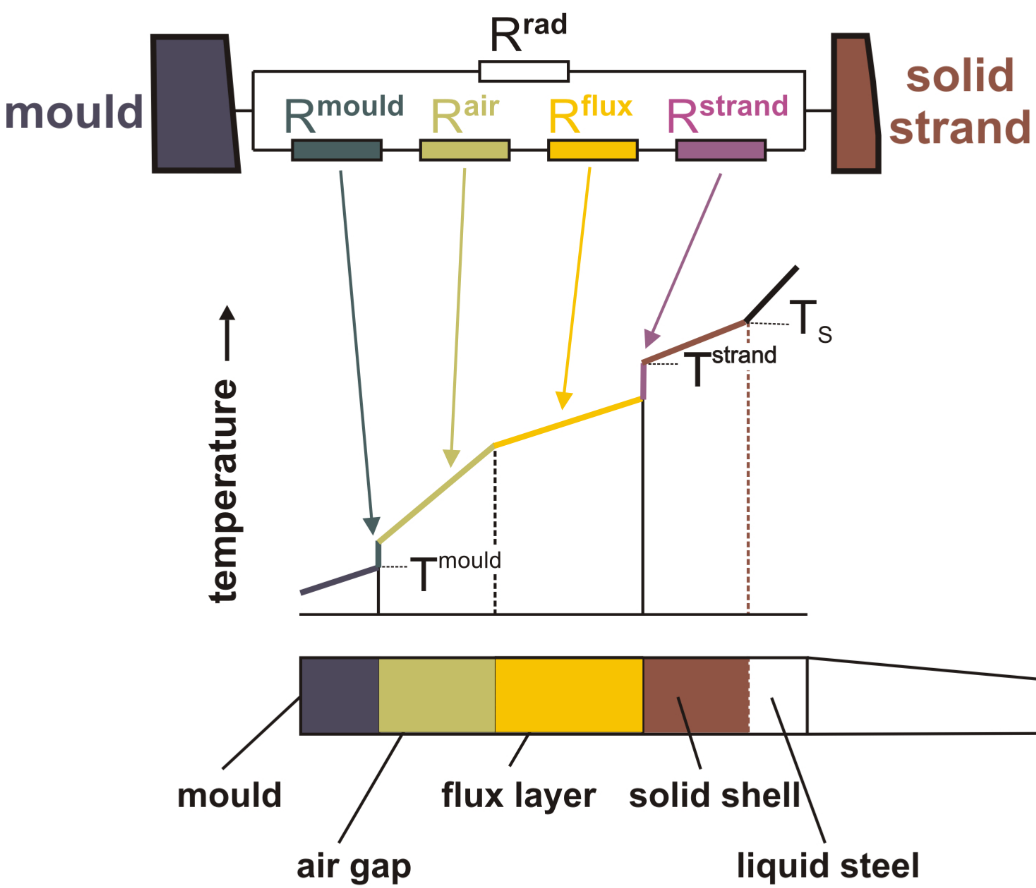
- **Schematic temperature distribution at the mould/strand interface:**
  - **Thermal conductivities of media assumed constant**

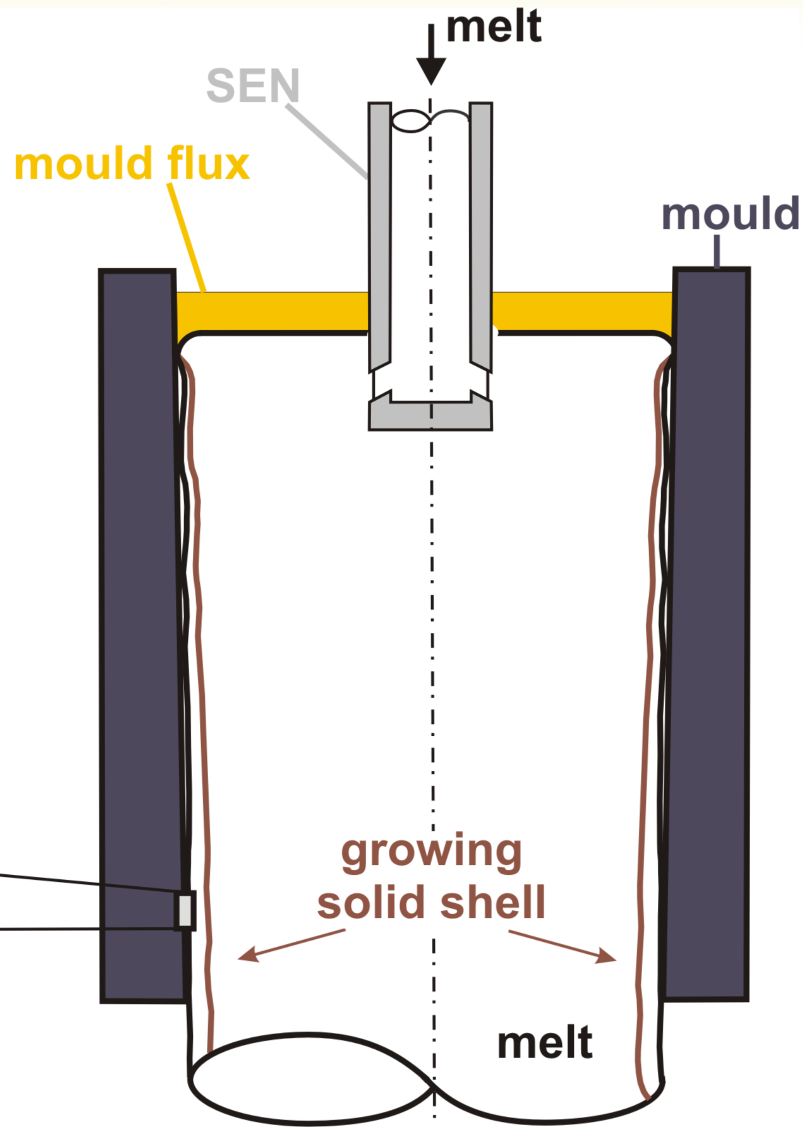




Cross section of mould and strand for a round bloom caster

- Model view by thermal resistances





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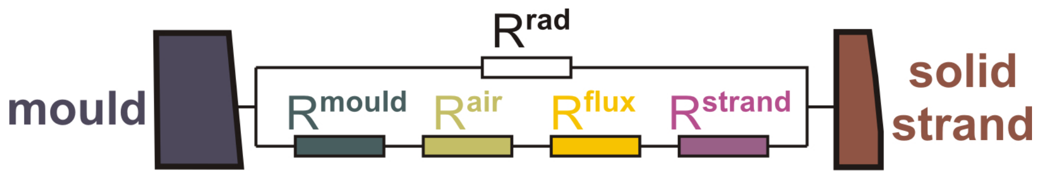
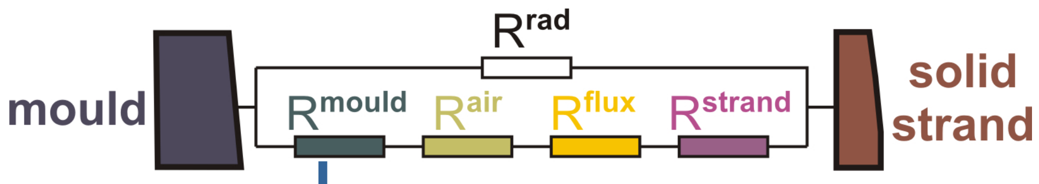
H. Han, J. Lee, T. Yeo, Y. Won, K. Kim, K. Oh, J. Yoon, ISIJ Intern. 39 (1999) 445–454.



