Utilization of Digital Twins in a rolling plant for Aluminium

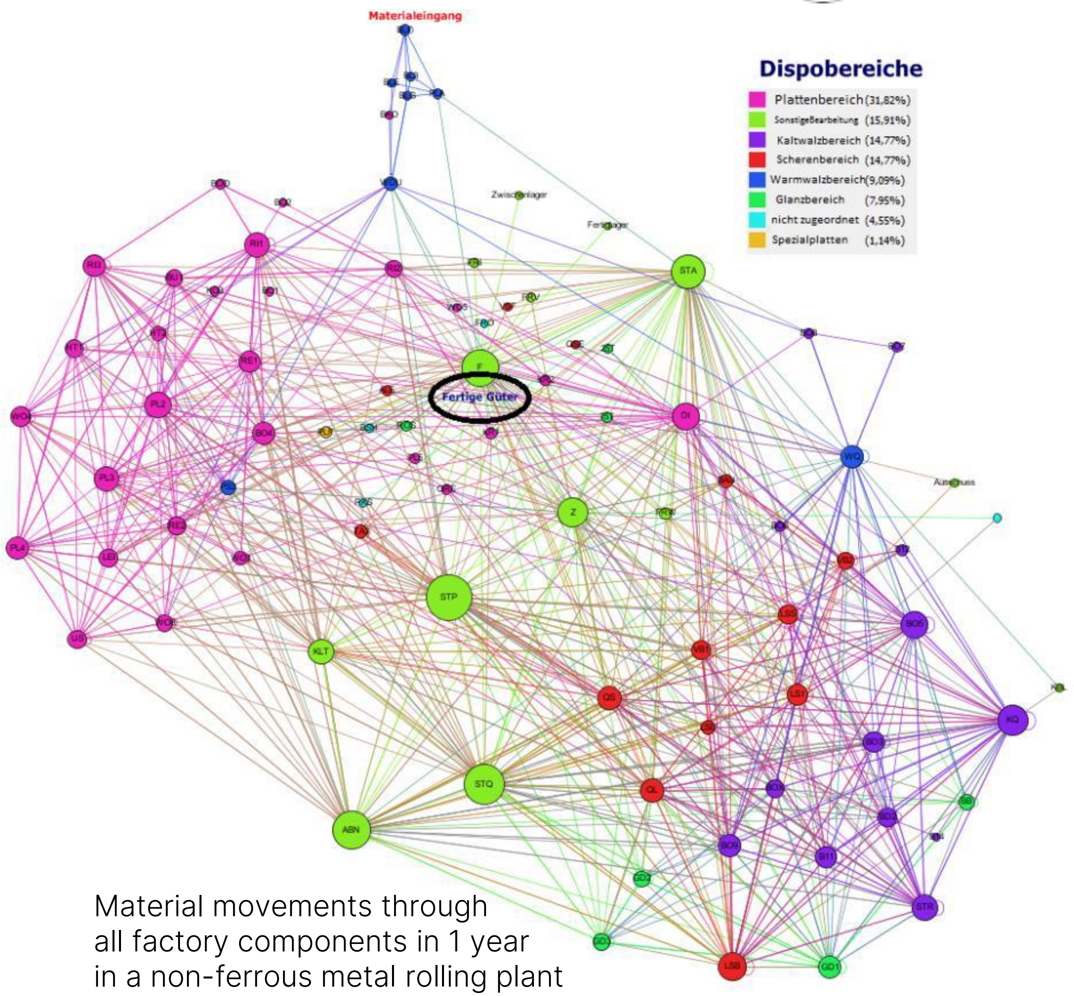
Dr. K. F. Karhausen, Speira F&E Bonn

Industry 4.0 in Rolling Mills

Typical i4.0 applications usually cover big data analytics, logistics or supply chain topics of short and aligned production operations (e.g. automotive assembly line).

The Rolling Process Chain is an exceptionally long production route on a single workpiece!

