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Séminaire NAFEMS France – Teratec : « IA et simulation numérique »
Arts et Métiers – Campus de Paris
10 juin 2026

Hybrid Physics-AI Twins for Industry: Applications from Manufacturing Processes to Embedded Systems.

Victor Champaney

Core technology

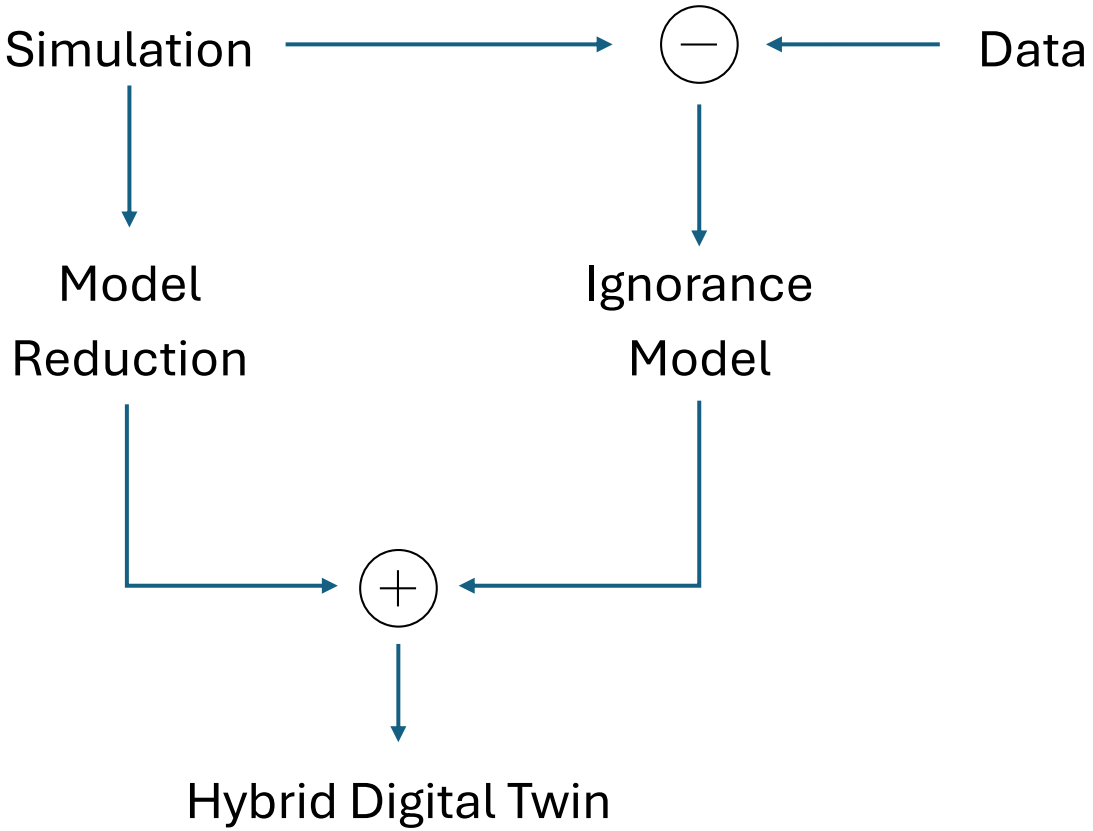
SOFTWARE

AI Algorithm

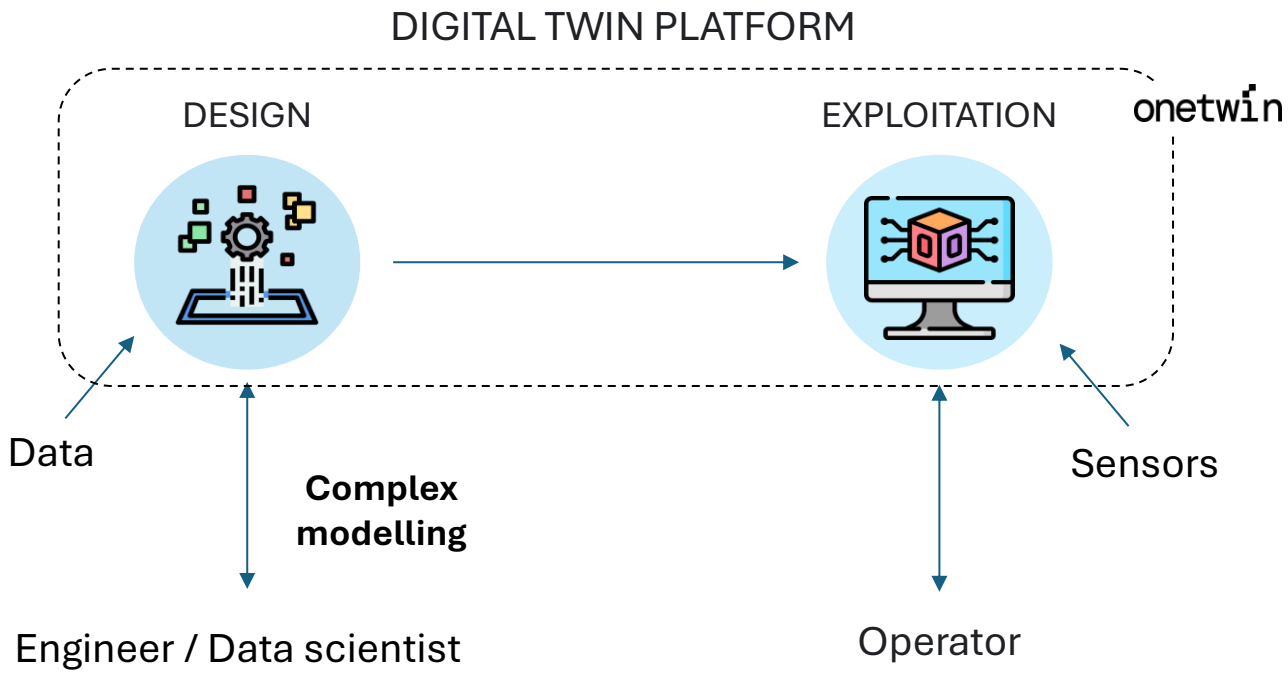
PANDA

Arts et Métiers Sciences et Technologies

cnrs



Vertical Hybrid Digital Twins



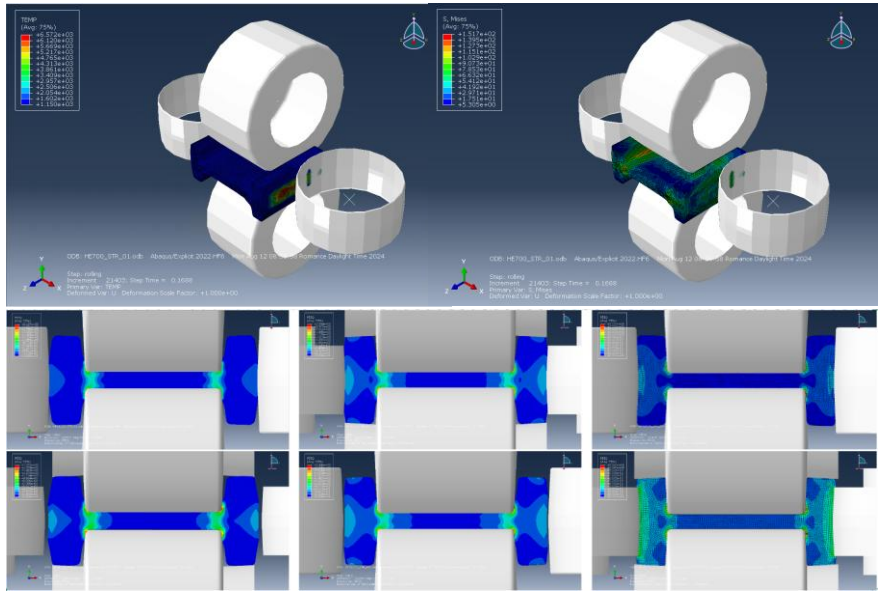
- **Scientific Machine Learning**
- **Linear/Nonlinear MOR and Regression**
- **Large Models/Foundation Models**