HTR ... Heat Transfer Resistance



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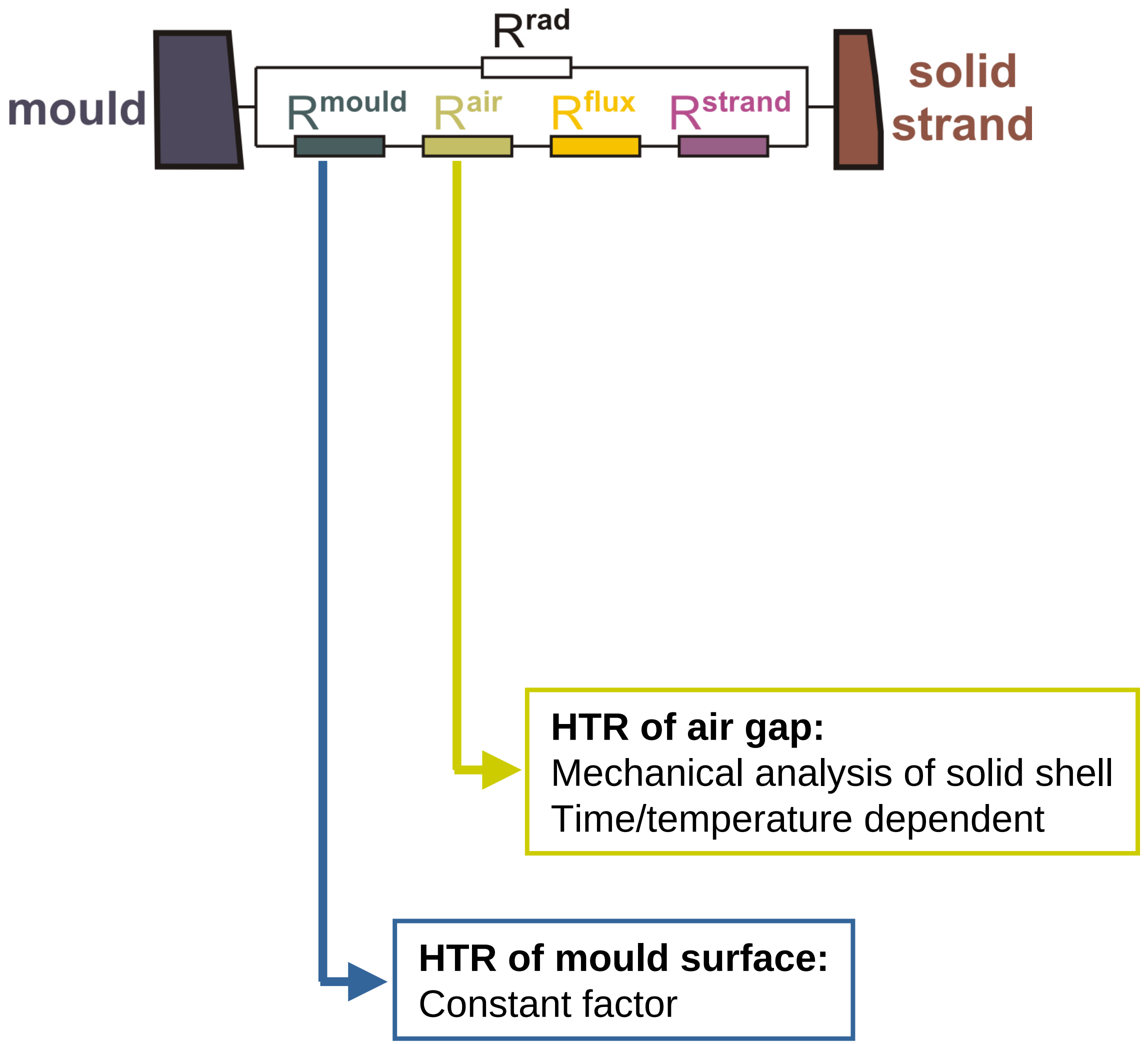
HTR of mould surface:
Constant factor



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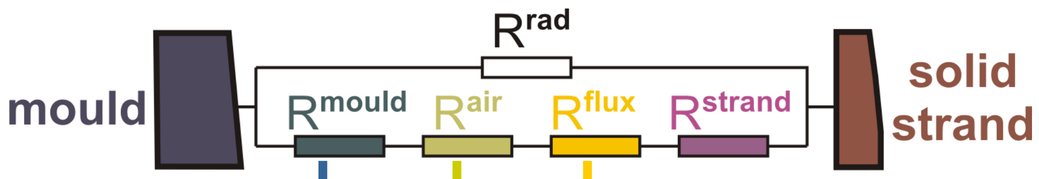

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HTR of flux layer:
Mould powder consumption model
Depends on casting parameters and steel grade

HTR of air gap:
Mechanical analysis of solid shell
Time/temperature dependent

HTR of mould surface:
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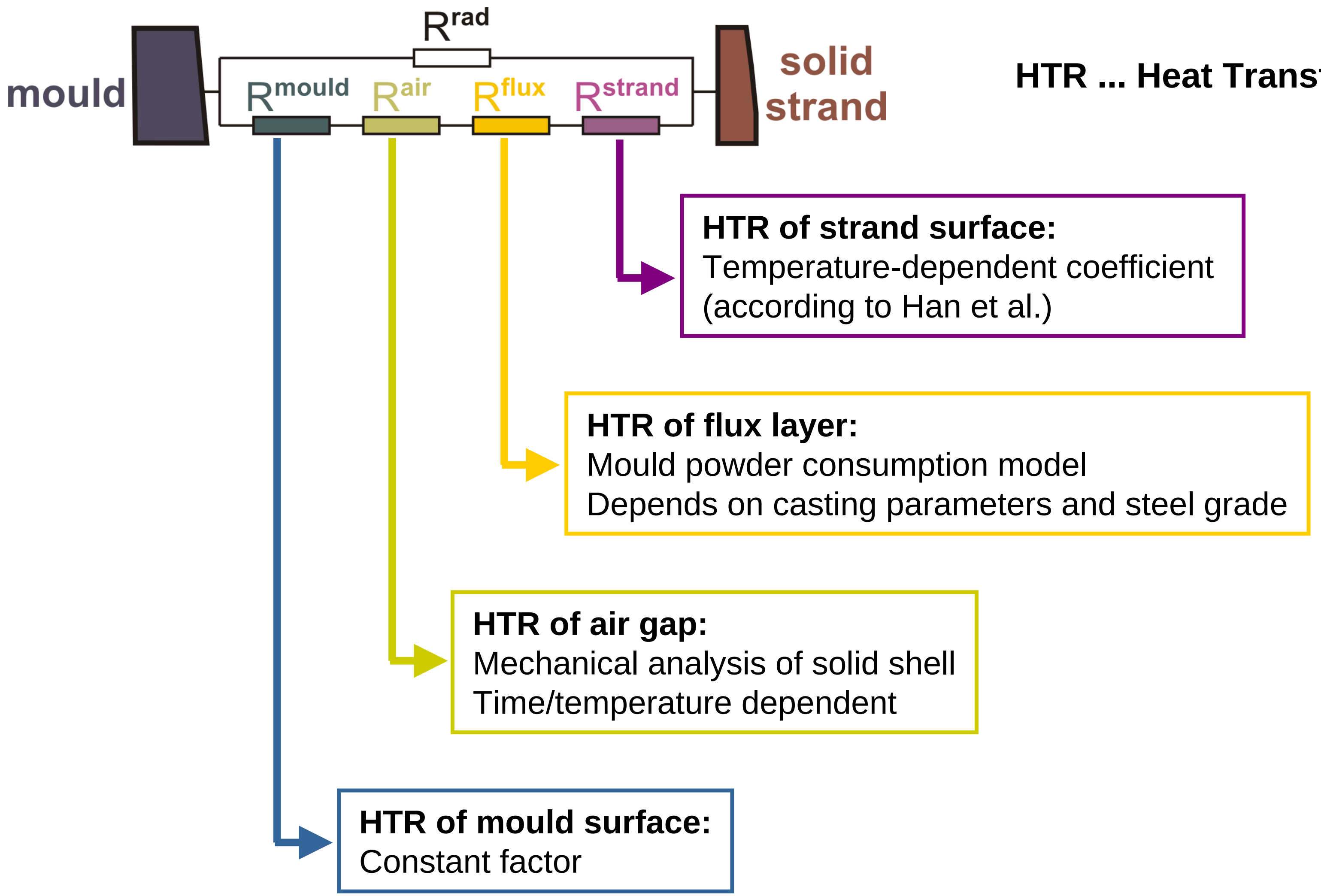

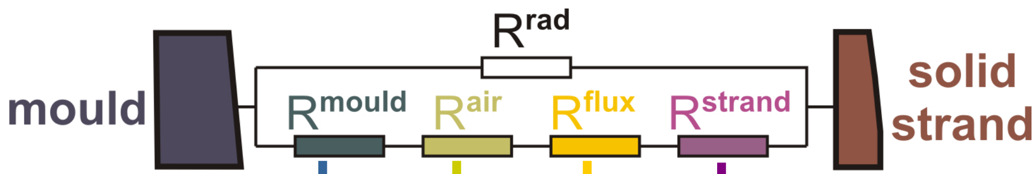

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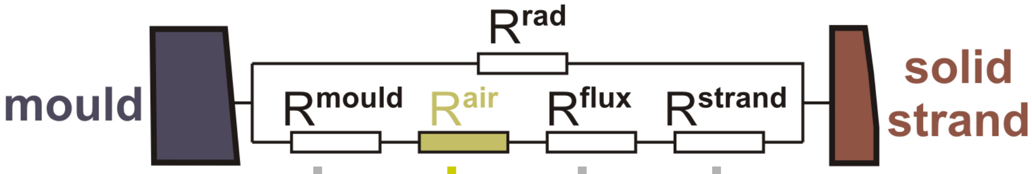