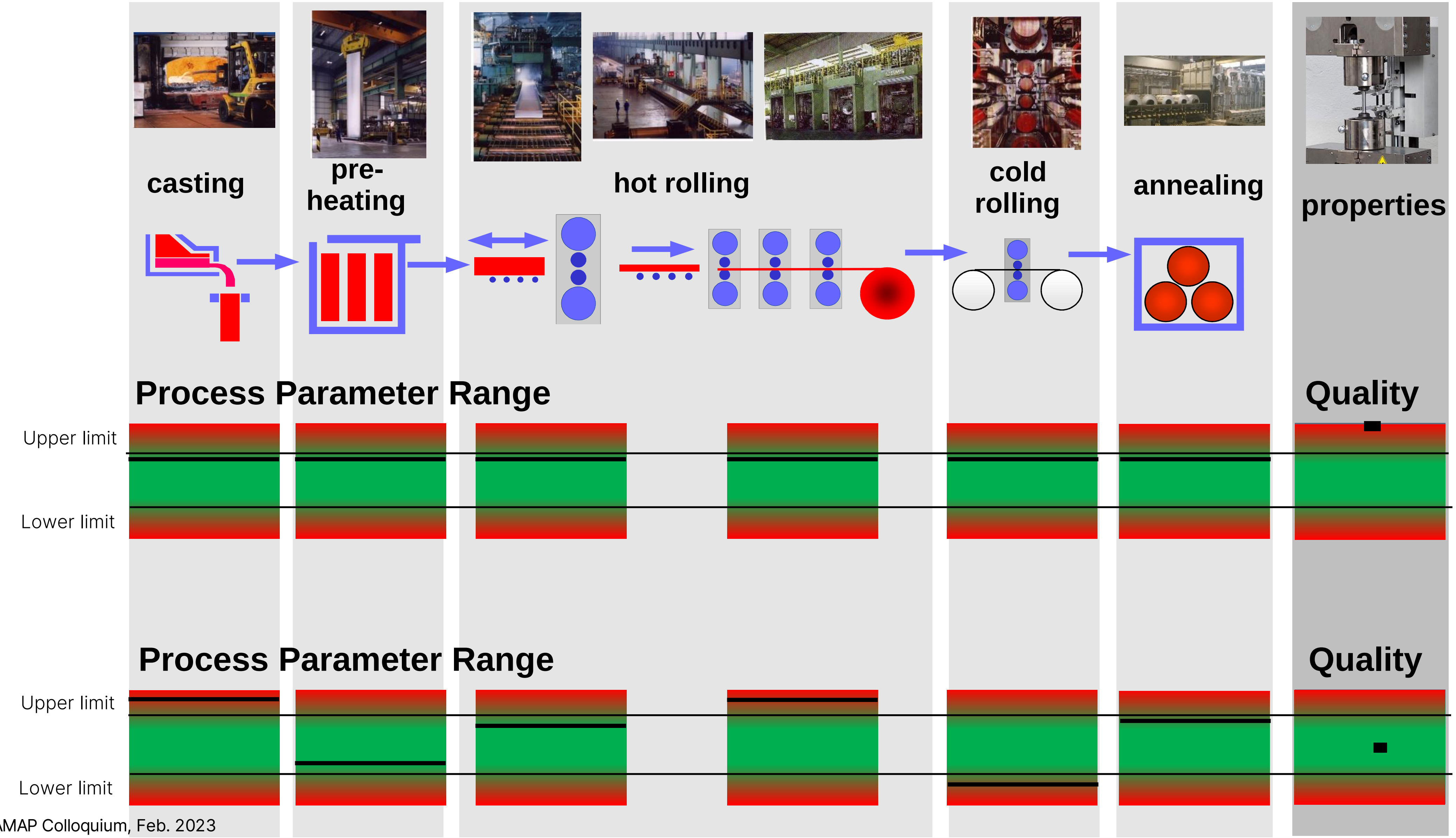
- Most rolling mills are historically grown and equipment and modernizations are from different stages and suppliers
- Sensors are available for mill control or for process documentation (Industry 3.0)
  - Many sensors of process data
    e.g.: temperature, force, speed, position, valves, ...
  - Few or no sensors of quality data
    e.g.: grain size, texture, strength, elongation, flatness, surface ...
- Production is driven by orders and machine availability, where the orders are based on fixed production recipes



Material movements through all factory components in 1 year in a non-ferrous metal rolling plant (34 products on 81 machine components) [*]

[*] Gram, Biedermann: Erhöhung der Ressourceneffizienz durch ein Modellierungs und Analysetool zur Unterstützung kognitiver Prozesse

Consequences of fixed production recipies



Pre-Requisite for Industry 4.0

Digital Twin of a Coil

Source: „Anwendungsbeispiele von Industrie 4.0 in der Metallindustrie“ • Prof. Dr. Harald Peters, BFI

Without a suitable material tracing, related to workpiece, position and orientation, Industry 4.0 cannot be implented efficiently in the metals industry!