→

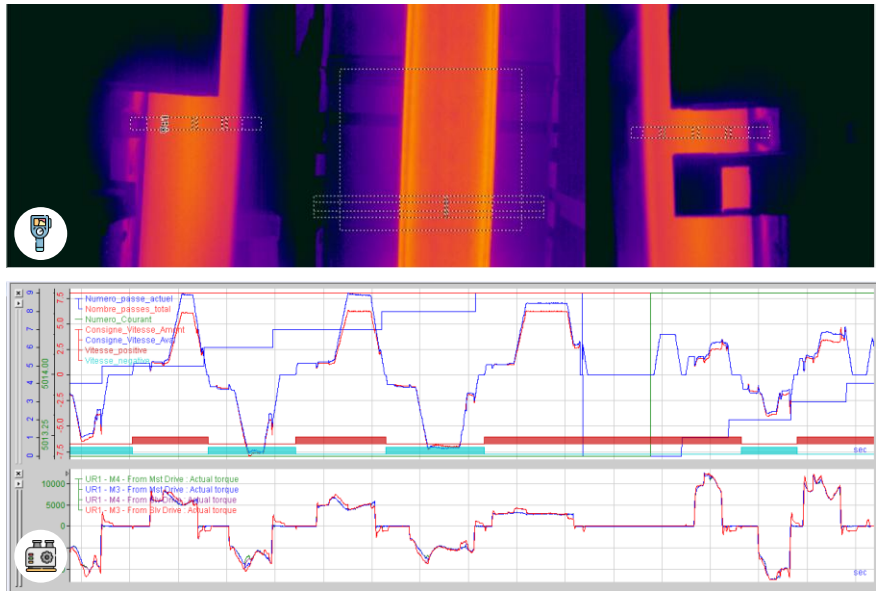
- **Optimal design & manufacturing**
- **Optimal operation & maintenance**
- **Evaluation of numerous scenarios to quantify the risks**
- **Embeddable**

Applications: Hybrid Twin in Rolling Processes

Physics-Based Simulation



Sensor & Experimental Data



Objectives

1 Accelerate evaluation

Replace heavy solver runs by the surrogate to enable fast what-if analysis inside the manufacturing workflow.

2 Reduce the model gap

Bring the simulation–pyrometer error towards a zero-mean, low-variance residual, usable for real-time process control.

3 Explain defects

Use the corrected thermal history as an enriched feature for defect prediction instead of raw process variables alone.

4 Be ready for new data

Design the pipeline so that upcoming solver updates and additional measurement datasets drop in seamlessly.

What is the ROI?

1.3 t/m

~700,000 t/y

~1.5% defect rate

~15 M€/y

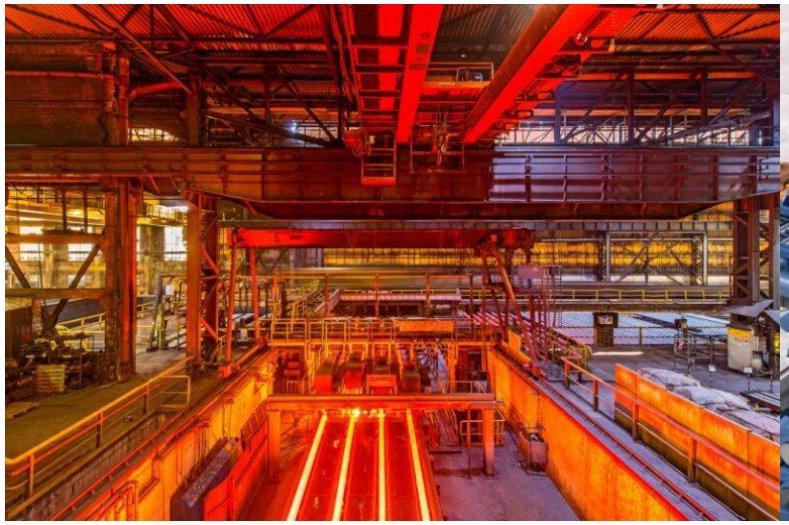
Return logistics (very long/heavy beams)
Reproduction & delays
Contractual penalties
Customer dissatisfaction

–20% defects → ~3 M€/y savings
–30% defects → ~€4.5 M€/y savings
–50% defects → ~€7.5M€/y savings

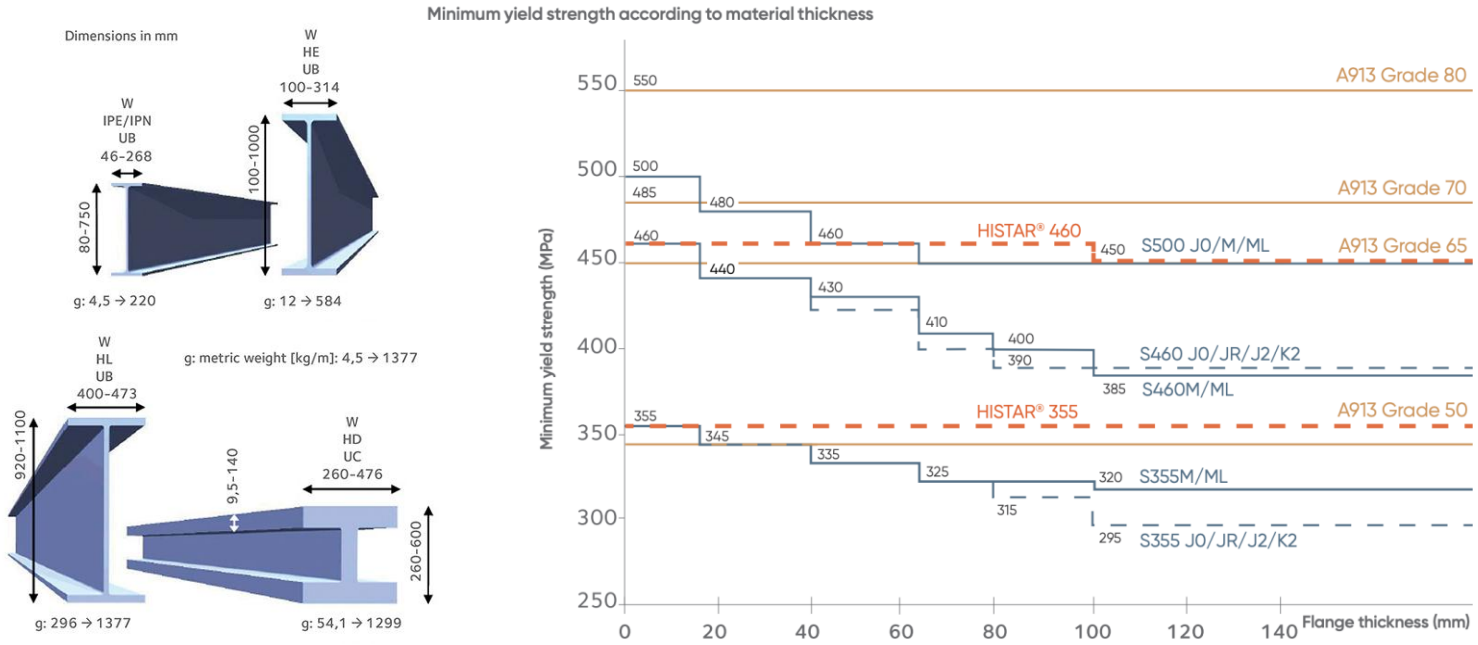
For jumbo beams (~1.3 t/m), even a small defect rate generates **tens of millions of euros in annual losses**.

