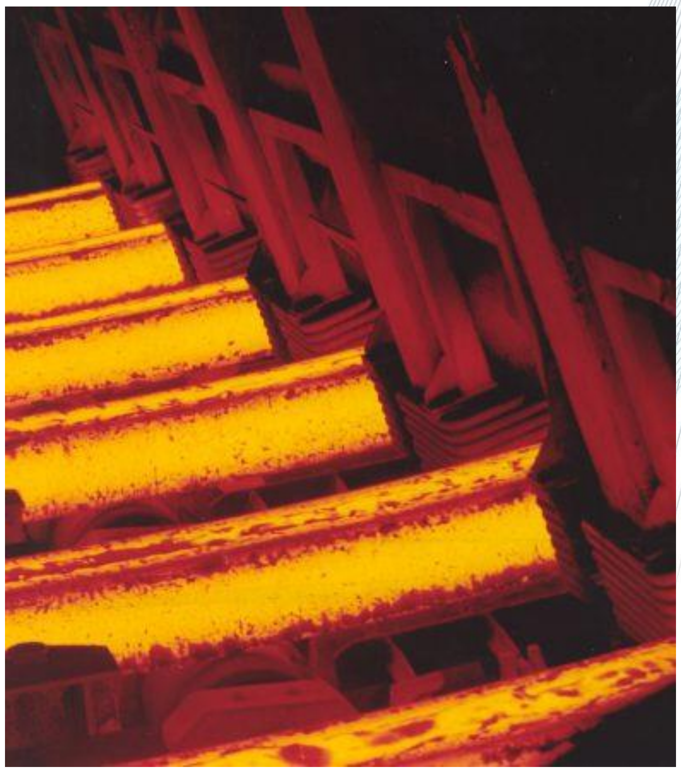
RealTimeCastSupport

Embedded real-time analysis of continuous casting for machine-supported quality optimisation

6th K1-MET Simulation Conference, Vienna
23rd of April 2025



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State of the Art

- Thermal and fluid-mechanical conditions in continuous casting moulds are only roughly known although highly relevant for the product quality.
- Operational windows for lubrication, mould heat transfer and shell growth were developed but did not provide a real-time process control.
- It was found that insufficient mould powder coverage has a tremendous influence on the strand surface quality.
- Anomalous casting conditions were identified with innovative sensors but could not be implemented in real-time.

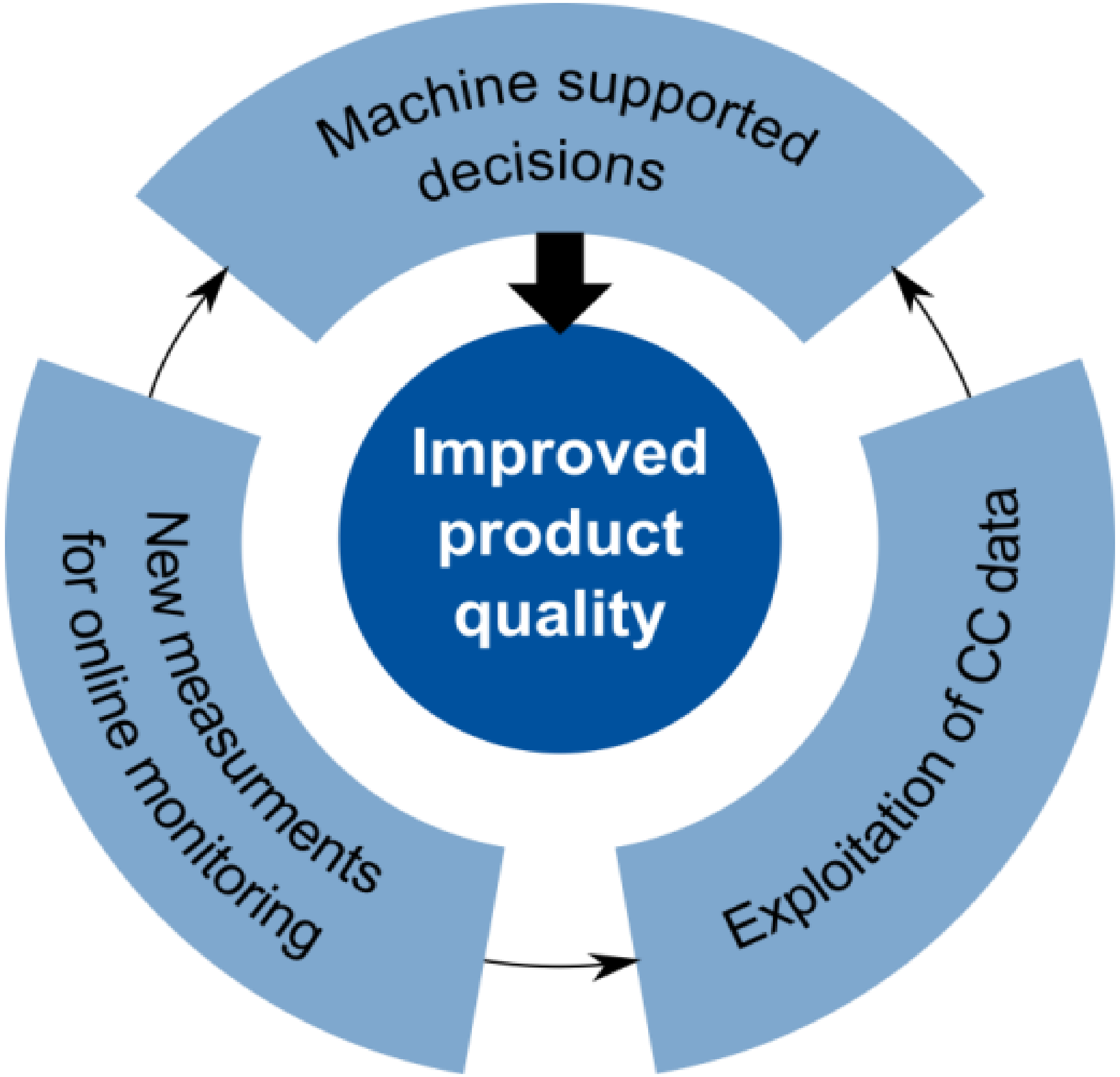
Problems

- Optimisation of surface quality of heavy plates is an ongoing challenge.
- Manual process control is difficult due to the big number of influencing factors.
- Up to now direct measurements in the area of early solidification are not possible.
- Operational monitoring is limited to the interpretation of several indirect measurements.
- Interaction of melt temperature flow and phase changes, casting powder and heat transfer are extremely complex.
- Assessment of data is difficult because feedback from quality supervision is only available hours or days later.

Objectives

- Improved product quality in terms of reduction of surface defects on heavy plates
- Online monitoring of tundish and mould with implementation of new measuring techniques
- Exploitation of various CC data and surface inspection to assess risk of quality issues
- Exploitation of big data technologies and digital twins
- Advanced CC process control in real-time offering machine supported decisions