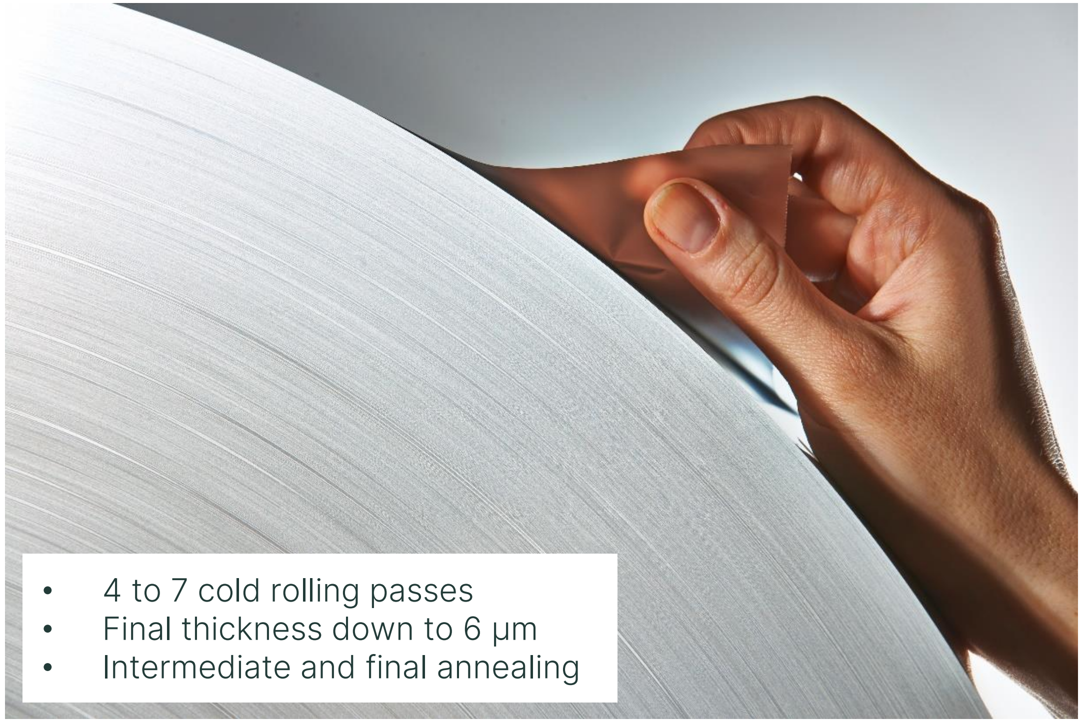
Implementation
Grevenbroich Plant – Foil Series 2

Process / value creation chain foil rolling

Hot & Cold rolled strip (AluNorf)

- DC Casting
- Hot Rolling
- Cold Rolling to ~0.7 mm

Foil rolling Series 2 (Grevenbroich)