A Hybrid Twin can deliver **multi-million € savings per year** with a **fast ROI (< 1 year)**.

Problem complexity



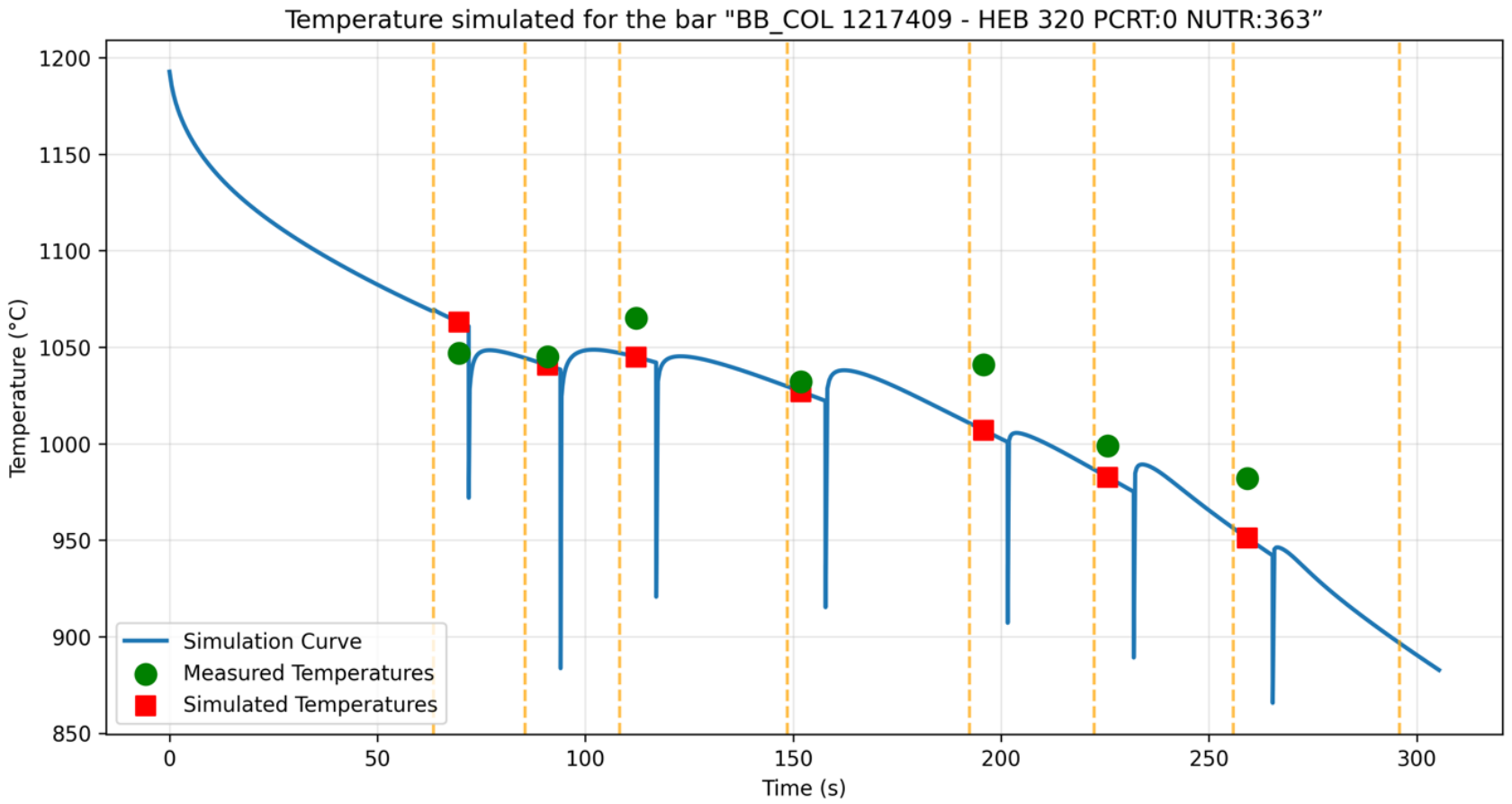
Many steps process means high variability

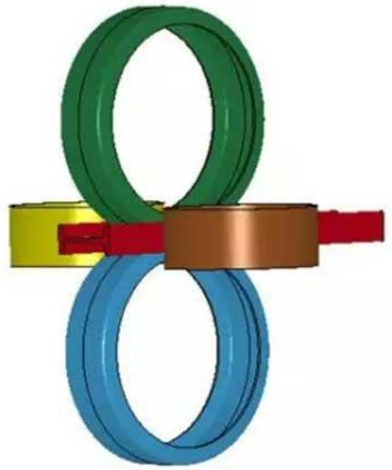


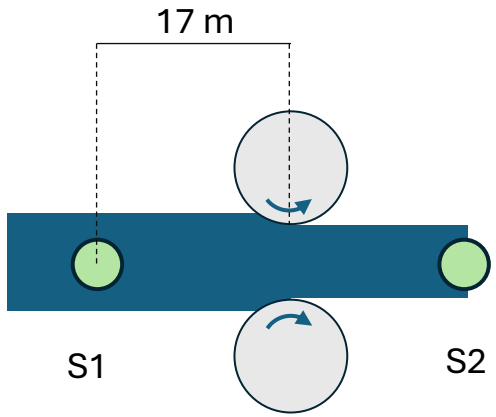
Many material, process and environment parameters

35 input features (geometry, chemical composition, steel grade, process parameters)