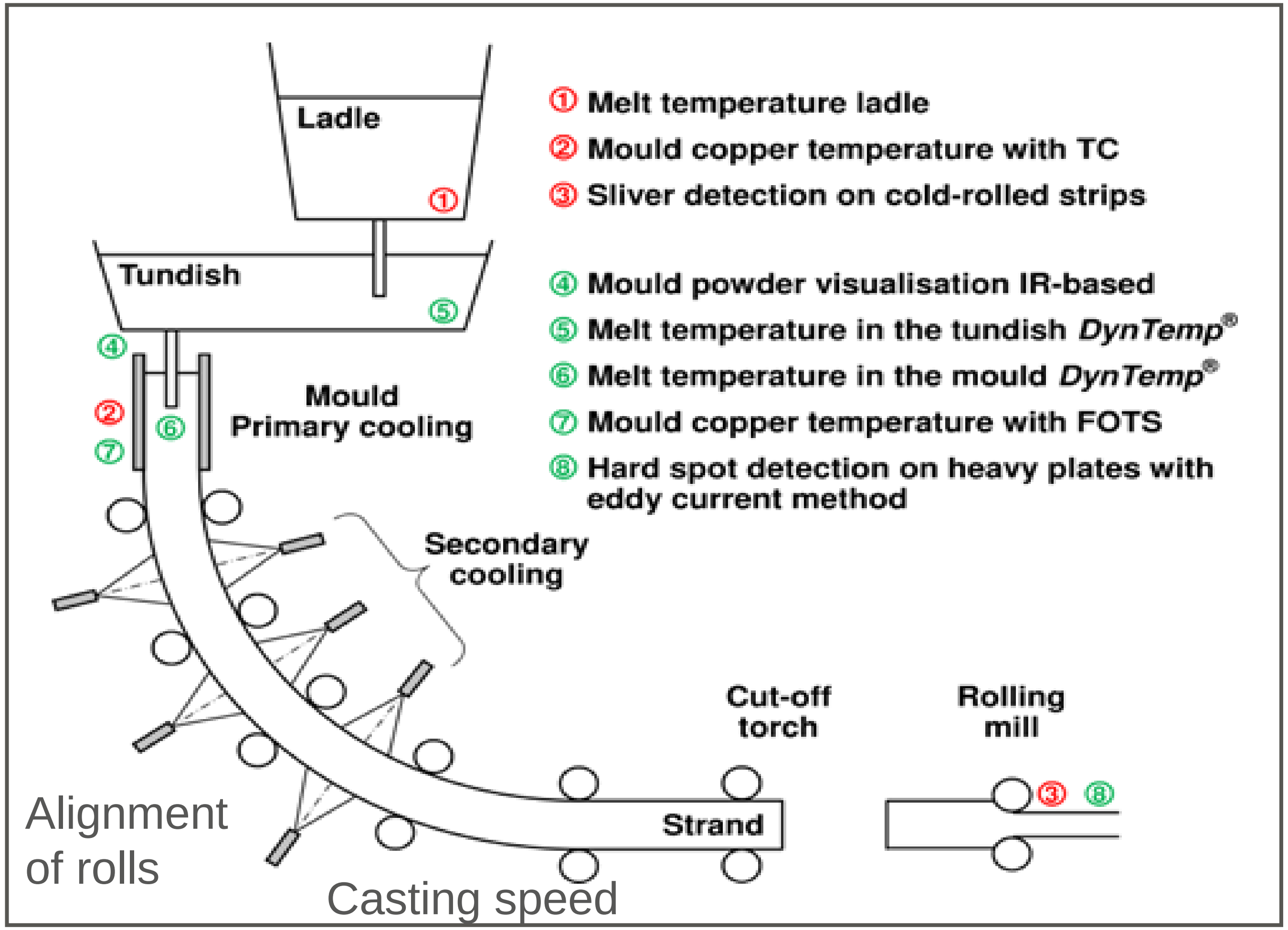
Work flow


Machine supported decisions
Improved product quality
New measurements for online monitoring
Exploitation of CC data