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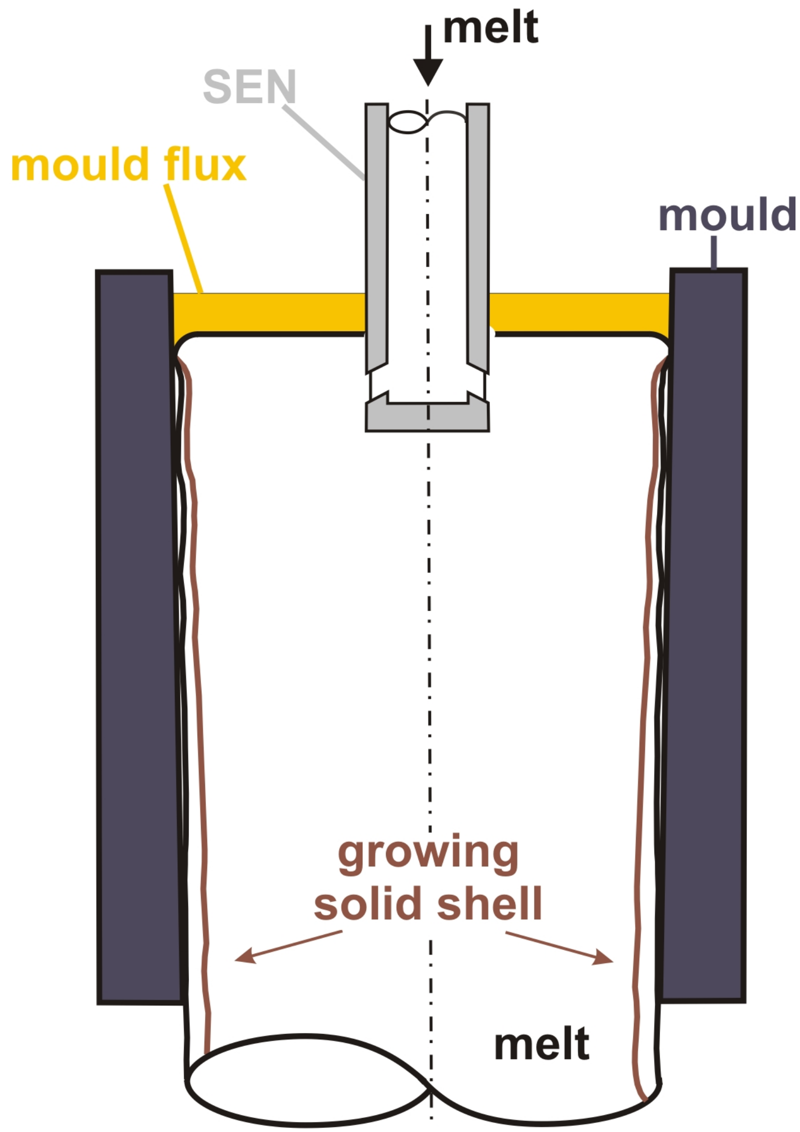
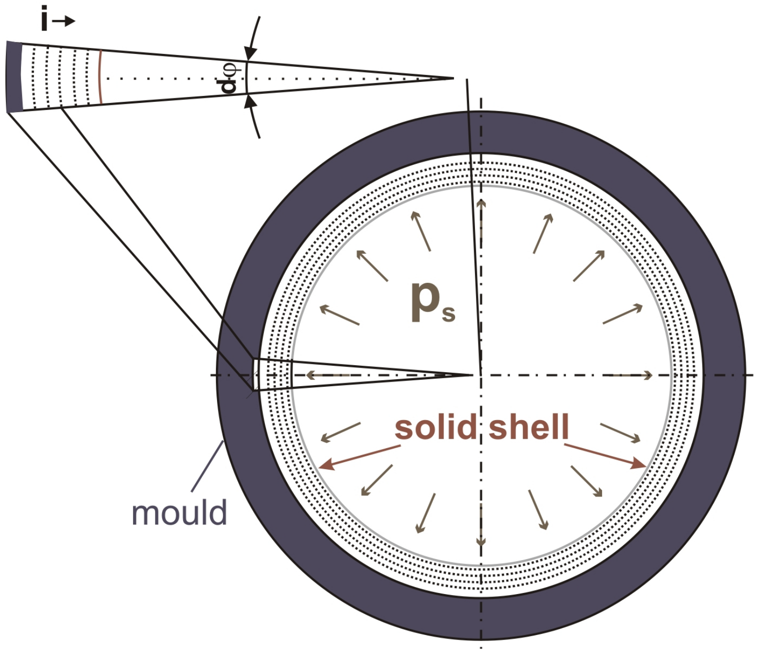
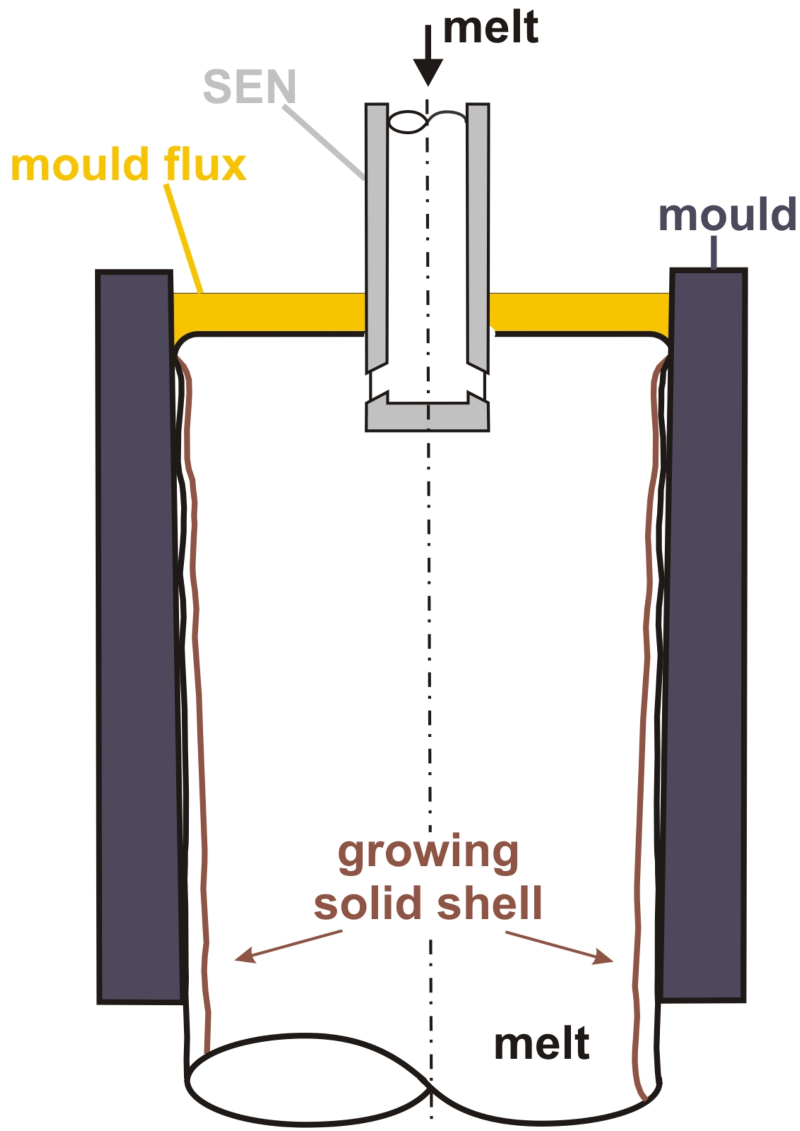