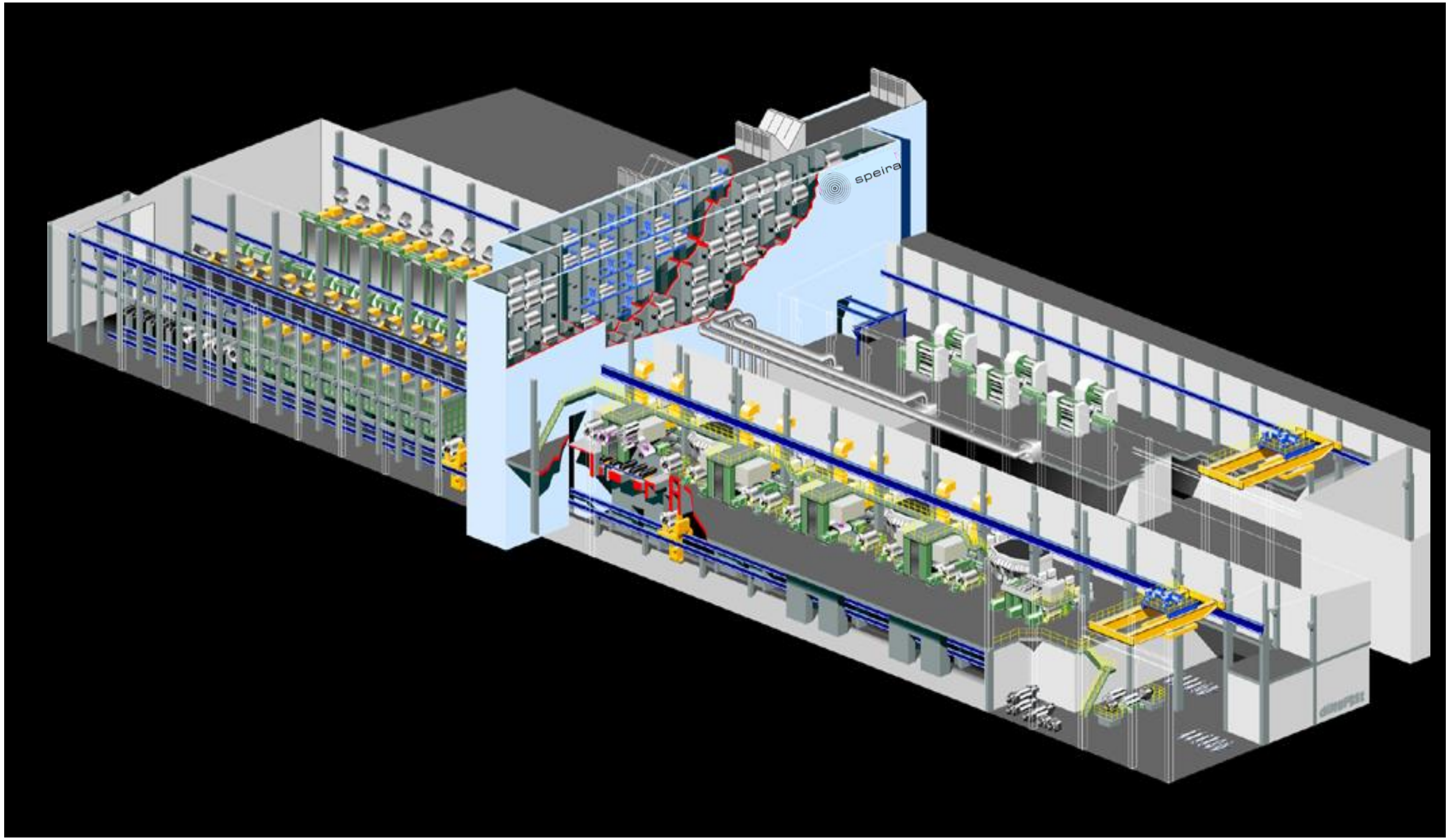


- 4 to 7 cold rolling passes
- Final thickness down to 6 µm
- Intermediate and final annealing