Lack of data



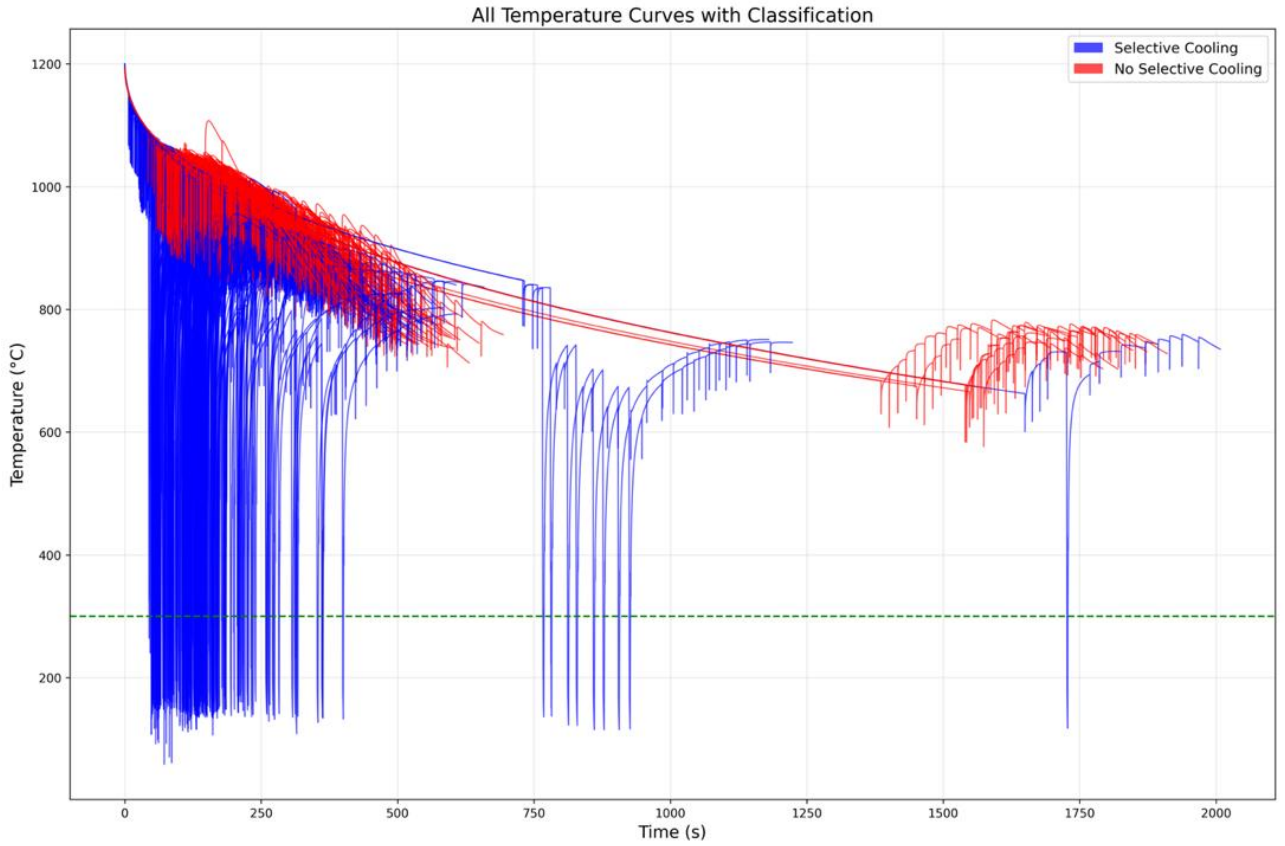


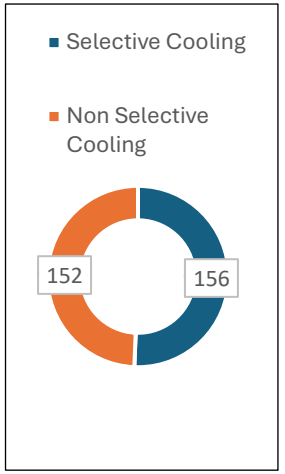


Sparse measures and different number of passes

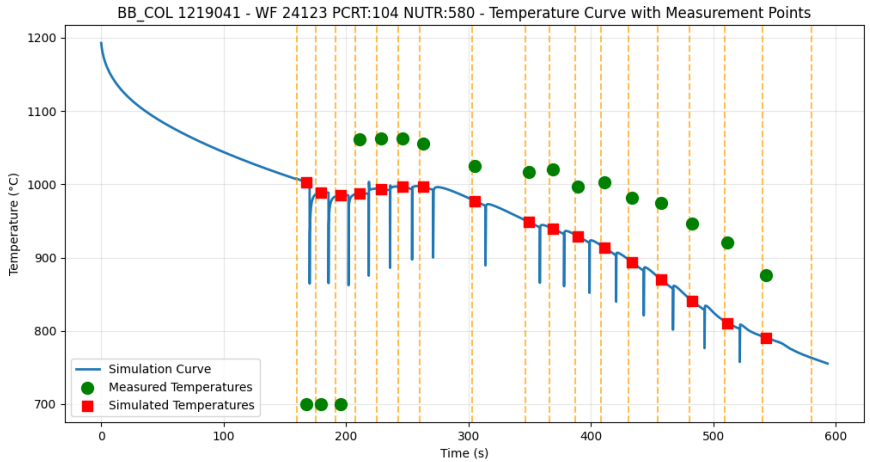
Even less...

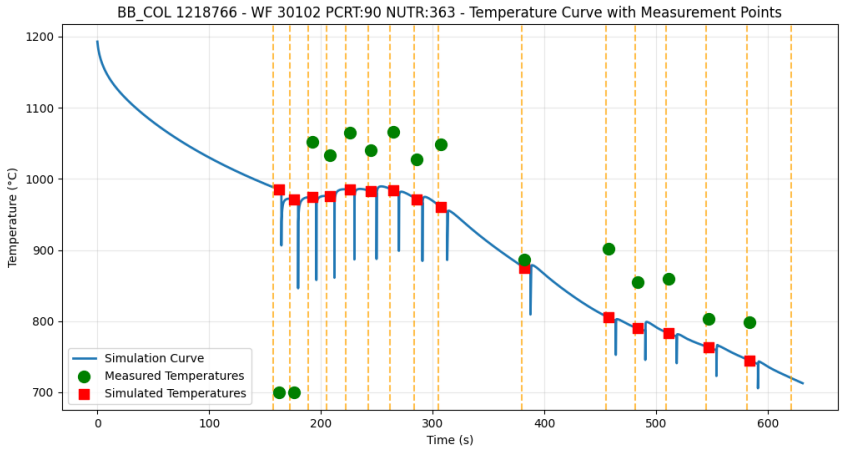

1

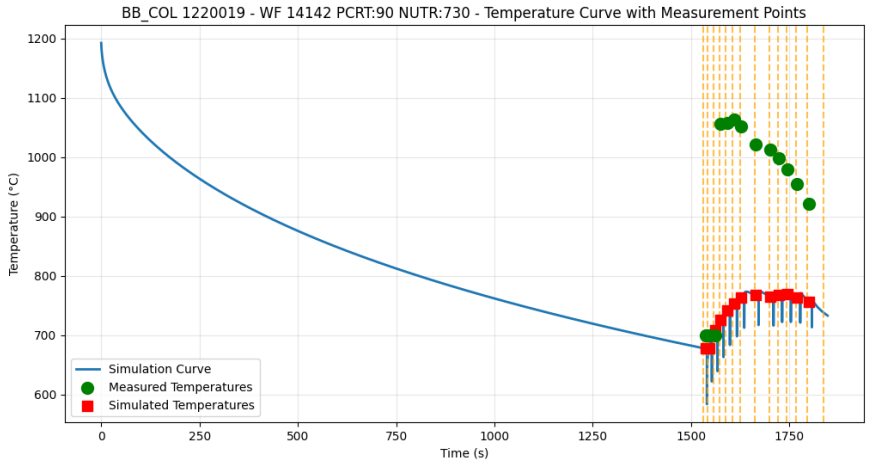

All Temperature Curves with Classification
Selective Cooling
No Selective Cooling
Temperature (°C)
Time (s)
1200
1000
800
600
400
200
0
250
500
750
1000
1250
1500
1750
2000

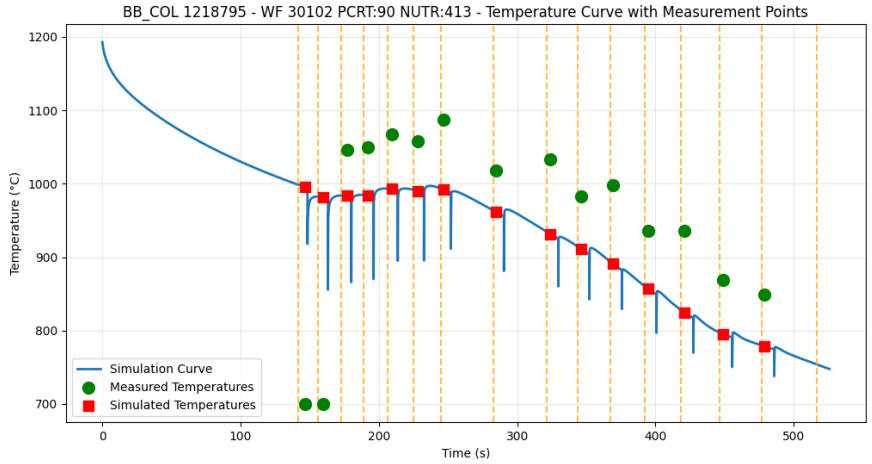

Selective Cooling
Non Selective Cooling
152
156

Even less...