melt
SEN
mould flux
mould
growing
solid shell
melt



i→
dφ
p_s
solid shell
mould



melt
SEN
mould flux
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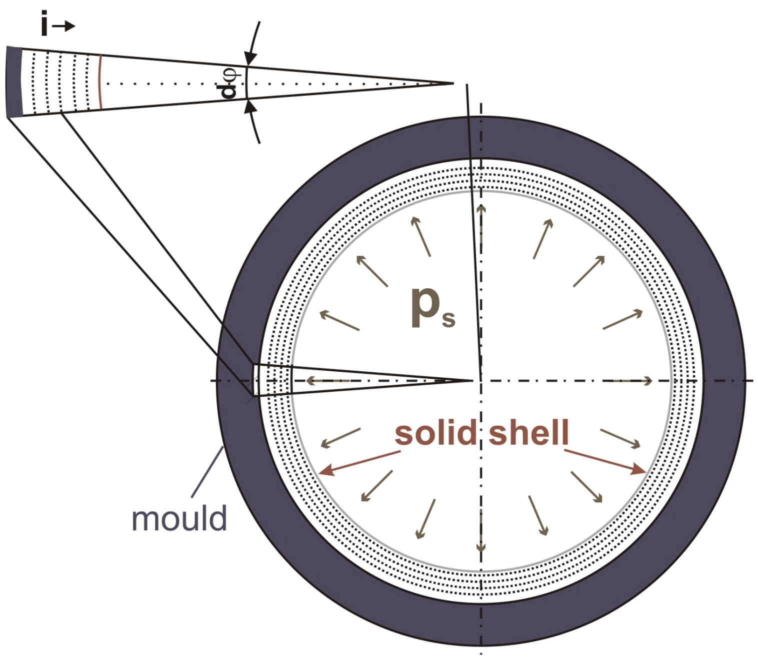
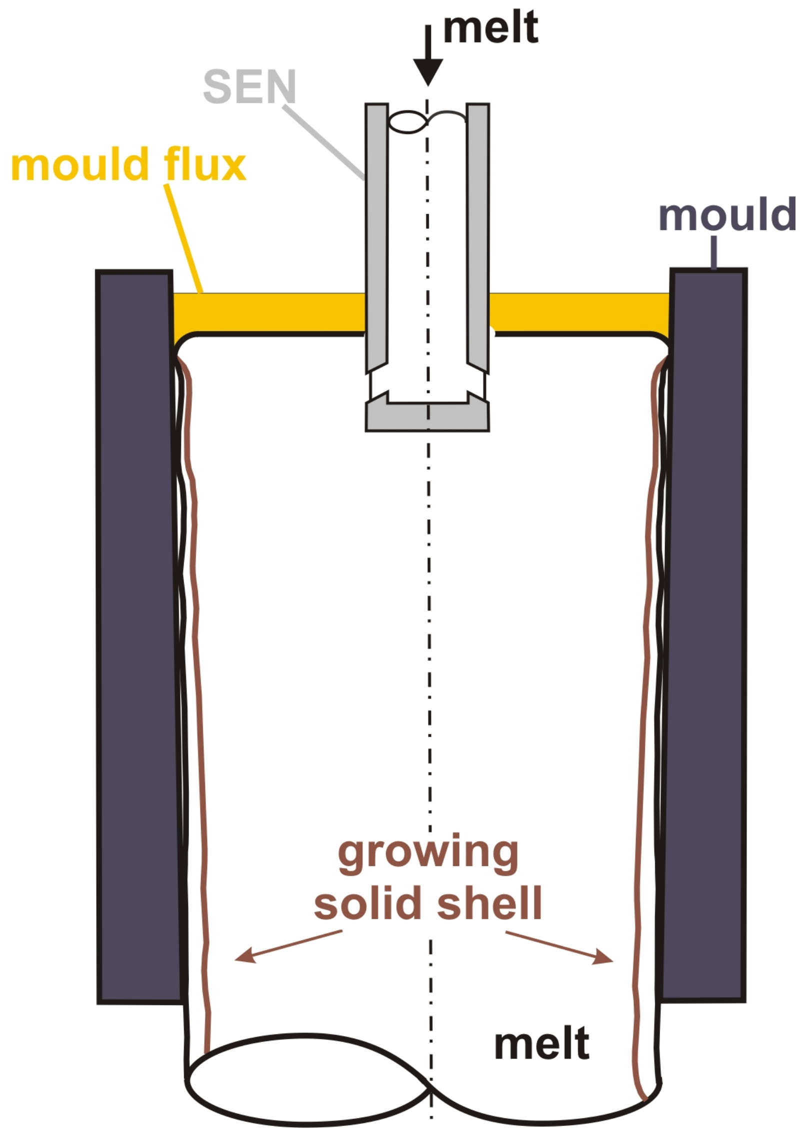
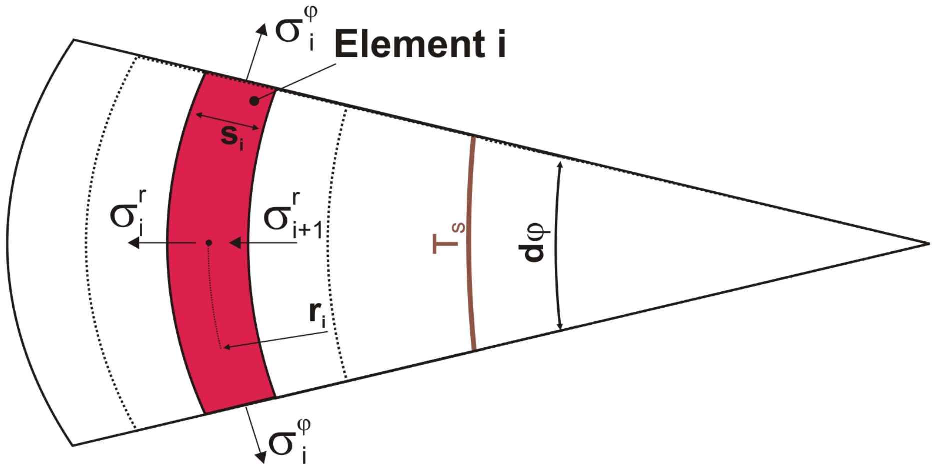
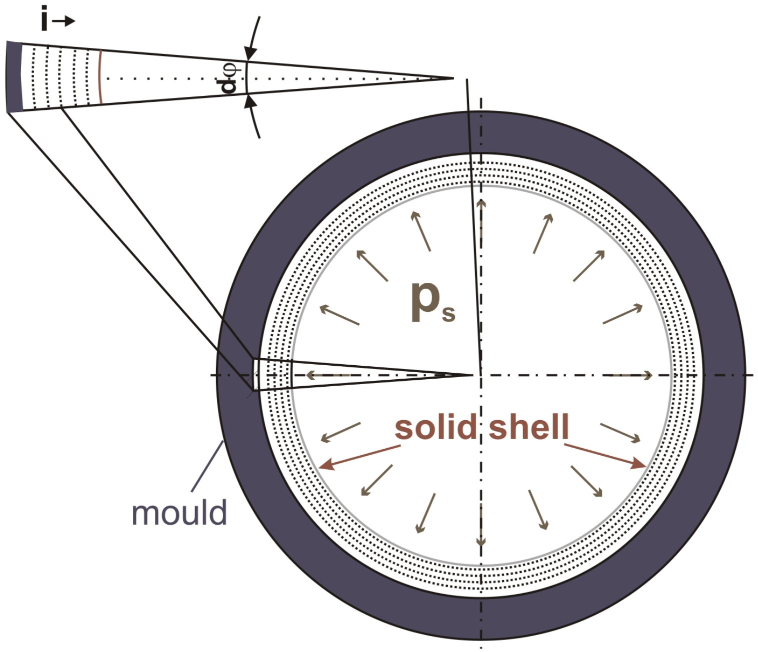
- **Transversal cut through the bloom:**
  - **Consider only elements below T_S**
  - **Elastic behaviour assumed (Schwerdtfeger)**

Schwerdteger K. et al., Metall. Mater. Trans. B., Vol. 29B (1998), 1057-1068.






Element i
σ_i^φ
s_i
σ_i^r
σ_{i+1}^r
r_i
T_s
$d\varphi$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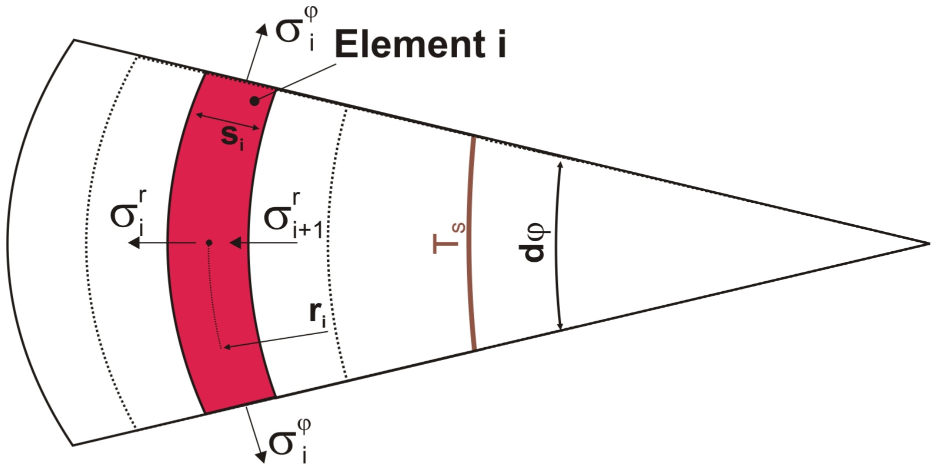
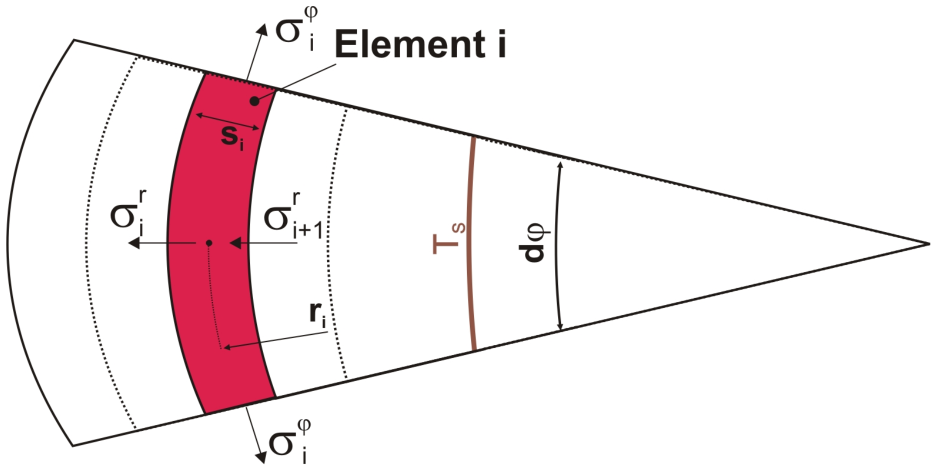


- **Force balance on each element i:**

$$2 \cdot \sigma_i^{\varphi} \cdot b \cdot s_i \cdot \sin\frac{d\varphi}{2} + \sigma_i^{r} \cdot \left(r_i + \frac{s_i}{2}\right) \cdot d\varphi \cdot b + \sigma_{i+1}^{r} \cdot \left(r_i - \frac{s_i}{2}\right) \cdot d\varphi \cdot b = 0$$

- **Additionally consider thermal strains (thermal linear contraction),**
- **Metallostatic pressure at the inside of the strand,**
- **No friction at the outside,**
- **Elements accumulate strain with time → accumulated strain.**



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Balance: Accumulated strain ↔ mould taper (diametrical decrease)