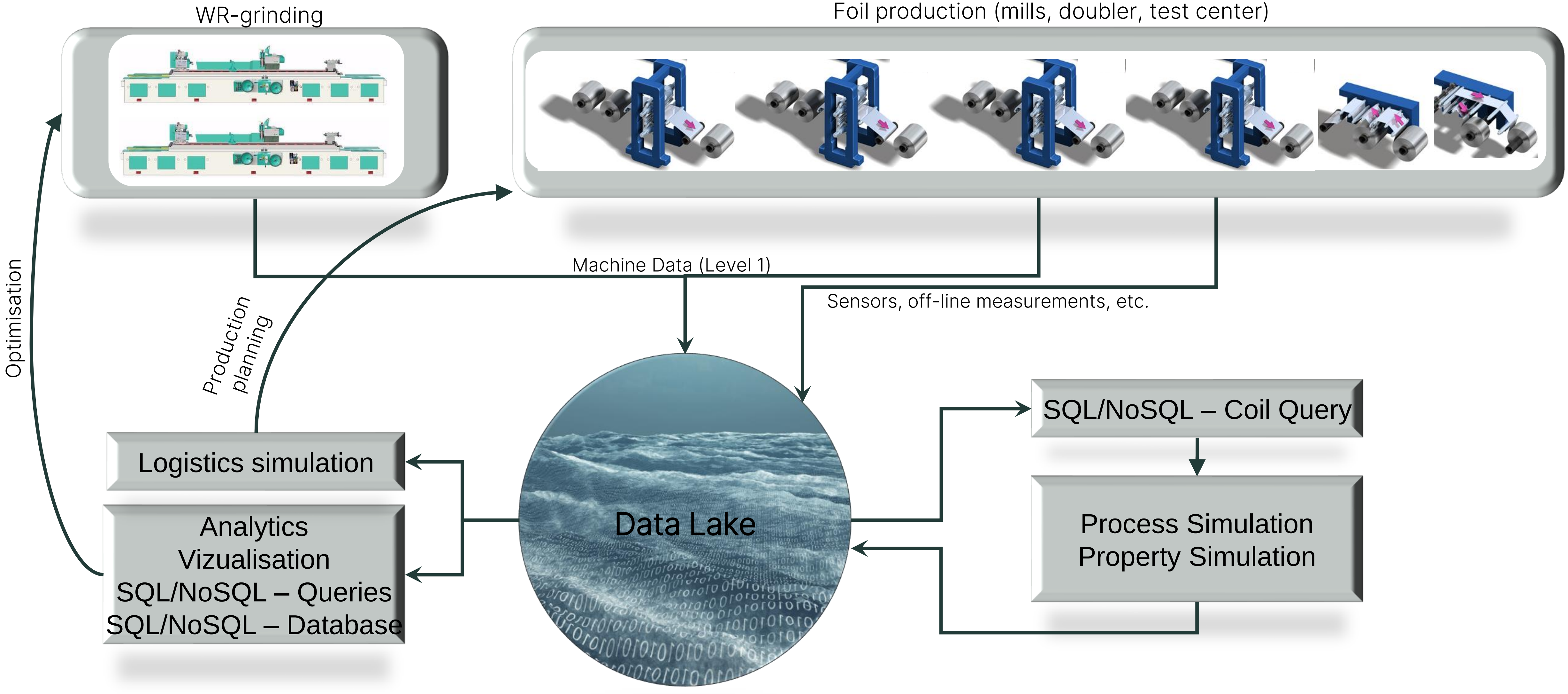
Production Foil-Series 2

Definition of the Cyber Physical System CPS

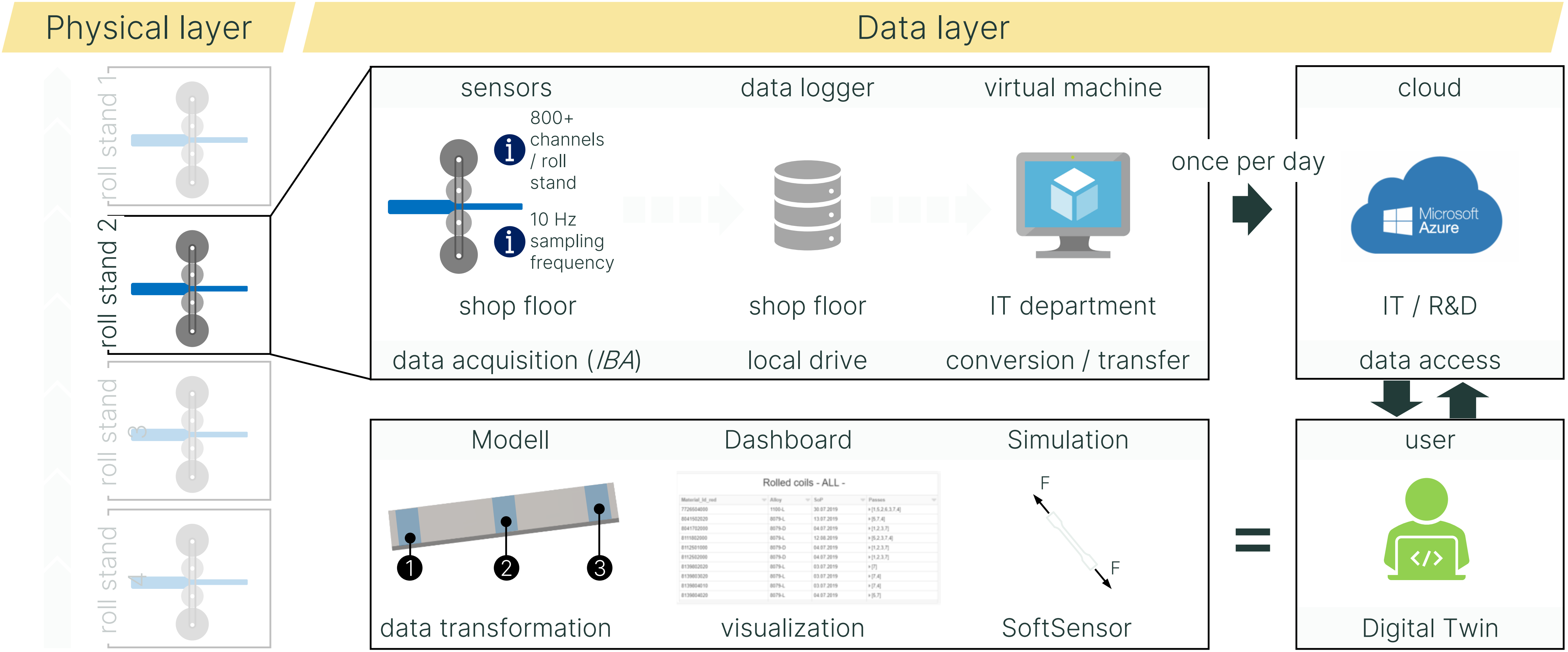
- o Pre-Processing in AluNorf
- ✓ Soft-Annealing
- ✓ Cooling
- ✓ 5 CR passes
- ✓ Cooling after each pass
- ✓ Doubling
- ✓ 1 CR pass to 6 µm
- o Separating & Slitting
- o Final annealing



Data Organisation of i4.0 (Series 2)