Measurement locations

Control of mould powder feeding

Cooling control



Alignment of rolls

Casting speed control

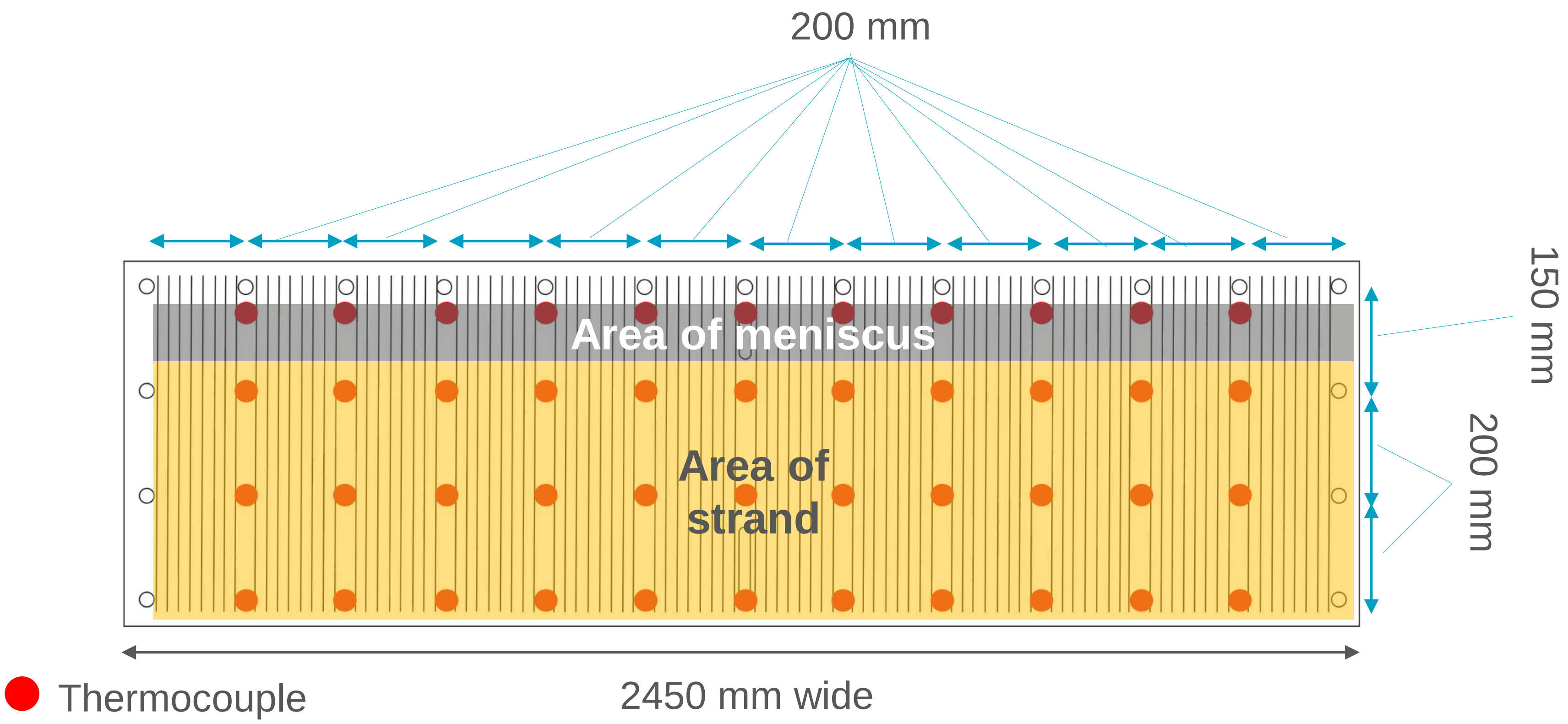
Surface inspection
Quality control

Real-time Support system

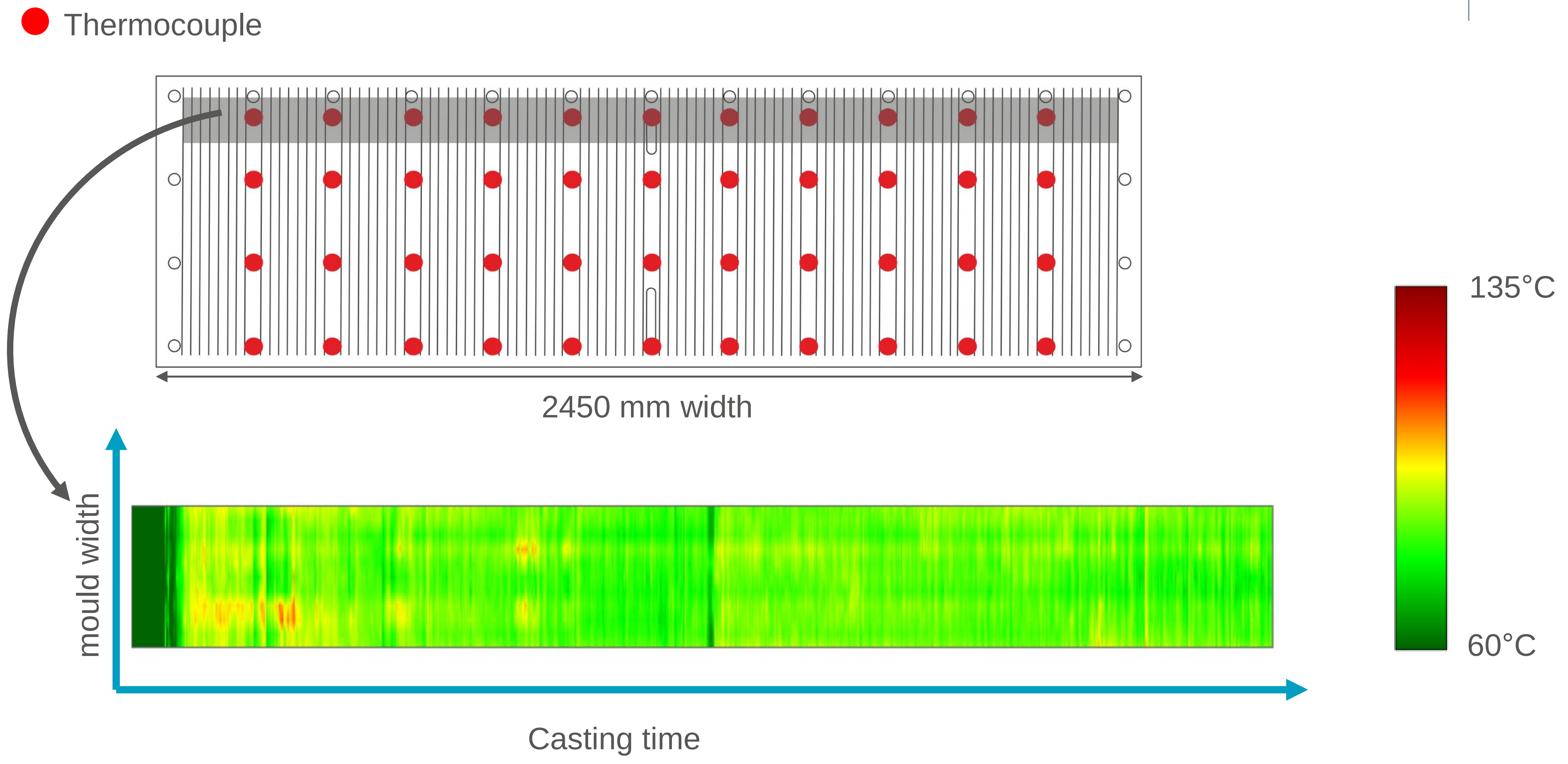
Temperature measurements in mould copper with TCs

2 moulds with thermocouple equipment on each broad face (44) are available at Dillinger

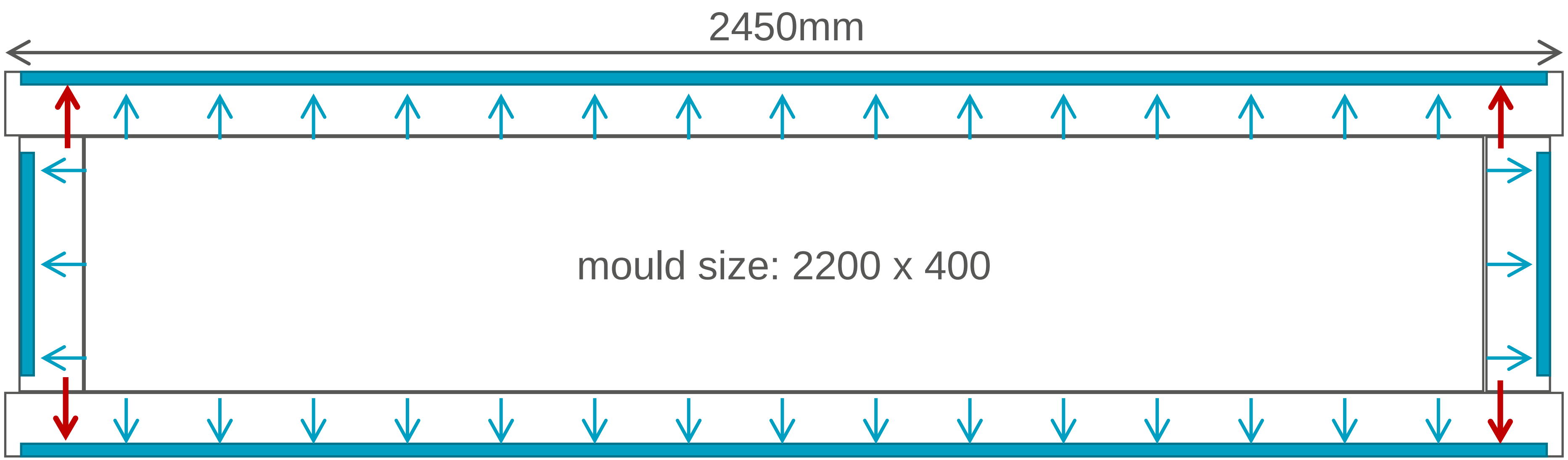
→ Thermocouples are installed between the cooling cannels



Temperature measurements in mould copper with TCs



Typical local heat flux in the Cu-mould



CFD-Model of the melt including a model of the heat flux in the mould copper

Because of the heat transfer at mould-mould contact (red arrow), the actual cooling on the **narrow** face is greater than the measured cooling (based on cooling water)!

Local heat flux estimates based on mould TC measurements are lower than measurements based on cooling water!