Detection and data reduction

And lots more ...

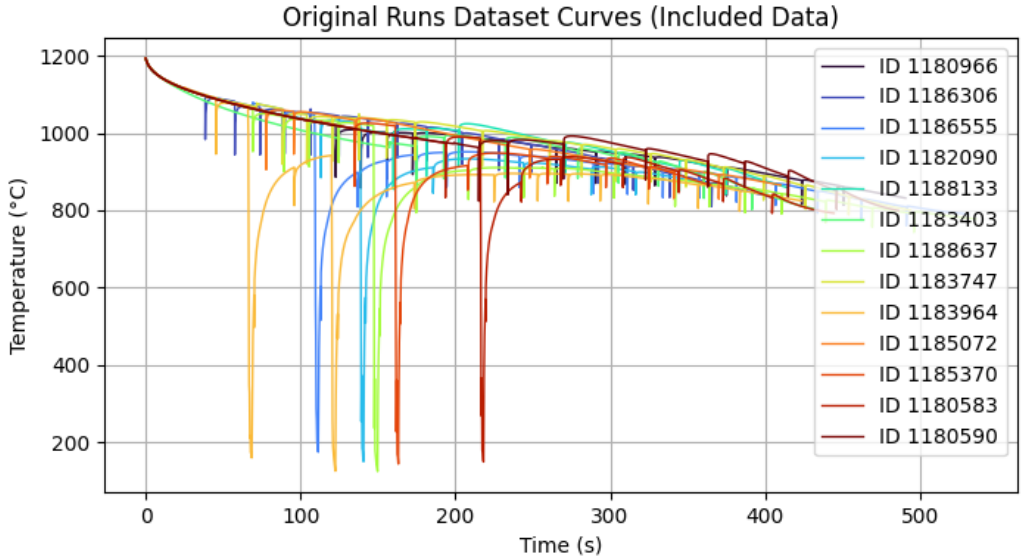
The main challenges

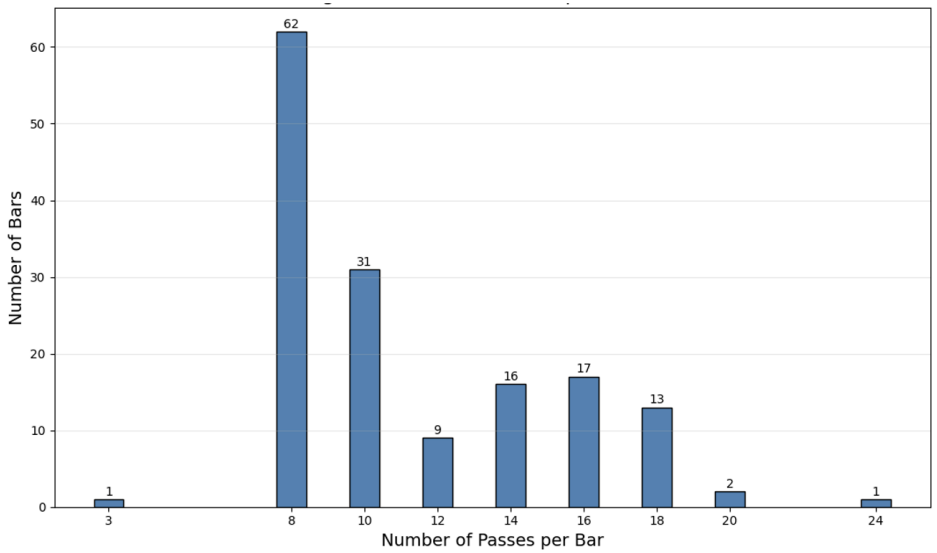
Physics model is not enough

Simulation vs. pyrometer on 152 bars shows gaps from −410 °C to +330 °C (σ = 93.5 °C, R^2 = −0.18).

Data alone is not enough

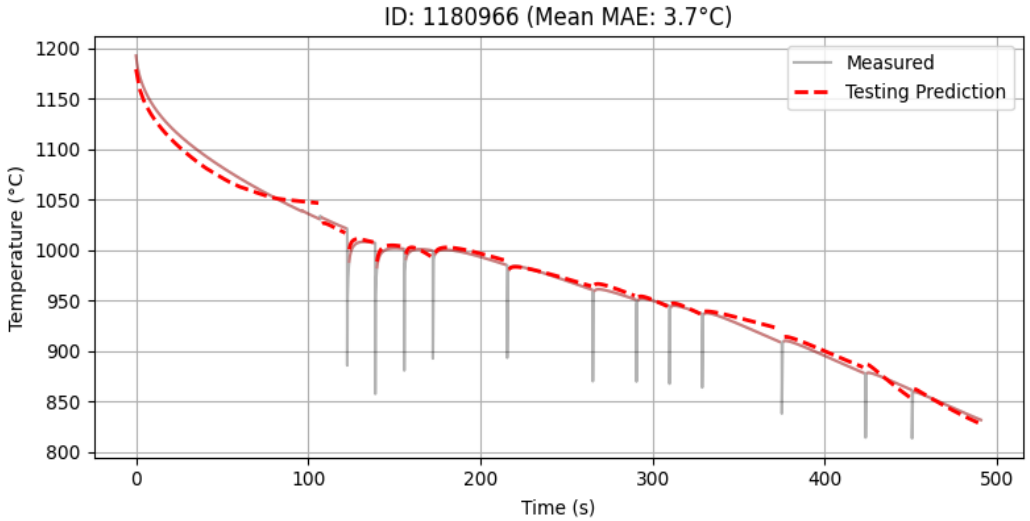
~84% missing values; best correlation with defect 16 is ~0.07.