⇒ AIR GAP

For every timestep

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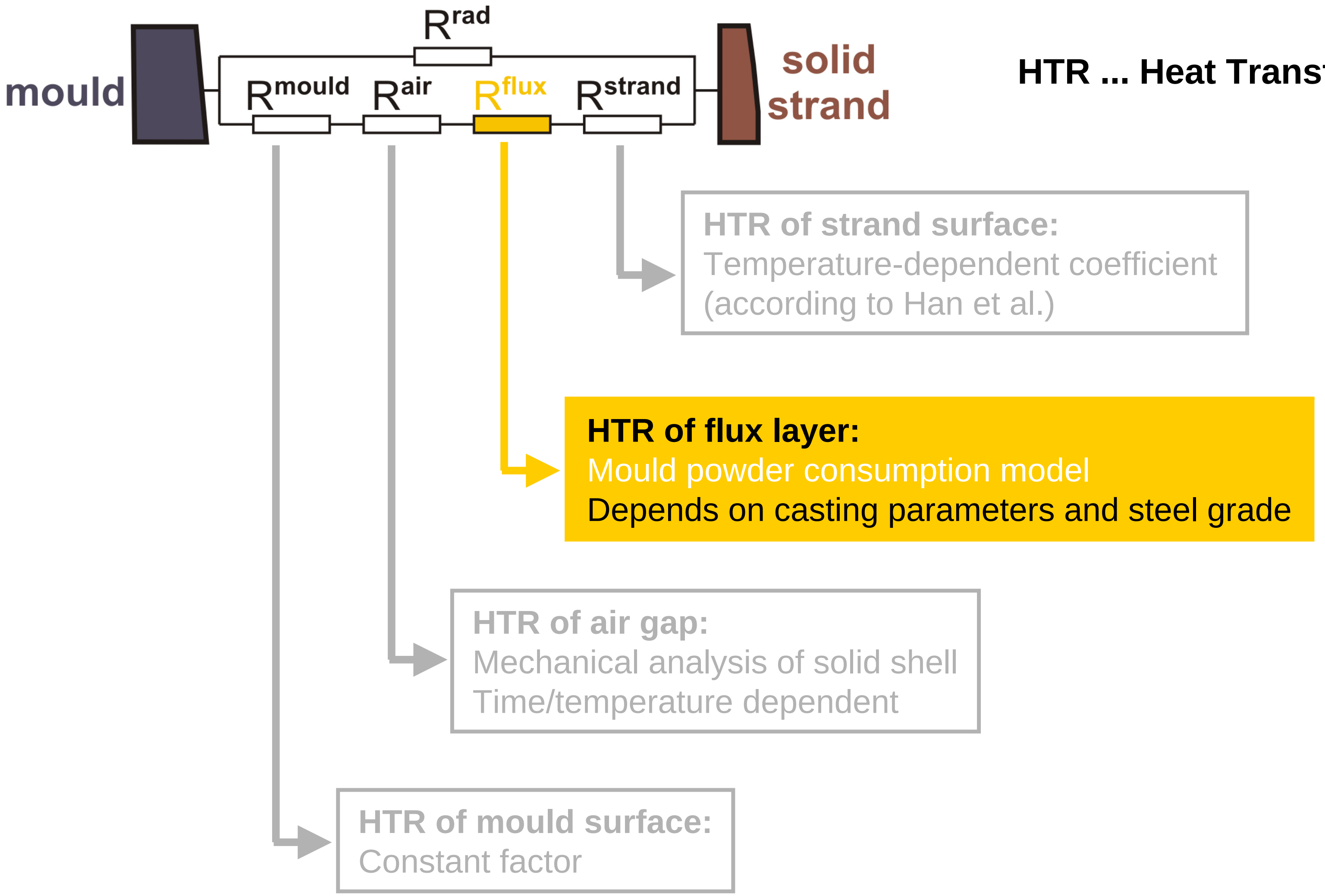

- **Mould flux consumption (MFC) depends on various process parameters:**
  - **Casting speed** v_c
  - **Oscillation parameters** t_N **(negative strip time)**
  - **Bath temperature** T
  - **Flux viscosity** η

- **Viscosity best calculated by Riboud's model**

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  Tsusumi, K. et al., Tetsu-to-Hagane, Vol 84 (2998), 617.

$$Q_S = \frac{F_A}{\sqrt{\eta(T)}} \frac{1}{v_c} \cdot t_N + F_B$$

Q_S ... MFC
F_A, F_B ... fitting parameters

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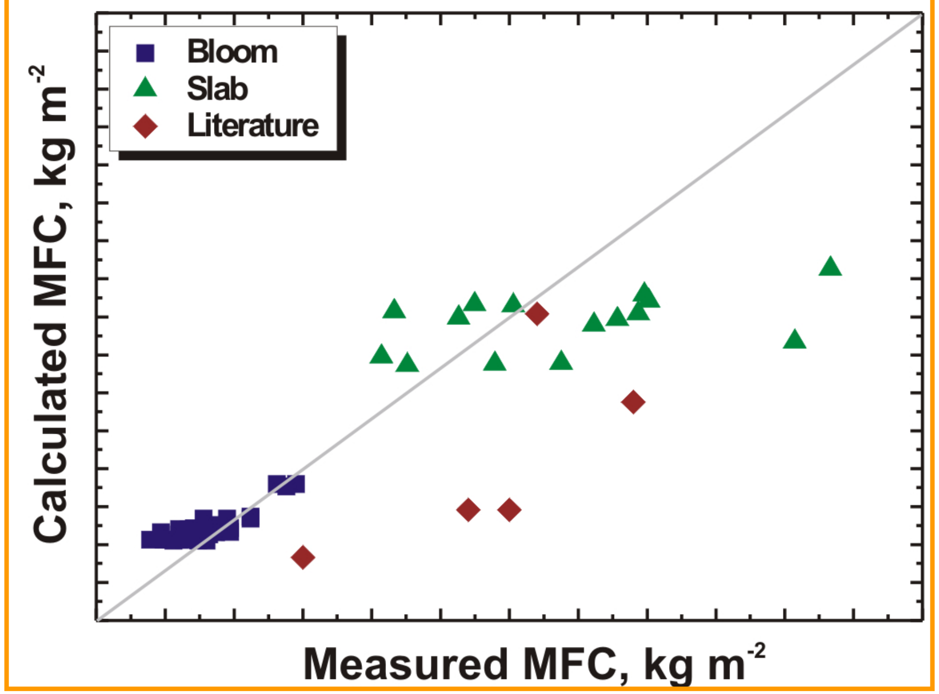
Validation by measurements on slab and bloom casters



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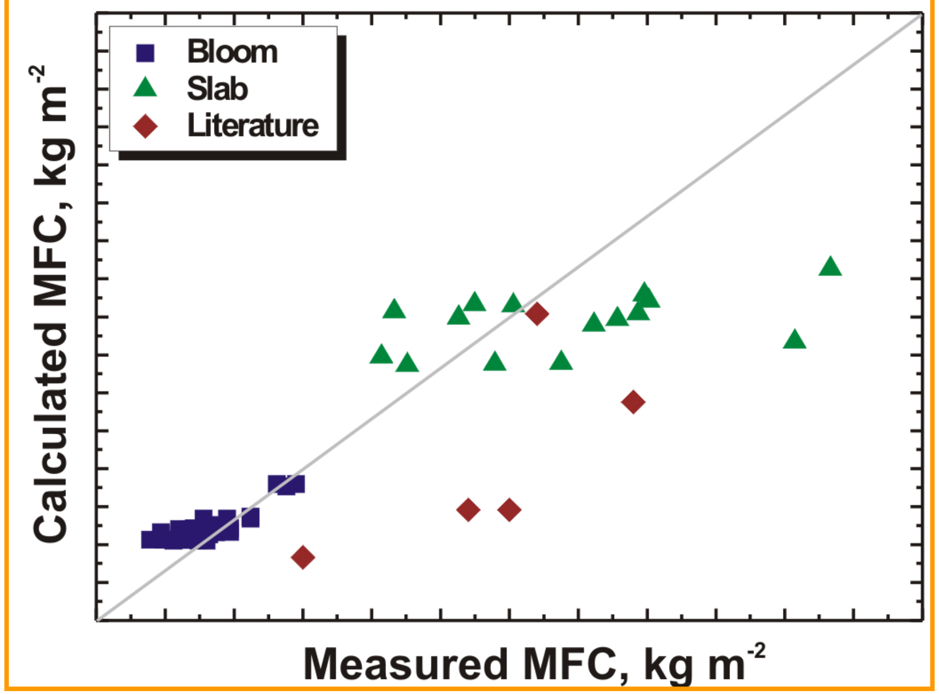
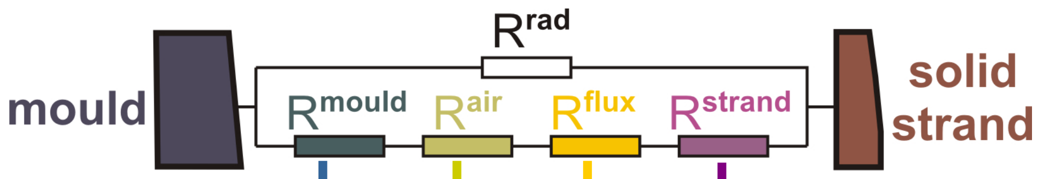


⇒ First step: constant flux thickness and conductivity

Modelling Boundary Conditions

General Parameters



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- **Model evaluated for 4 different steel grades**
- **Constant casting speed and superheat**

Steel	C_p
A	0.09
B	0.11
C	0.37
D	0.82

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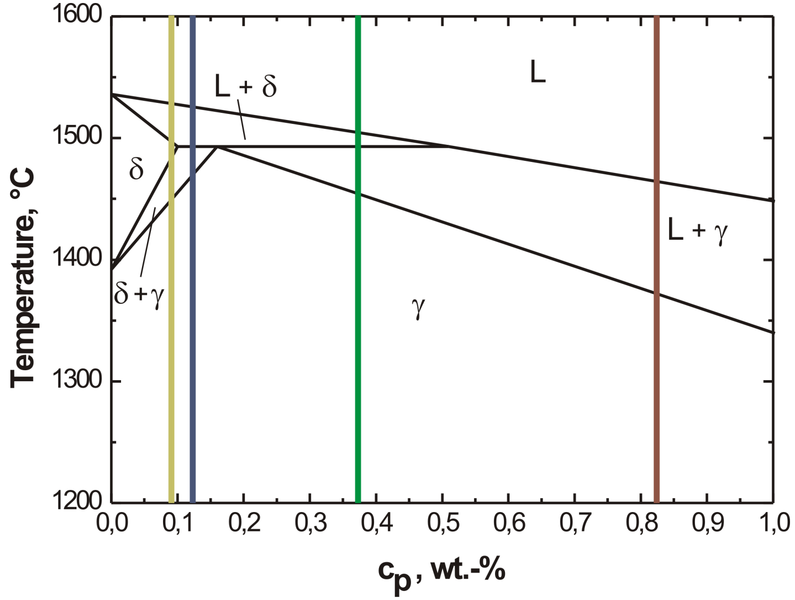