CFD simulation to study the effect of the SEN geometry

SEN-A: smaller outflow port

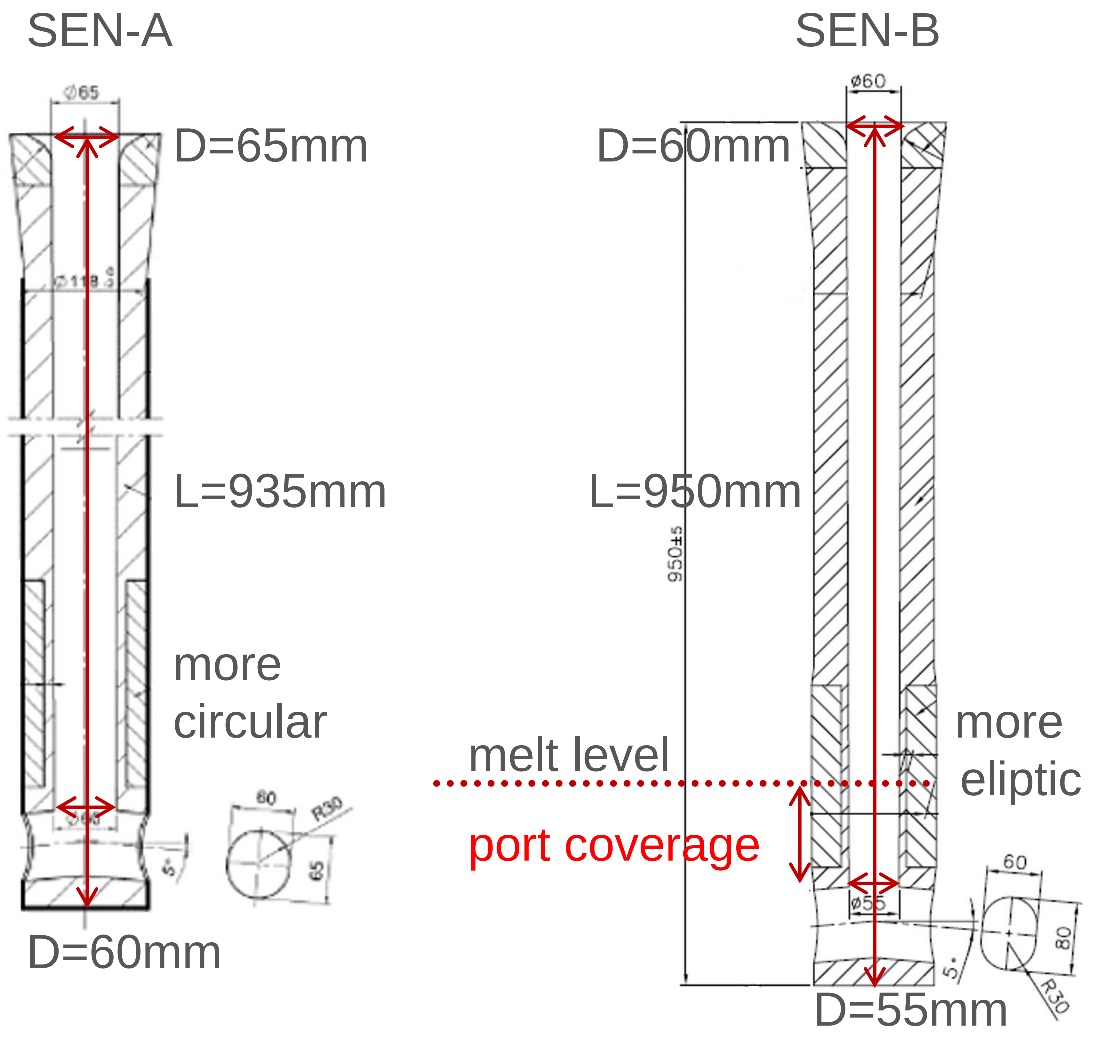
SEN-B: smaller inner diameter

4 computations are performed

- SEN-A, port coverage: 80mm, format: 400er
- SEN-B, port coverage : 80mm, format: 400er
- SEN-B, port coverage : 120mm, format: 400er
- SEN-B, port coverage : 120mm, format: 600er

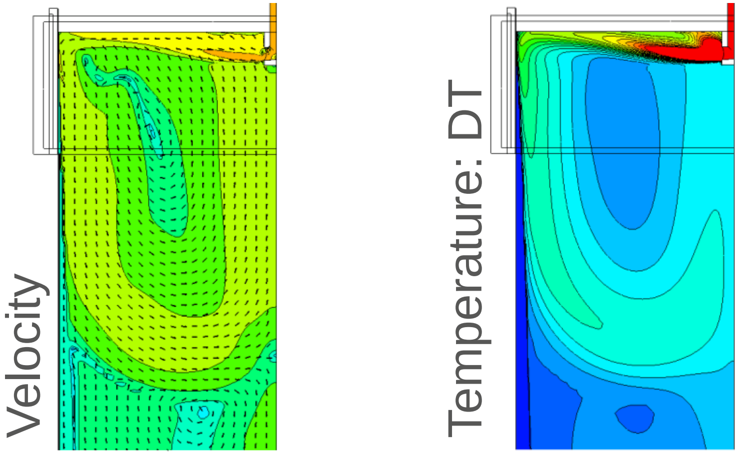
Targets:

- How the flow field in mould is affected
- How the steel shell formation is affected
- How the heat-fluxes and top-freezing are affected

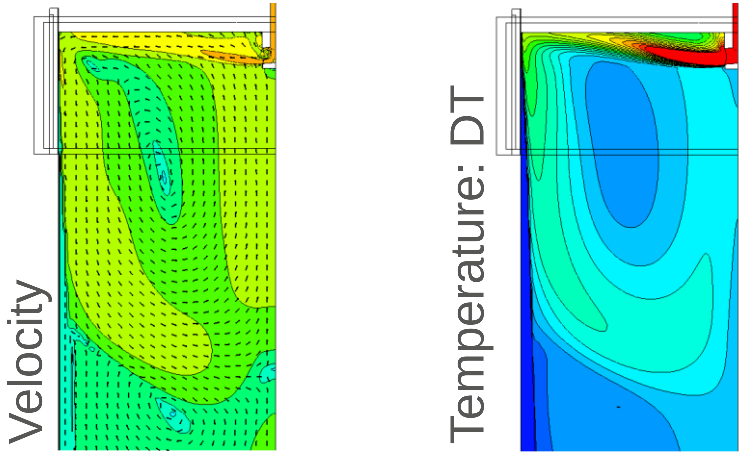


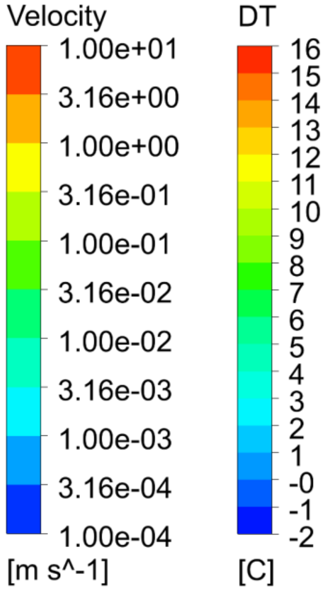
How the flow field in the mould is affected
i.e., velocity and temperature fields

SEN-A, port coverage: 80mm, format:400er

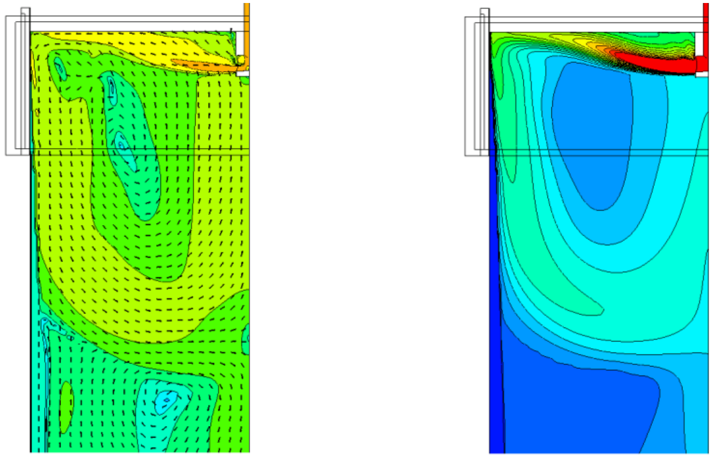


SEN-B, port coverage: 80mm, format:400er

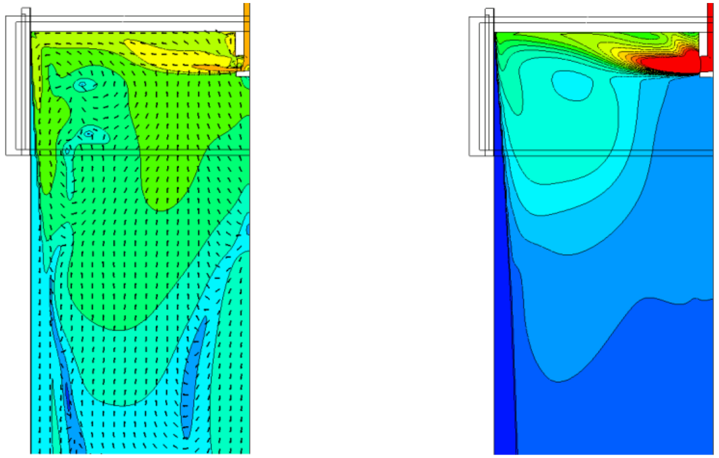




SEN-B, port coverage: 120mm, format:400er



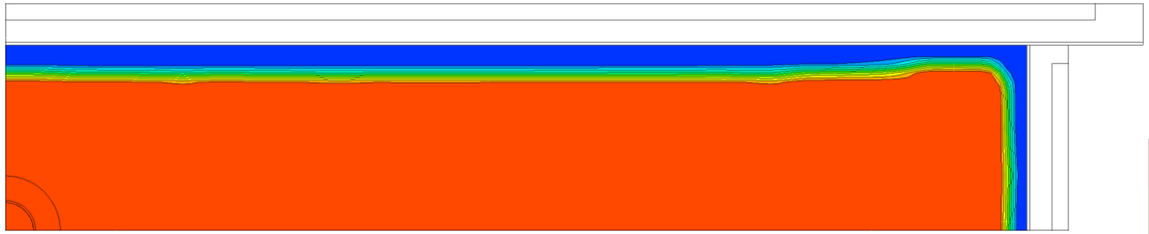
SEN-B, port coverage: 120mm, format:600er



Velocity and Temperature distribution is quite different for the 600er format!