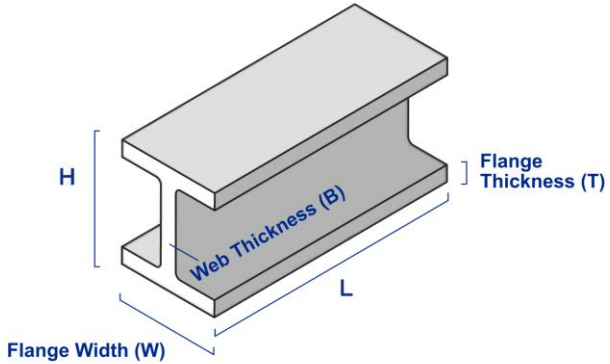


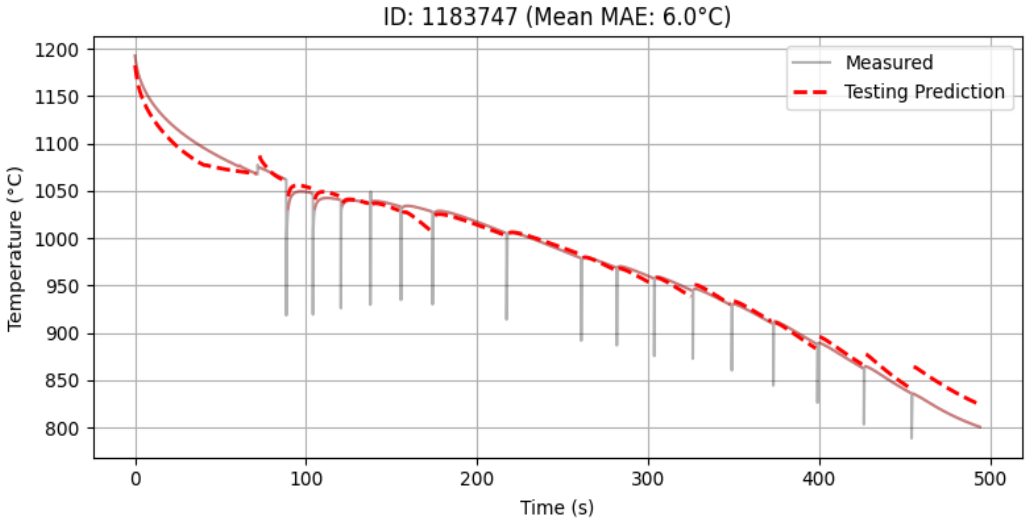
Surrogate incremental (by pass) model

Product Parameters
(26 features)
- Chemical composition (carbon, manganese, silicon, etc.)
- Initial dimensions (initial flange thickness, initial flange width, etc.)
- Final dimensions (final flange thickness, final flange width, etc.)



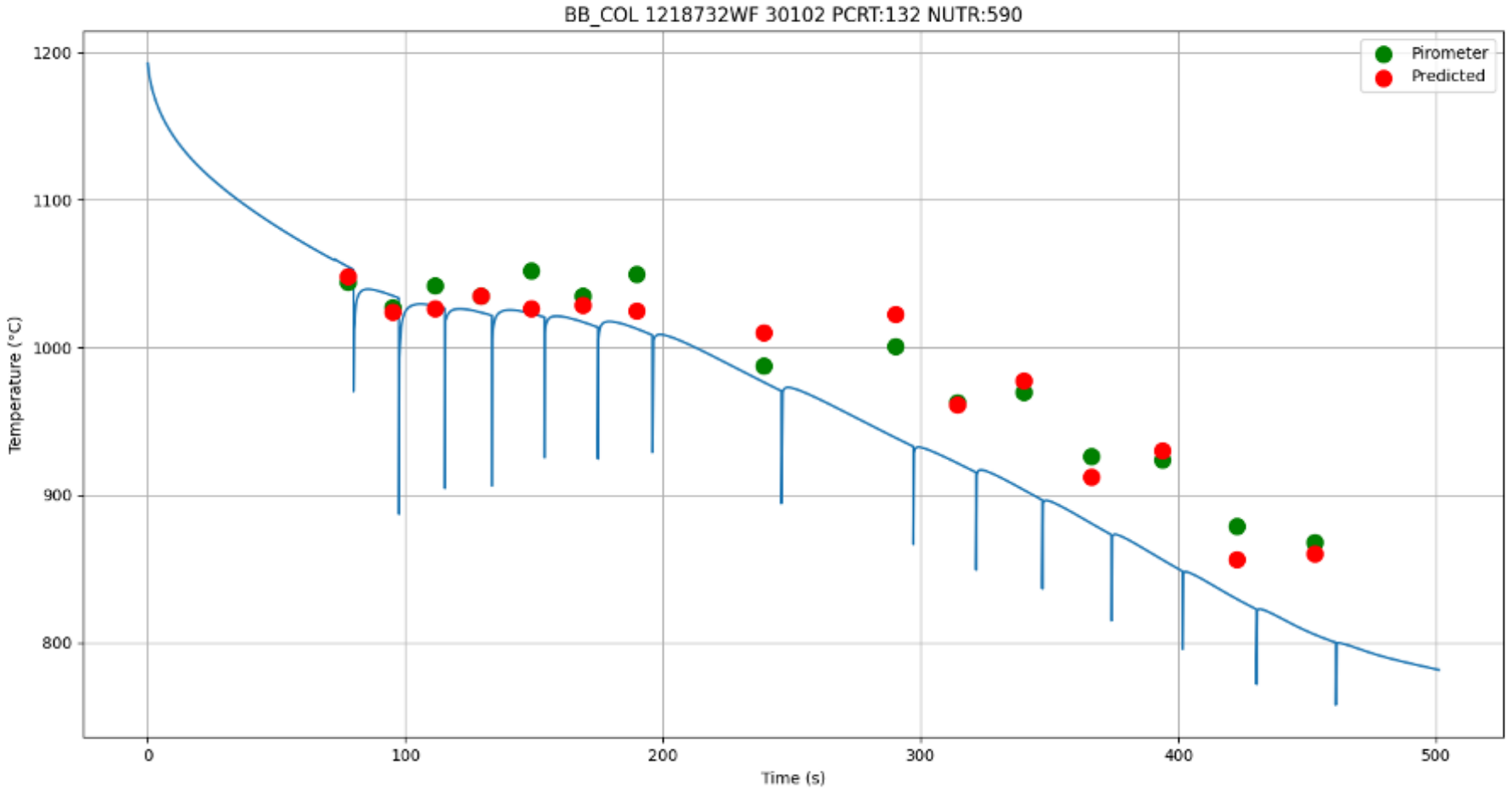
Pass Parameters
(7 features per pass)
- Flange width during the pass
- Flange thickness during the pass
- Web height during the pass
- Web thickness during the pass
- Time between passes
- Rolling speed
- Maximum entry temperature for each pass



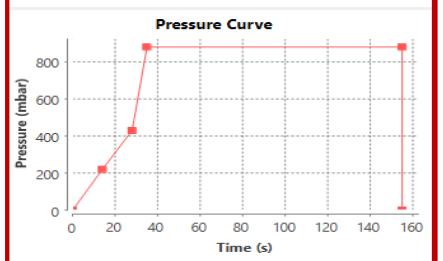
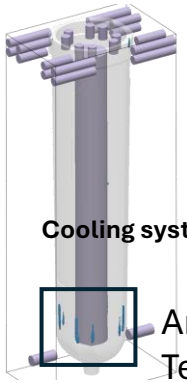
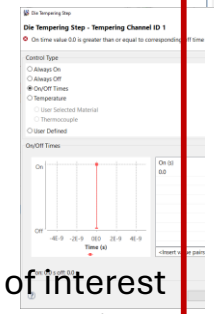
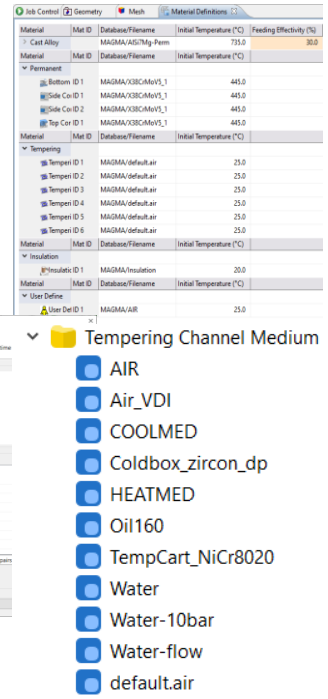
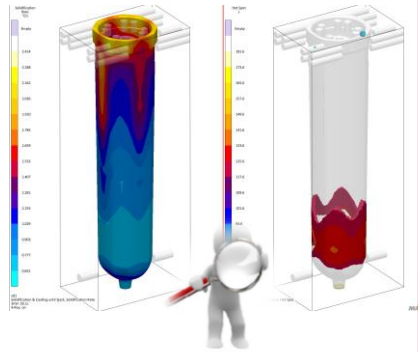
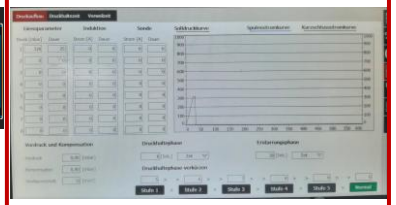
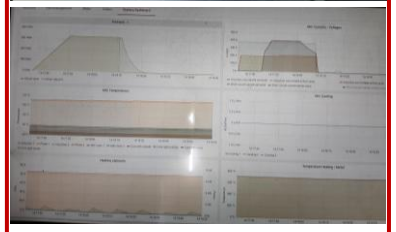
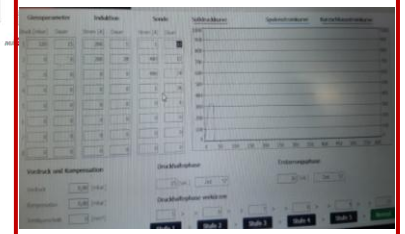