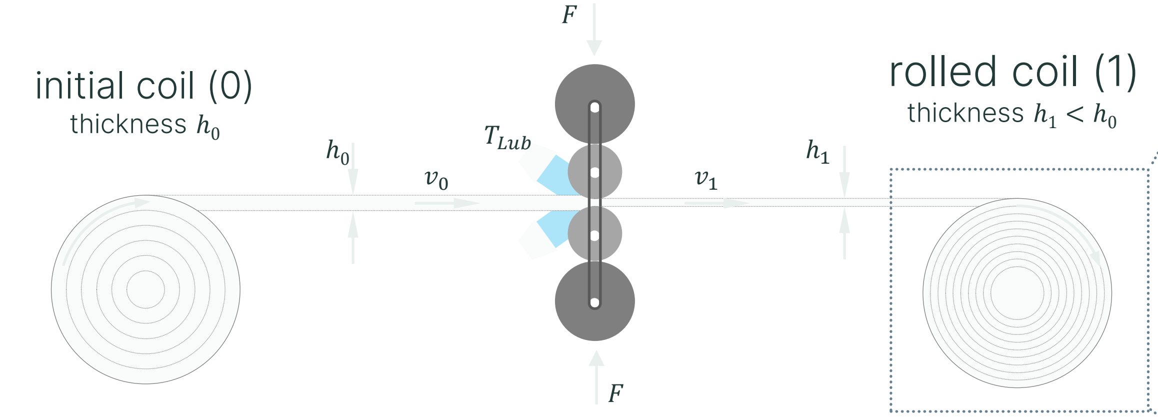
Demonstration Digital Twin prototype



Digital Twin of Coil

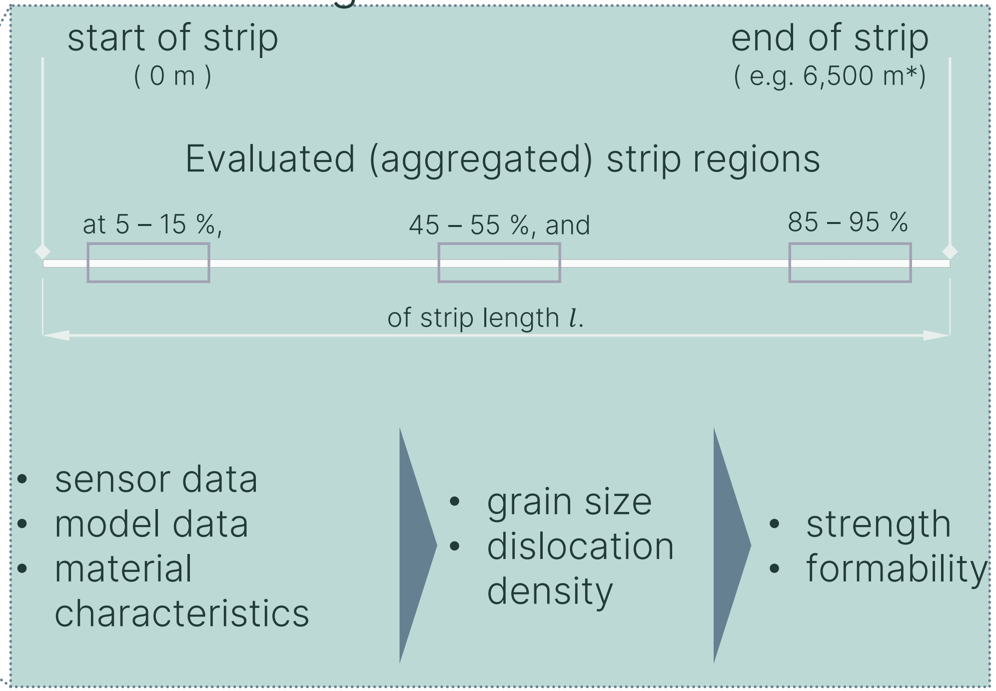