How the steel shell formation is affected
i.e., shell thickness at mould exit

SEN-A, port coverage: 80mm, format: 400er



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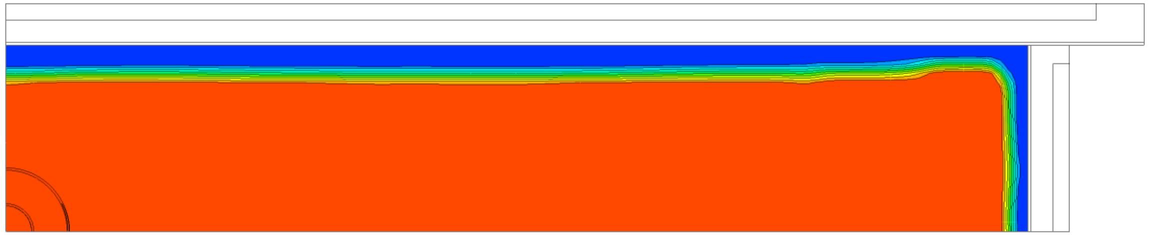
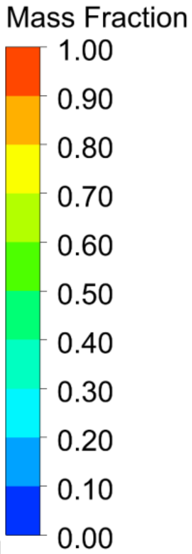
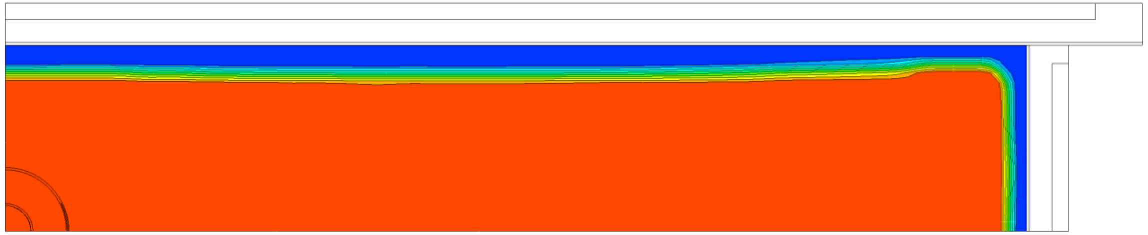




400er format 0.30 m/min → 7.7 kg/s

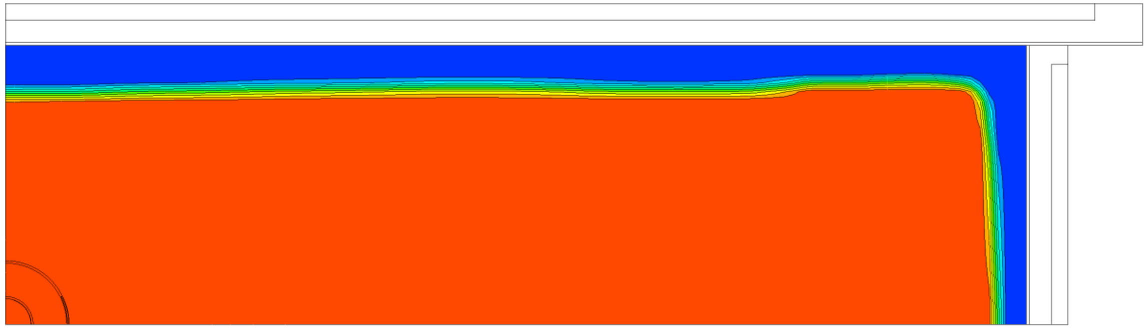
600er format 0.15 m/min → 5.775 kg/s

SEN-B, port coverage: 120mm, format: 400er



SEN-B, port coverage: 120mm, format: 600er

Steel shell is thicker as the mass flow rate is less!



How the heat-fluxes and top-freezing are affected
i.e., melt temperature at top, below casting powder

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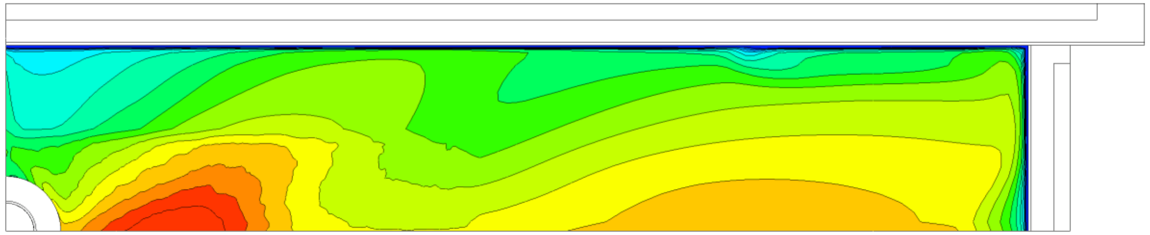
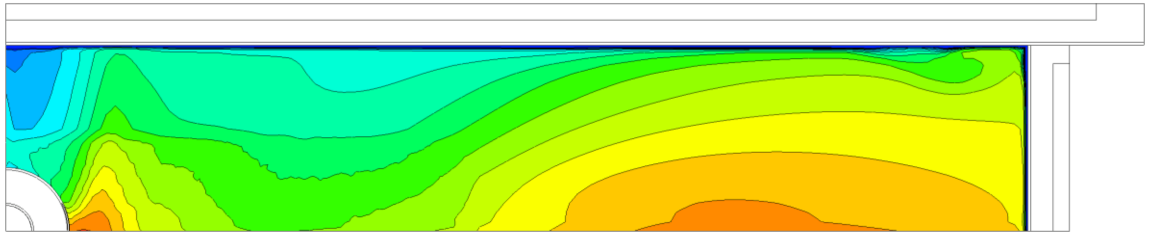
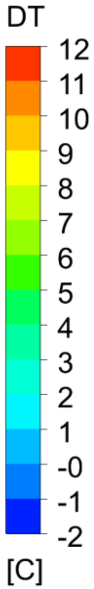
SEN-A, port coverage: 80mm, format: 400er