Hybrid gap model

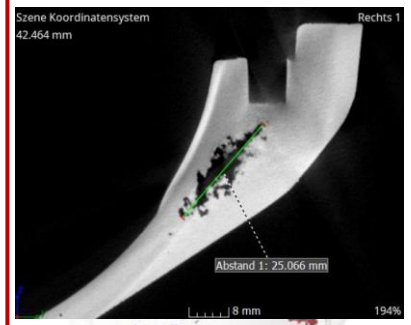
- Curated dataset: 152 → 111 (sensor filter) → 82 bars (|gap| < 100 °C).

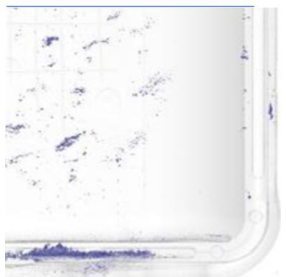


Casting Processes

Simulation Boundary conditions	Material Properties	Simulation Results	Process Parameters
   Cooling system Area of interest Temp. gradient Hot Spots		  Identify Area of interest	  

Goal: Sealed Housing by 10bar

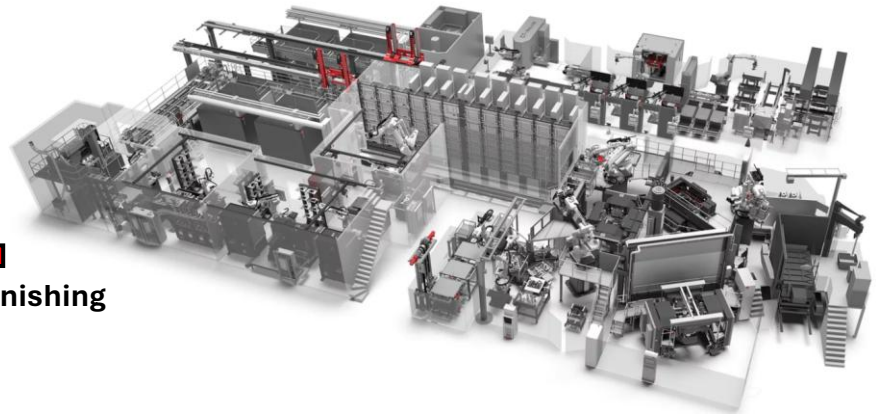




Hybrid Twin in Casting

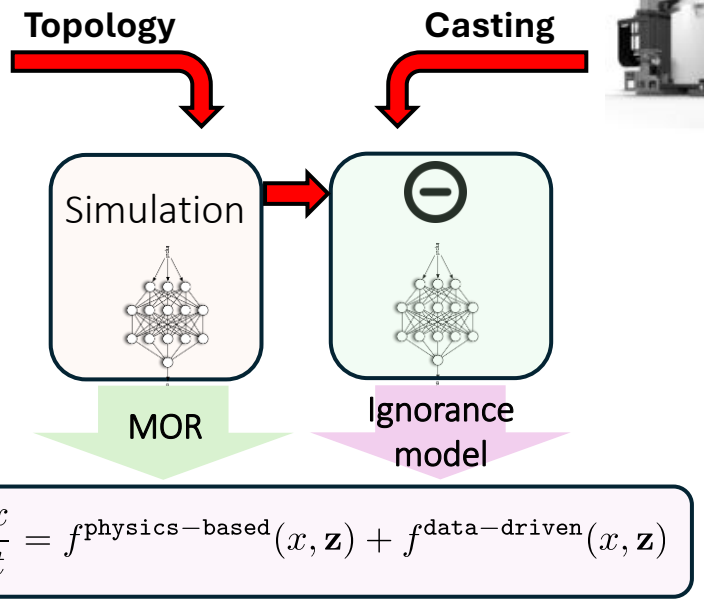
Product Family
1. Product Variation
2. Mold Variation
3. Requirement variation
4. …

Manufacturing Process
1. Pressure Curve
2. Cooling
3. Ejector
4. …



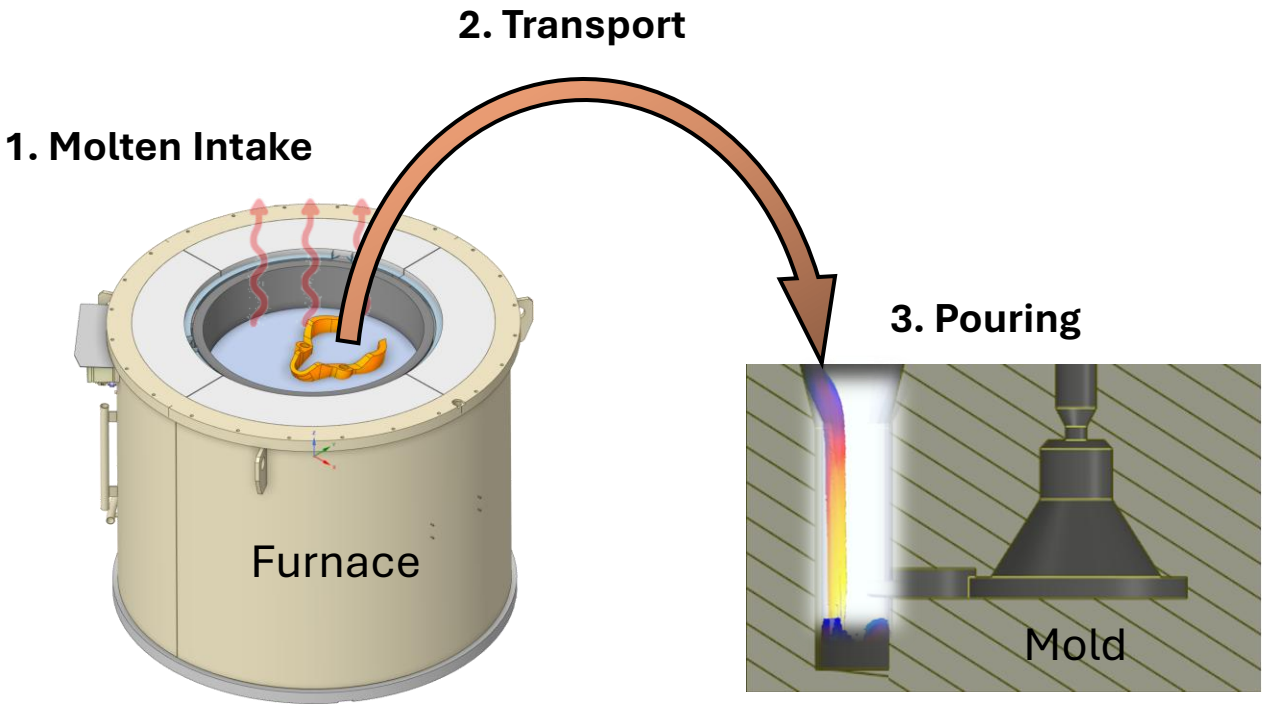
Finishing

Product Goal:
1. Minimize scrap
2. Maximize end quality
3. …



Productivity Goal:
1. Reliable Process
2. Resilient (ability to adapt to product variation)
3. …