Position of steel grades in the Fe-Fe_3C Diagram

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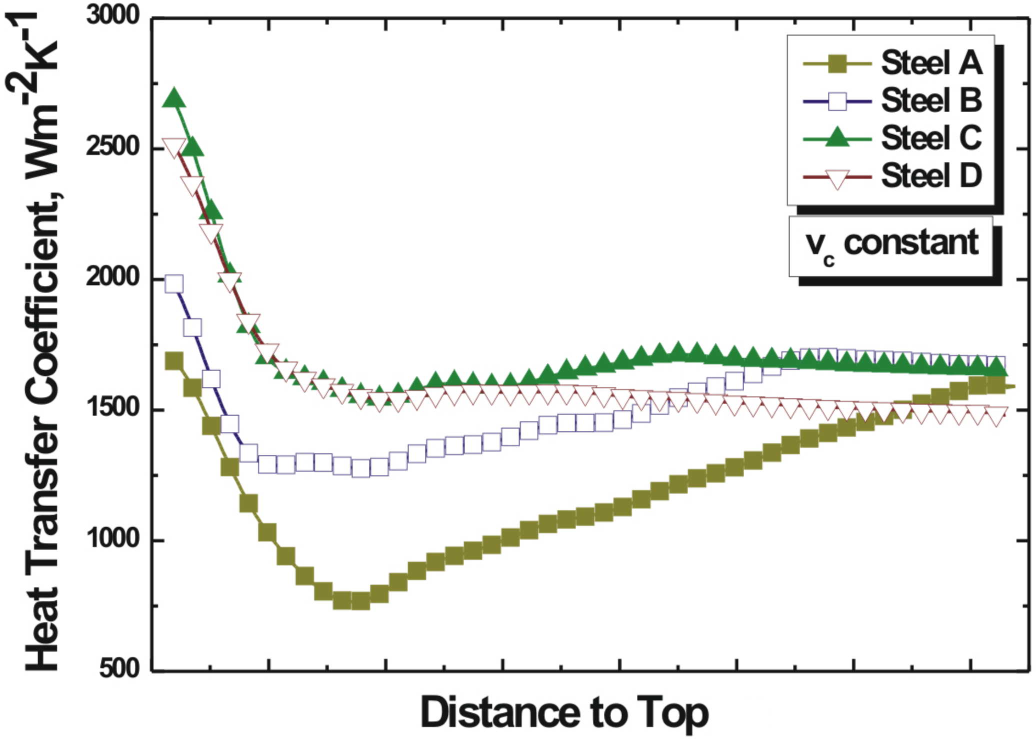
- Resulting total heat transfer coefficients



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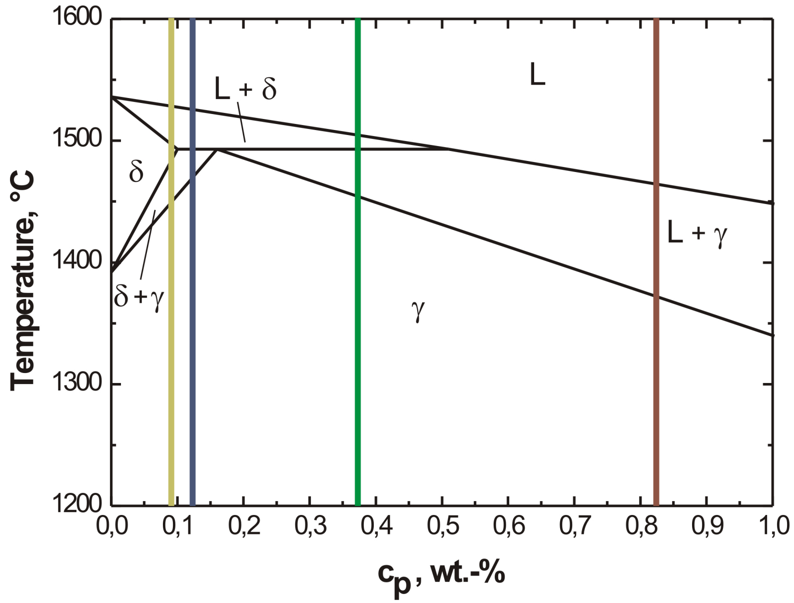
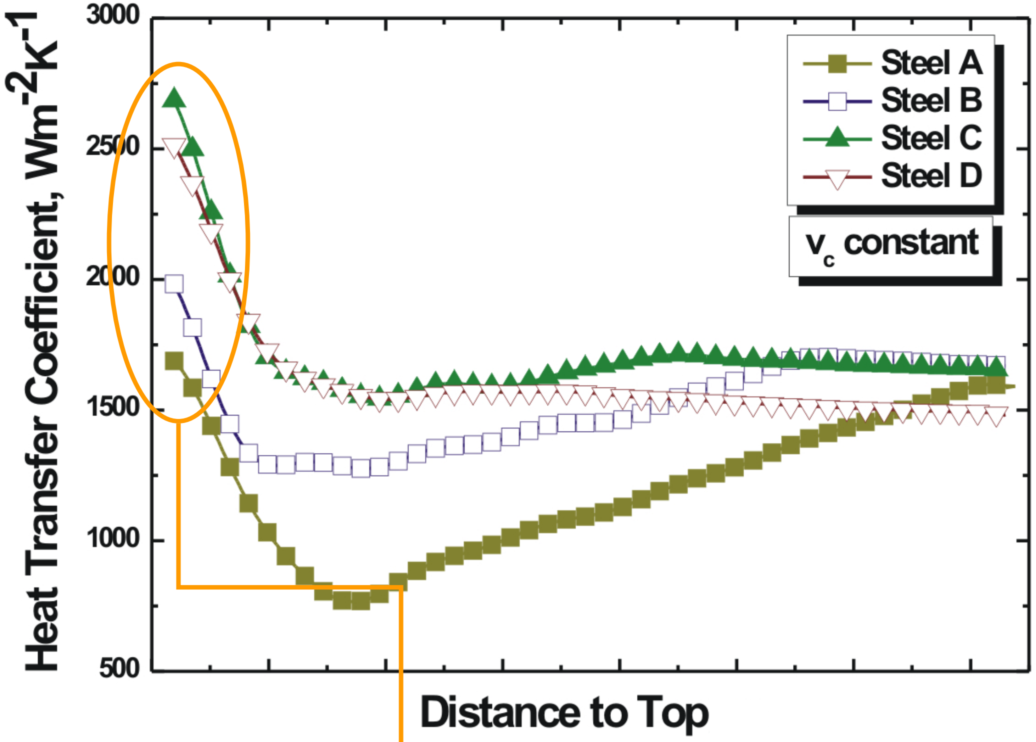


Position of steel grades in the $Fe\text{-}Fe_3C$ Diagram

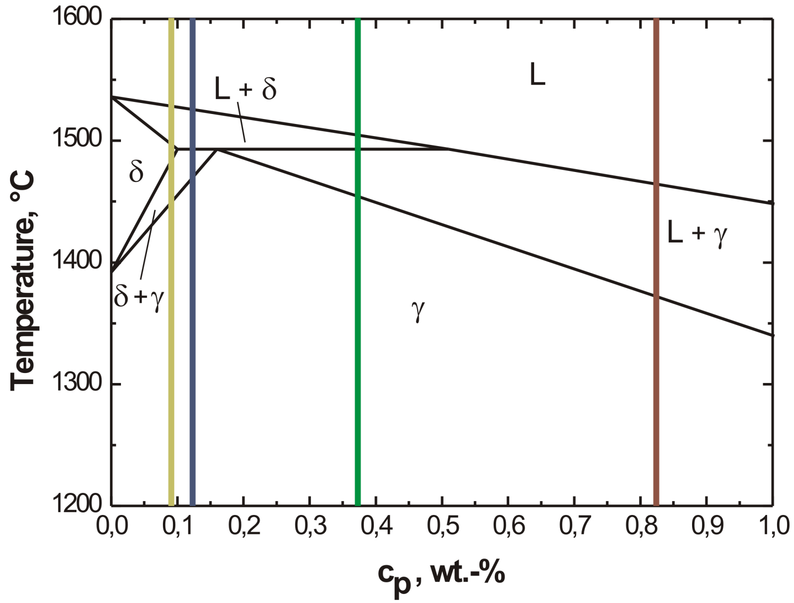
- Model evaluated for 4 different steel grades
- Constant casting speed and superheat