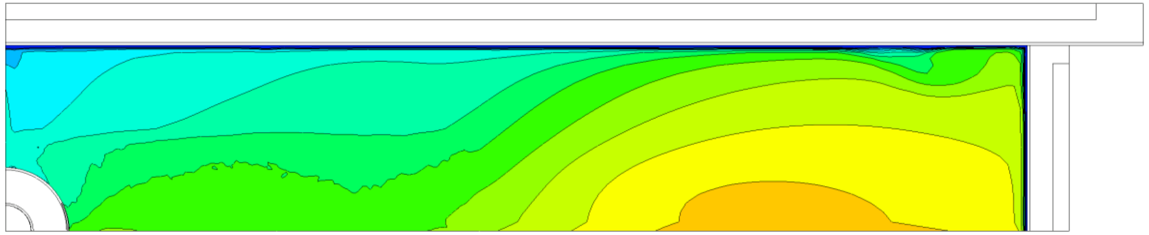


SEN-B, port coverage: 80mm, format: 400er

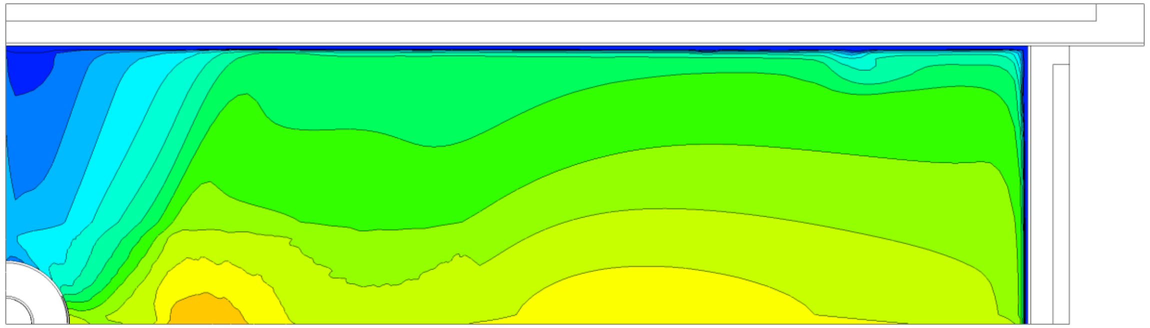




SEN-B, port coverage: 120mm, format: 400er



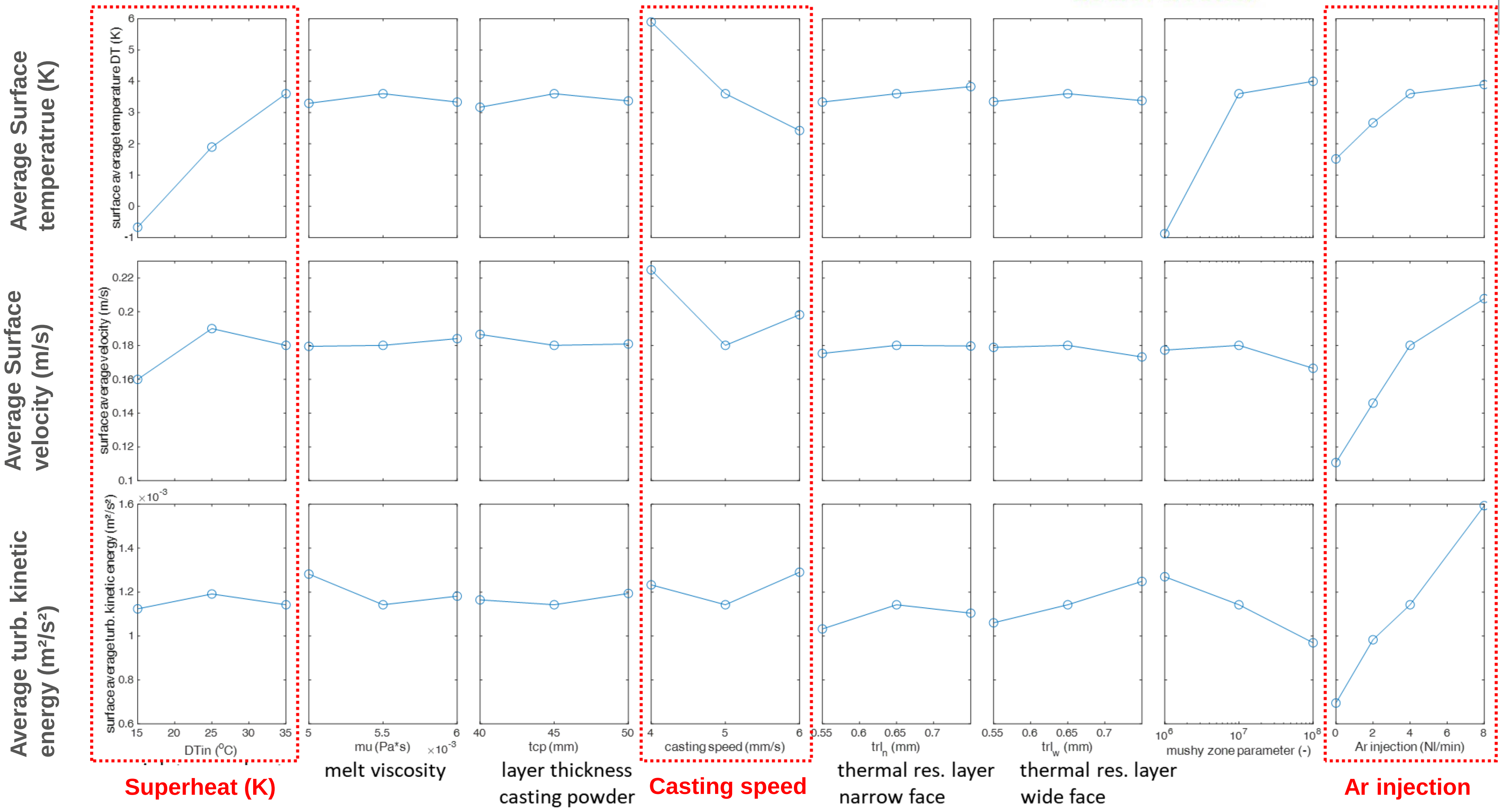
SEN-B, port coverage: 120mm, format: 600er



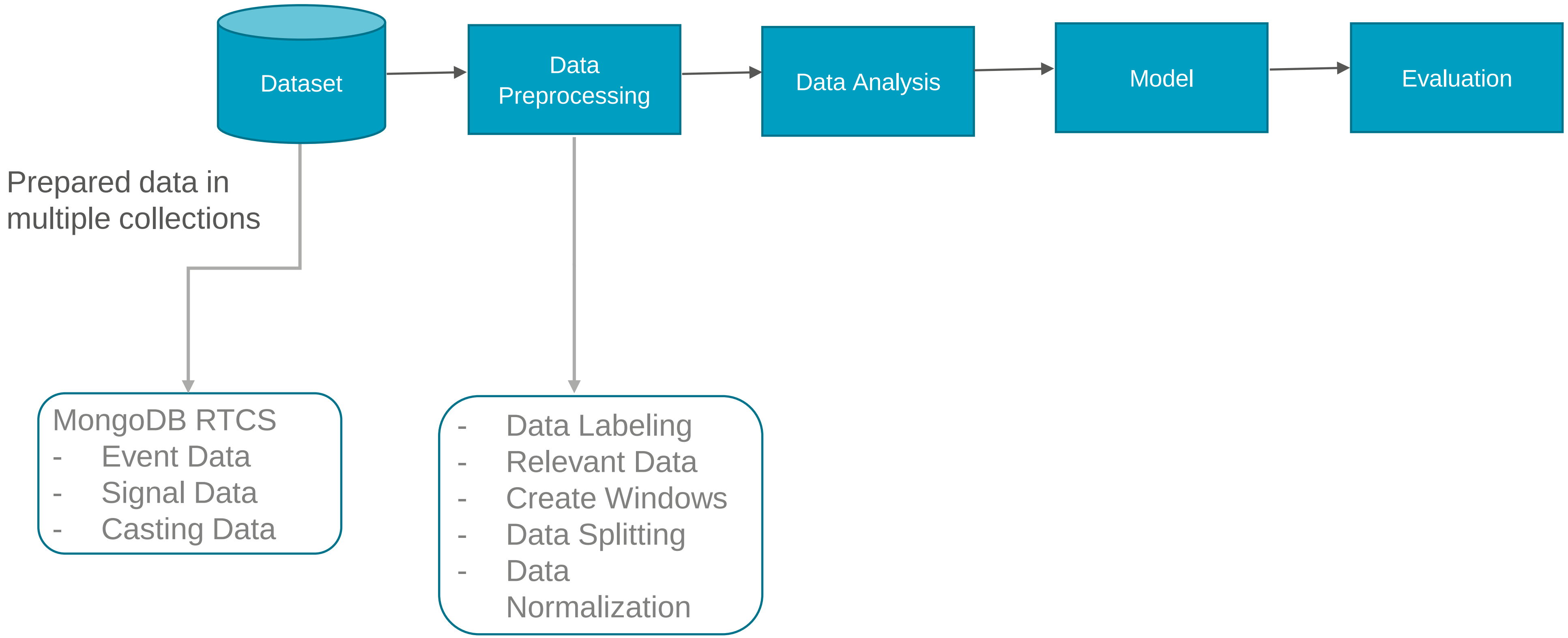
for larger port coverage,
top-freezing danger slightly increases!

for larger format,
top-freezing danger further increases!