Overview of Gravity Casting



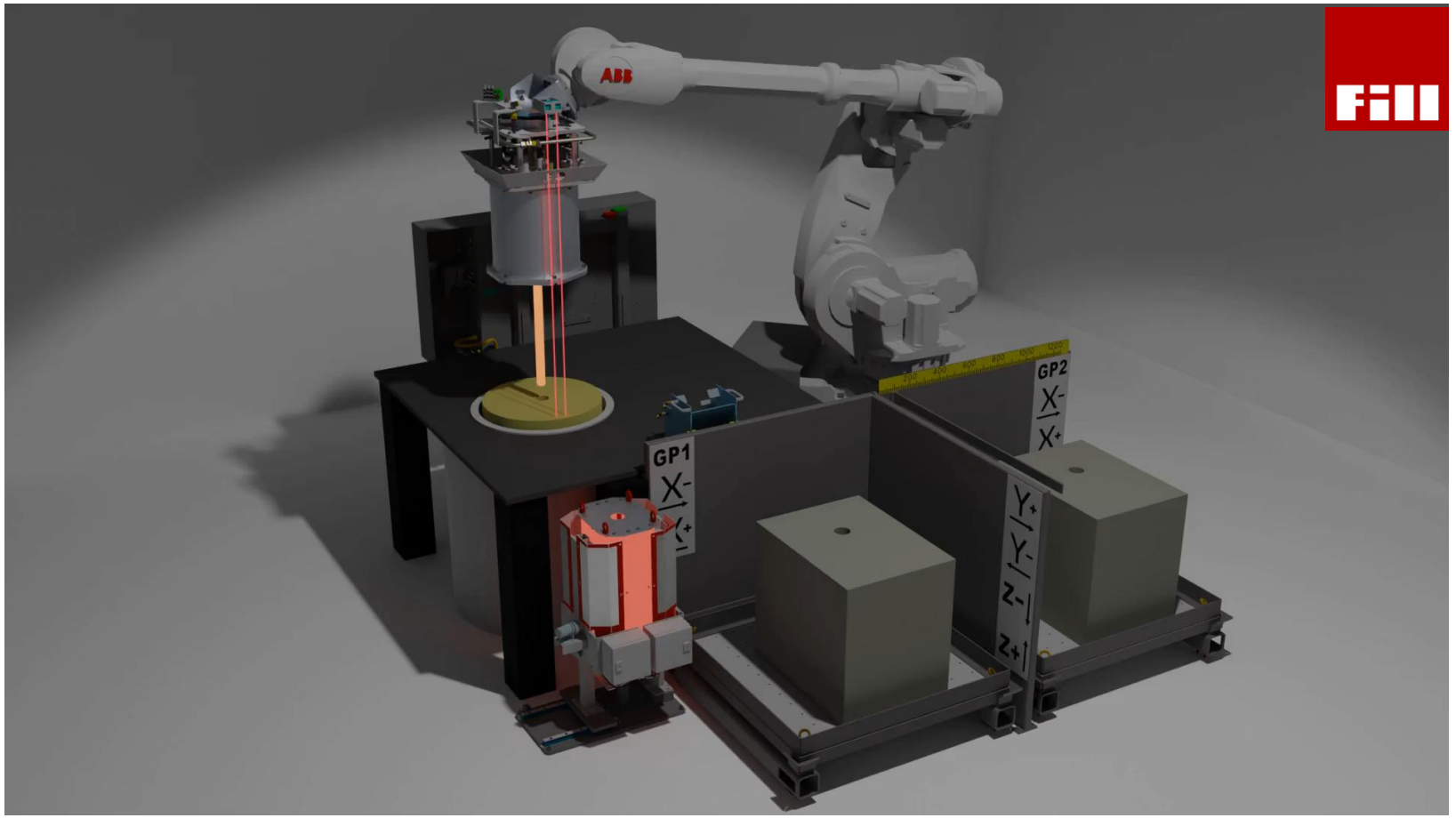
1. Moten Intake
- Temperature Loss
- Collect impurities from the molten surface
- …

2. Transport
- Temperature Loss
- Labor Risk
- …

3. Pouring
- Temperature Loss
- Poor Consistency
- …

Molten metal is poured into a mold and fills it naturally under the force of gravity.

Robocasting



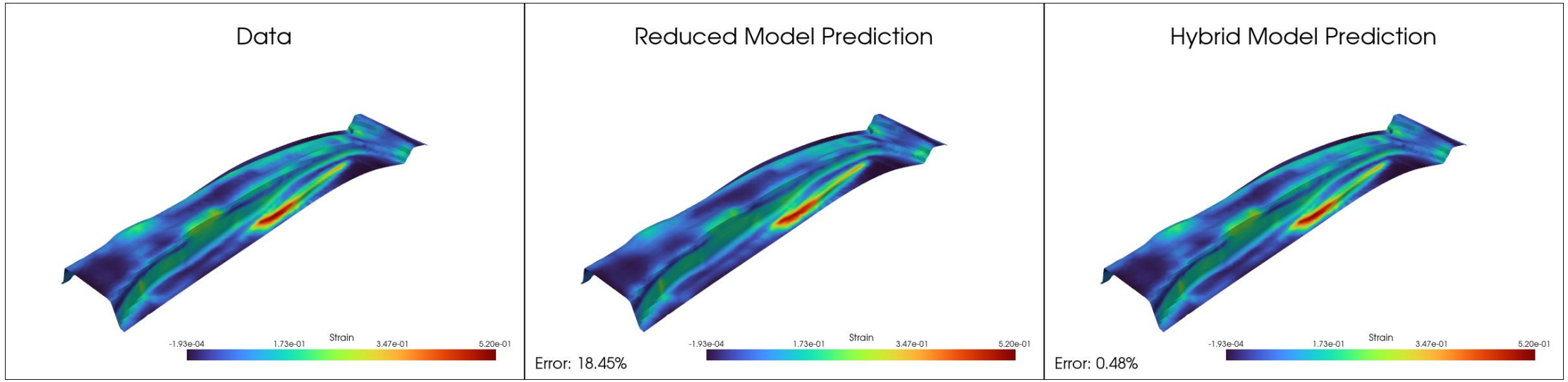
1. Take metal: controlled suction
2. Move metal: robot transport
3. Deliver metal: controlled injection

A robotic system builds a part layer by layer by extruding a paste-like material without using a mold.

Hybrid Twin role in Robocasting

	1. Molten Intake	2. Robot Motion	3. Molten Dosage
Controllable parameters	• Vacuum pressure • Intake time • Immersion depth • Metal temperature	• Robot speed • Trajectory • Waiting time	• Flow rate (mass flow) • Pressure during release • Nozzle position • Pouring speed profile
Hybrid twin	 how much metal is captured	temperature loss during transfer	filling behavior, turbulence, defect formation
	 • temperature variation • viscosity changes • bath level changes	• speed • timing	• flow rate curve • injection timing
	 underfilling / overfilling inconsistent dosing	metal cooling bad flow in mold	porosity / air entrapment incomplete filling

Hybrid Twin in Stamping



- Improvement of stamping process models
- Optimal process parameters to minimize defects such as wrinkling, thinning, springback, and tearing
- Real-time prediction of forming behavior and adaptive process adjustments

Contact Us

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