Steel	C_p
A	0.09
B	0.11
C	0.37
D	0.82

- Resulting total heat transfer coefficients



Shell formation → Decrease of HTC



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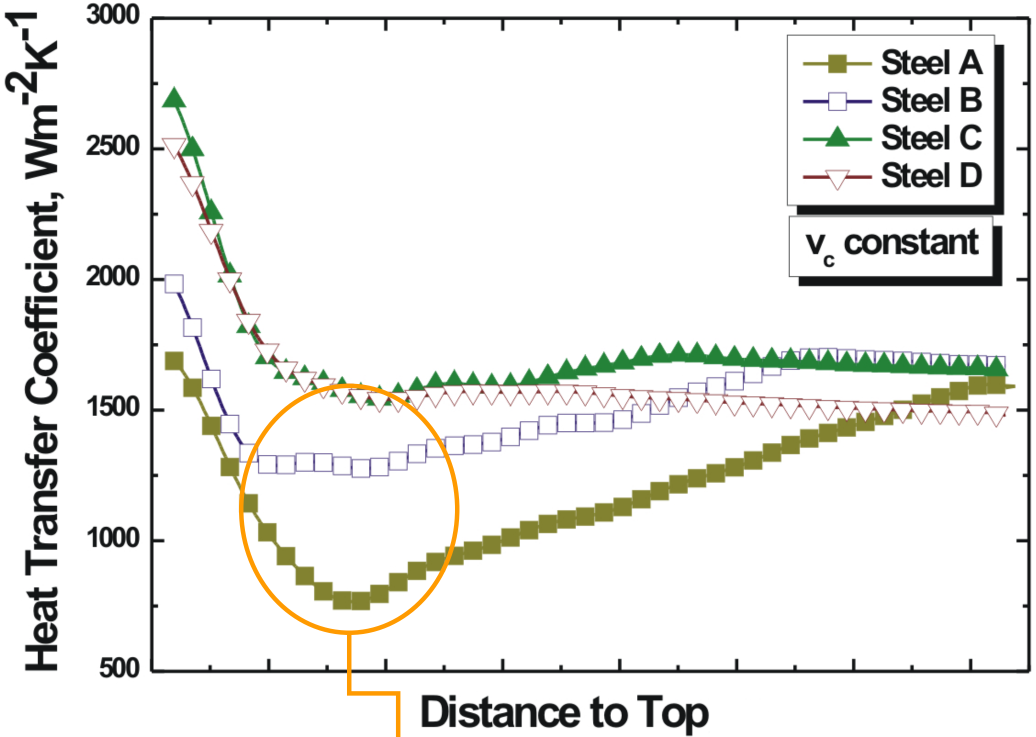
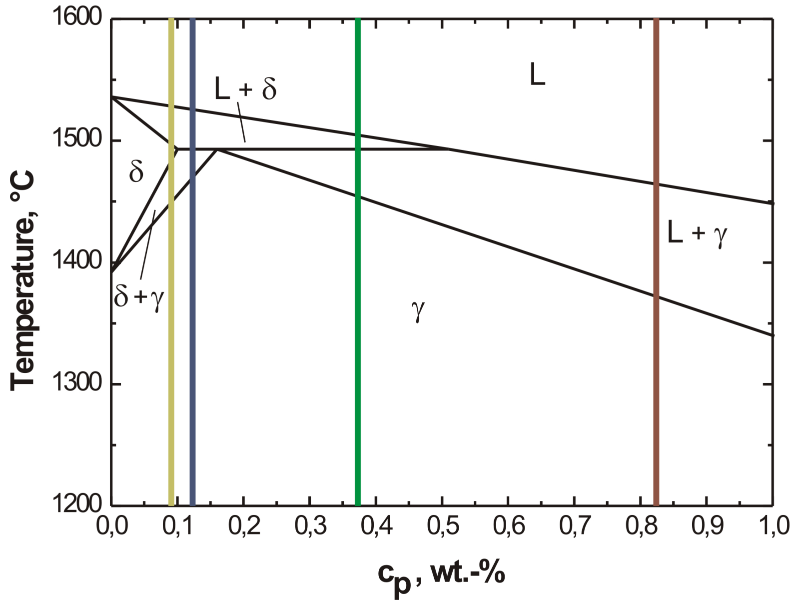


Strong decrease of HTC due to air gap



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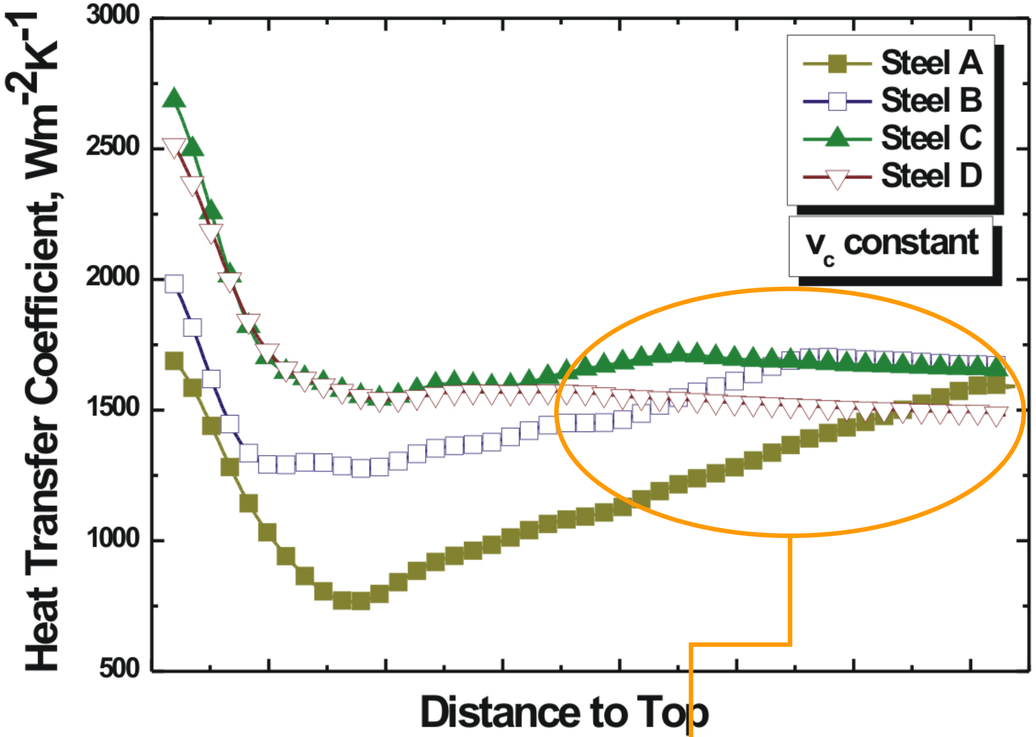
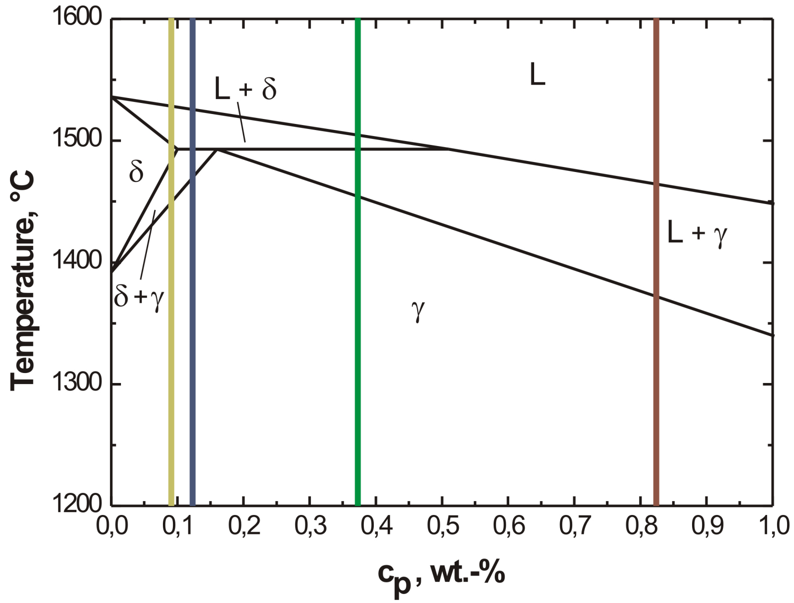




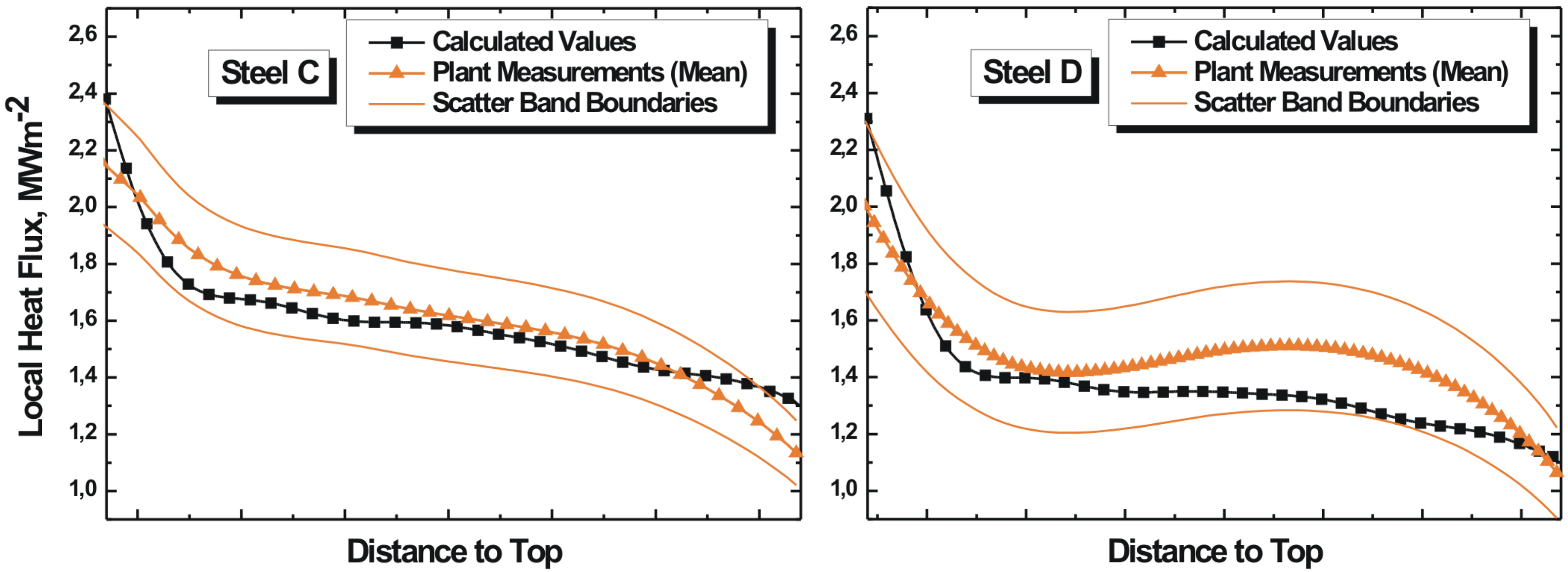
Position of steel grades in the Fe-Fe_3C Diagram

Shell presses on mould again (mould taper) → HTC increases again

Transferability to practise:

- Plant measurements at caster with the same dimensions.
- Local heat flux determined by inverse modelling.