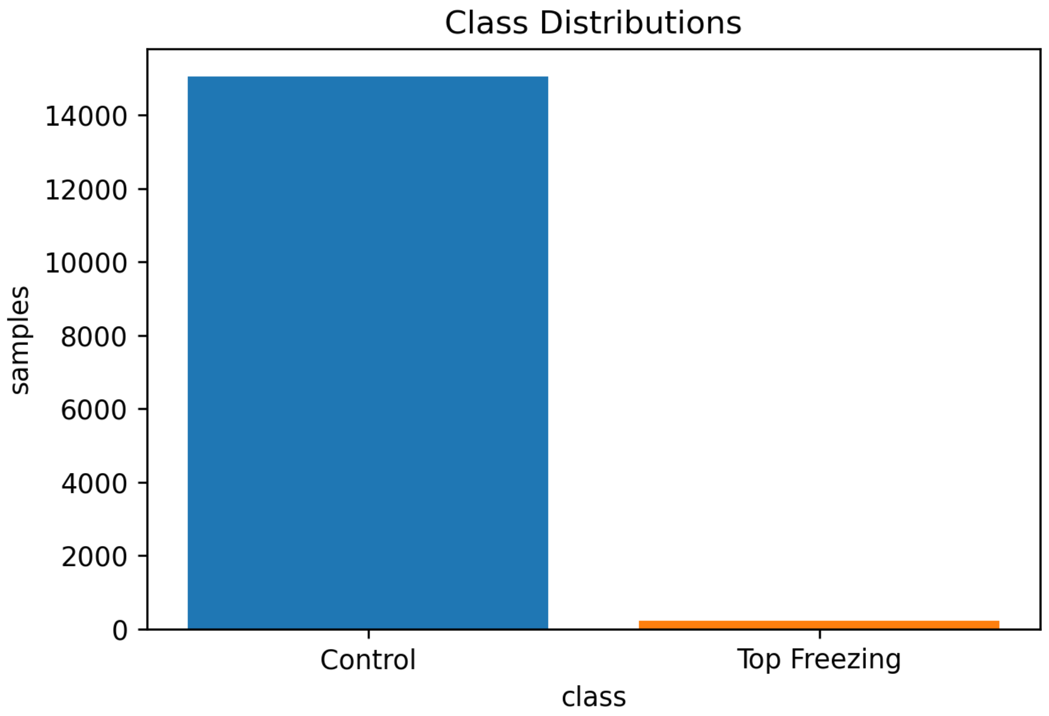
Parameters influencing top-freezing



Framework for Data Analysis



Data Analysis



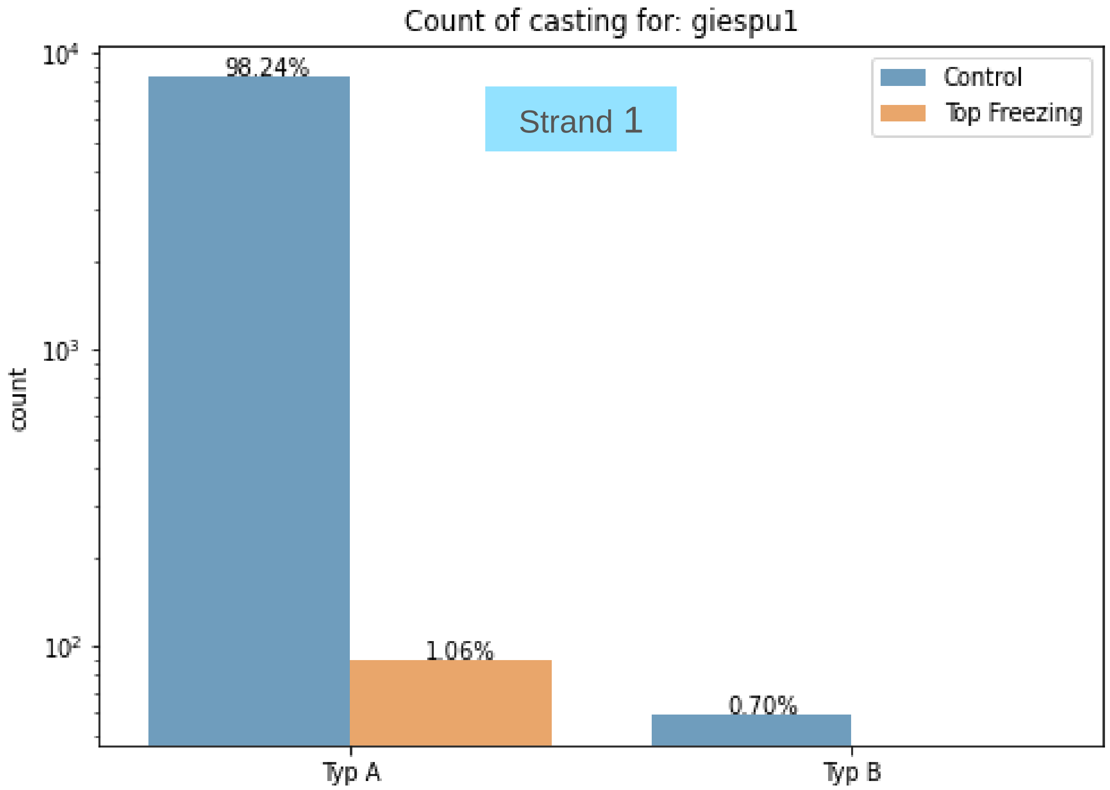
Surface defects on the slabs are determined extremely seldom. So we tried to predict **top-freezing** events which occur more frequently and are a possible cause for defects.

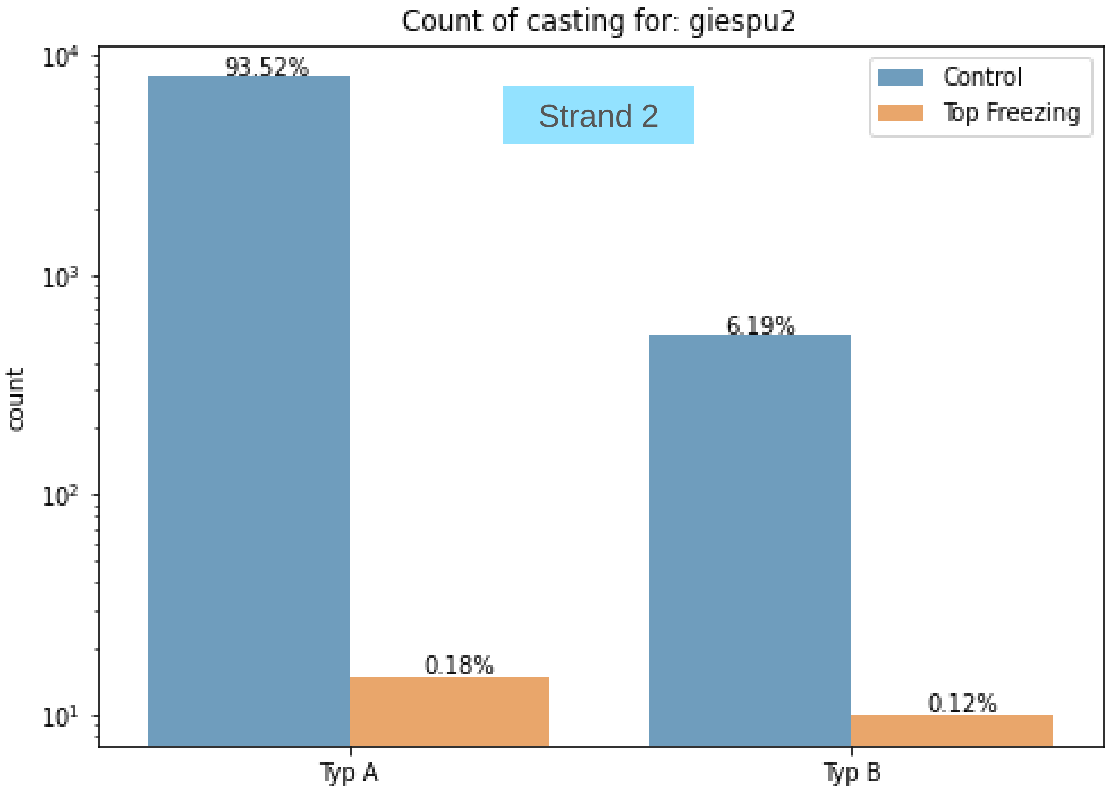
The percentage of samples:

Control class: 98.55 %
Top-freezing class: 1.44 %

Highly Imbalanced Dataset

Data Analysis





Casting Powder

Type A has a lower carbon content than Type B

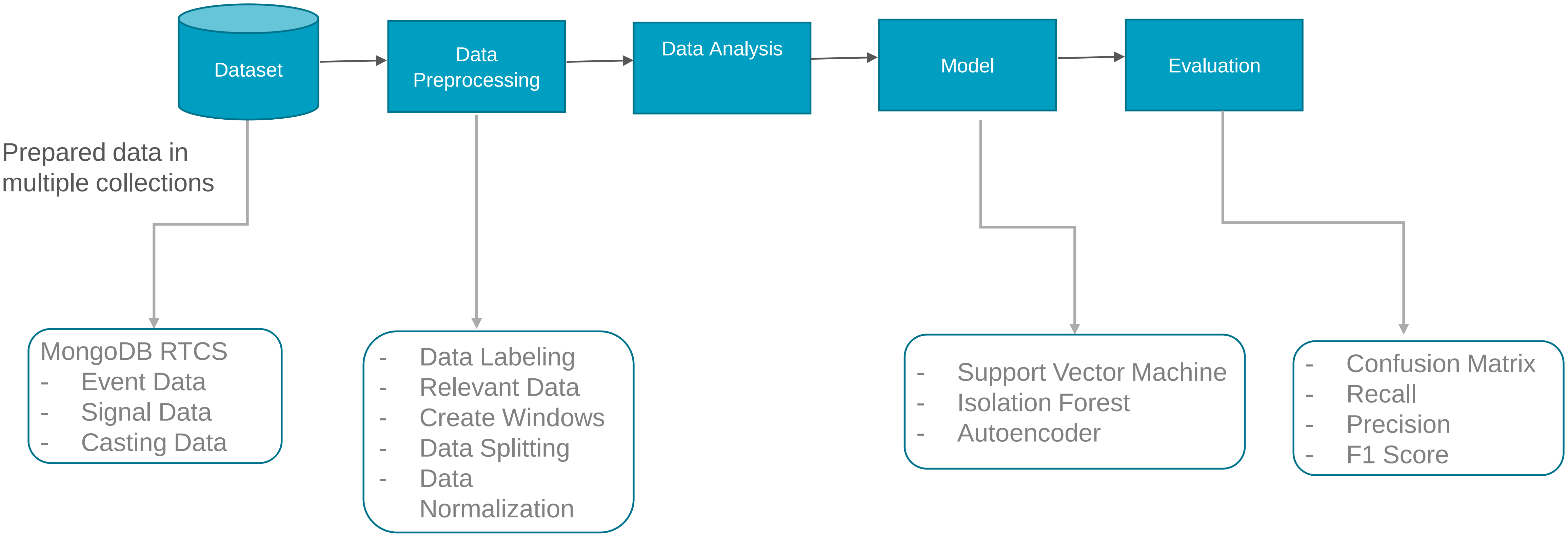
More top-freezing events with mould powder Type A

Modeling

- Identification of rare events (Anomaly detection)
- Highly imbalanced dataset
- One-class classification Machine learning models use a normal training dataset to create a model that represents normal behavior. Anomalies can then be detected by deviating from this model.

- One-Class Support Vector Machines
- Isolation Forest
- Autoencoder

Framework for Data Analysis

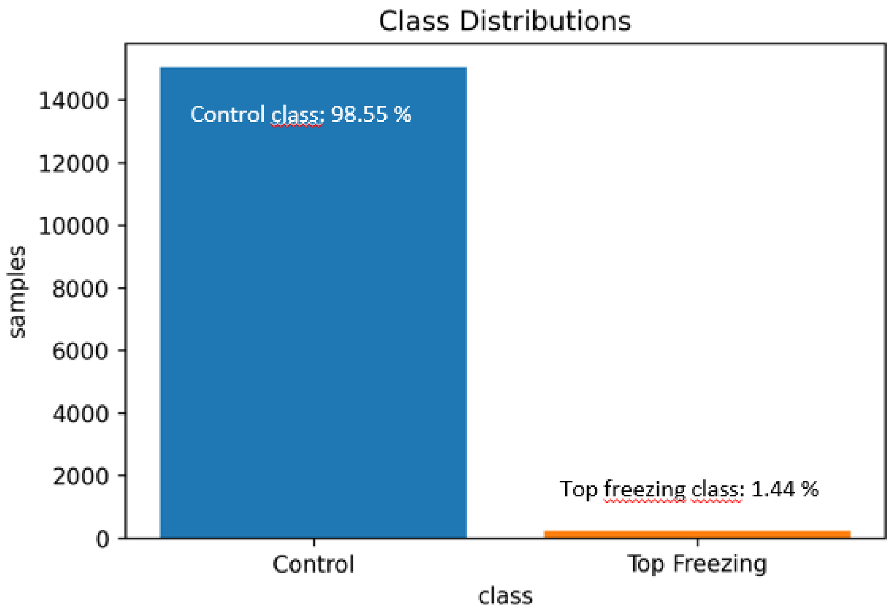


Guidelines for online monitoring application of Big Data to digitize CC plants

- Leveraged critical casting parameters to gain data-driven insights into top-freezing events during continuous casting
- Challenge with imbalanced data distribution
- Explored a range of One-class classification Machine learning models
- Evaluated model effectiveness using the 'Recall' metric:

Recall: What proportion of true anomalies was identified ?

$$Recall = \frac{TP}{TP + FN}$$



Model	Data Set	Recall
One-Class SVM	CC5/Strand1	0.48
One-Class SVM	CC5/Strand2	0.58

Impact

- **Technical breakthrough with:**
  - Minimisation of surface defects on slabs
  - New online measuring techniques for process control
  - Real-time machine supported suggestions for the operator
  - Reduction of energy consumption and increase of yield by decreasing rejected products which have to be scrapped
  - The results can be applied and transferred in short time, after adaptation to the specific plants.

Next Steps

- As quality requirements are high demanding in continuous casting, the plant operation should be improved to increase the quality and avoid product waste
- **Topics for future research projects:**
  - CFD+FEM: Extension of models to compute thermal stresses within the solidified shell, parameter studies, sensitivity analysis and surrogate model development
  - Fibre Optical Temperature Sensors (FOTS) measurement system for monitoring of mould temperatures and inference on melt/strand behaviour in mould
  - Monitoring of crater end position using laser vibrometry
  - Online supervision of the strand surface using cameras and enhancing a defect detection with supervised machine learning

Thank you for your attention!

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