speira

Rolling Process



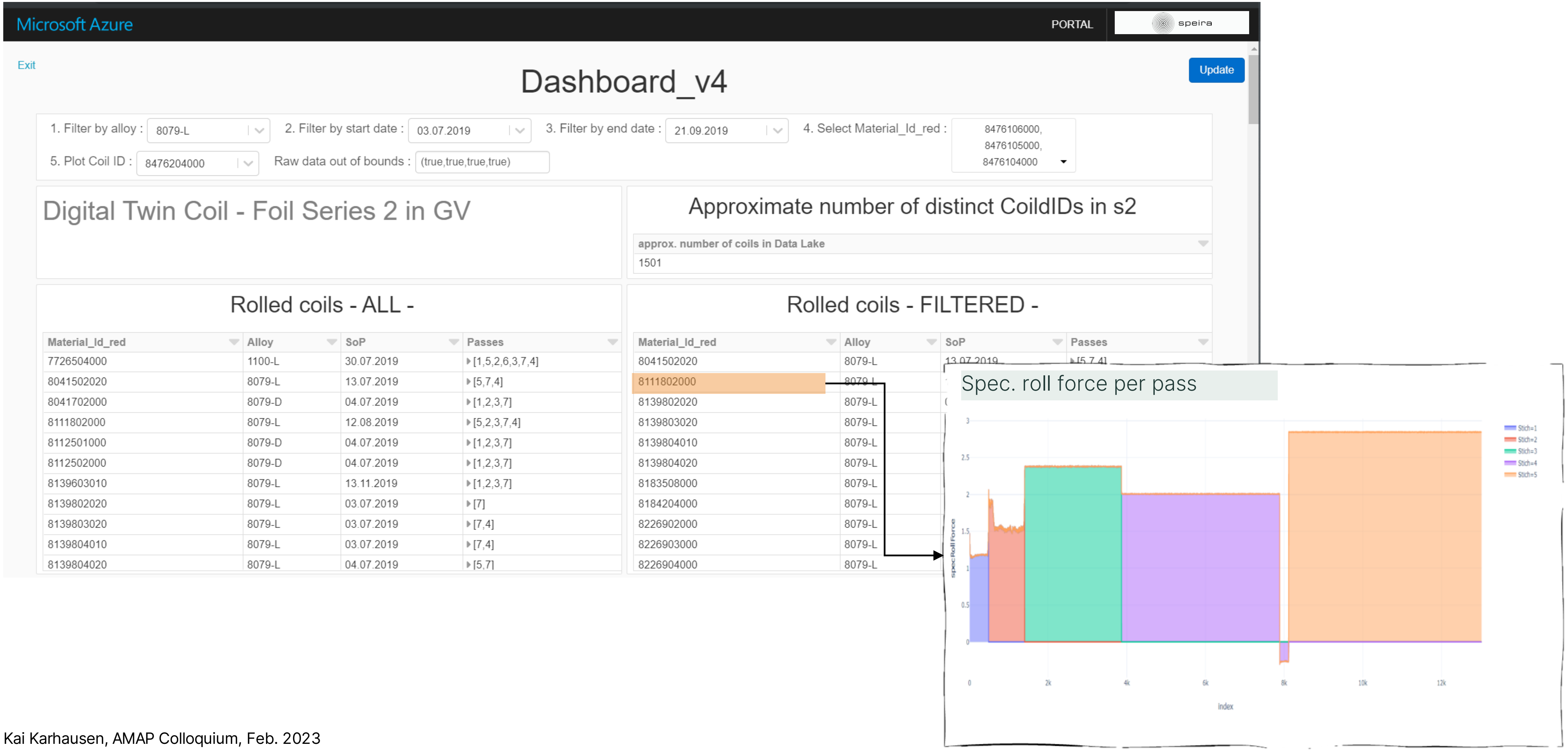
T_{lub} ... lubricant temperature | v ... strip speed | F ... rolling force