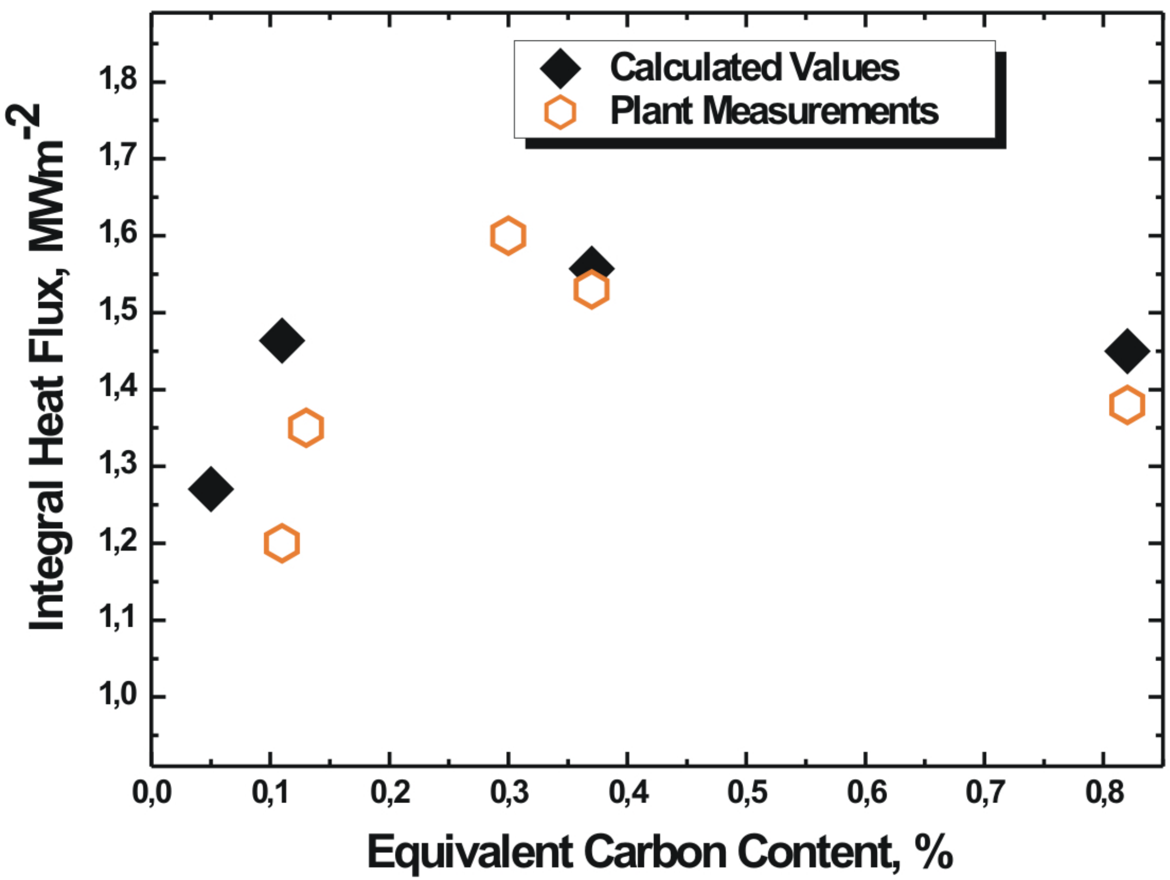
- Comparisons for Steels C and D



Lechner, M., J. Reiter, C. Bernhard, M. Forsthuber and O. Zach, BHM, Vol. 149 (2004), 101-106.

Transferability to practise:

- Integral heat flux as an overall benchmark quantity
- Reference points at several equivalent carbon contents



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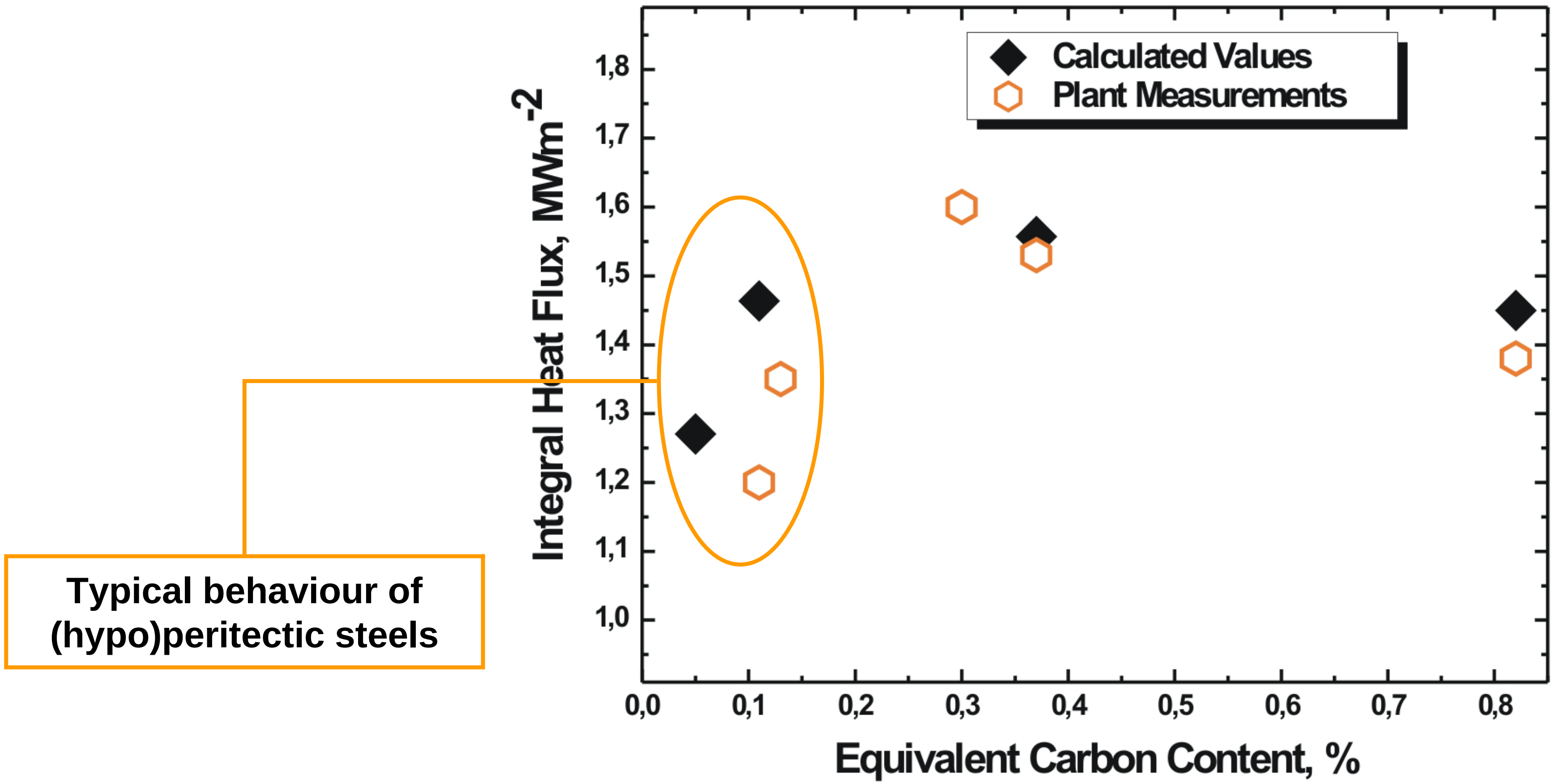

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- Introduction
  - The System Strand-Mould
  - Objectives
- Modelling Boundary Conditions
  - Model View
  - General Parameters
  - Mechanical Analysis of the Strand Shell
  - Mould Flux Consumption Model
- Results
  - Variation of Steel Grades
  - Comparison with Plant Trials
- **Summary**

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- **Heat transfer resistance is made up of several components:**
  - **Resistances of mould and strand surfaces,**
  - **Resistance of air gap,**
  - **Resistance of mould flux.**

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  - Resistances of mould and strand surfaces,
  - Resistance of air gap,
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⇒ Literature

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  - Resistance of air gap, ⇒ Mechanical model
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  - ⇒ Great overall consistency with measured local heat flux;
  - ⇒ Integral heat flux as an overall benchmark correlates well.

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- Next steps: Detailed analysis of flux layer
  - Variable thickness,
  - Changing thermal conductivity.

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Numeric Modelling of the Heat Transfer in the Continuous Casting Mould

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