Digital Twin Coil



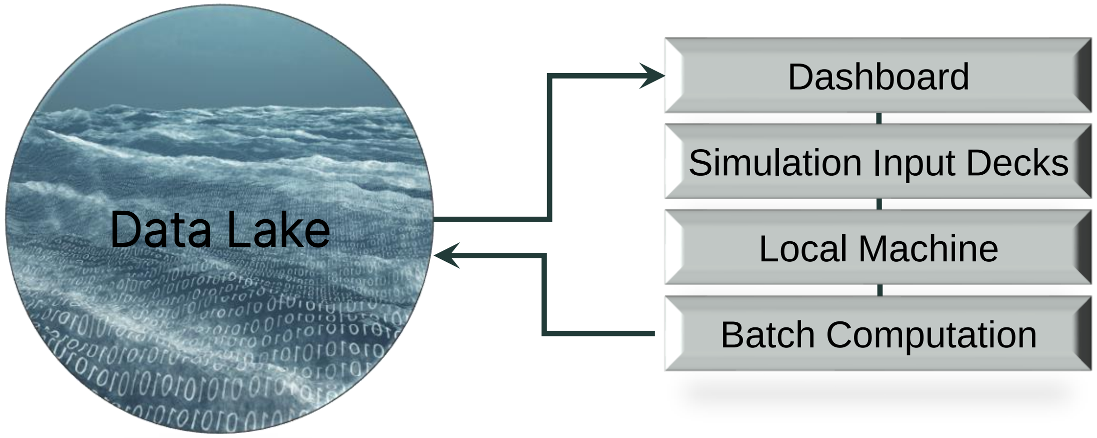
➢ Transformation of time oriented data to location oriented data

User Interface: Dashboard



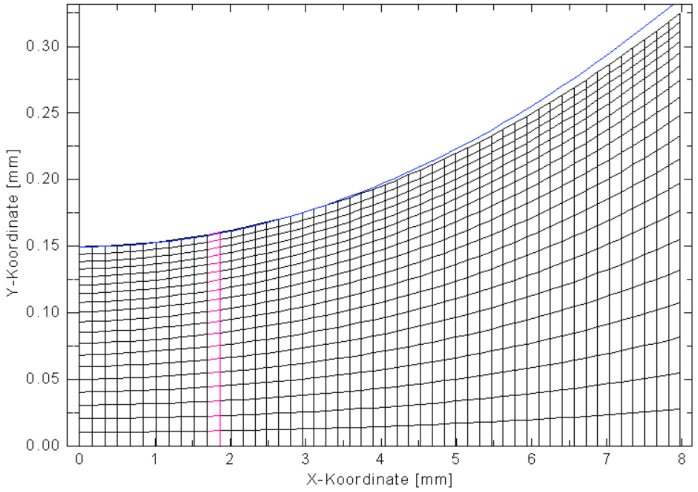
02 Digital Twin Components

Process Simulation: ROSE

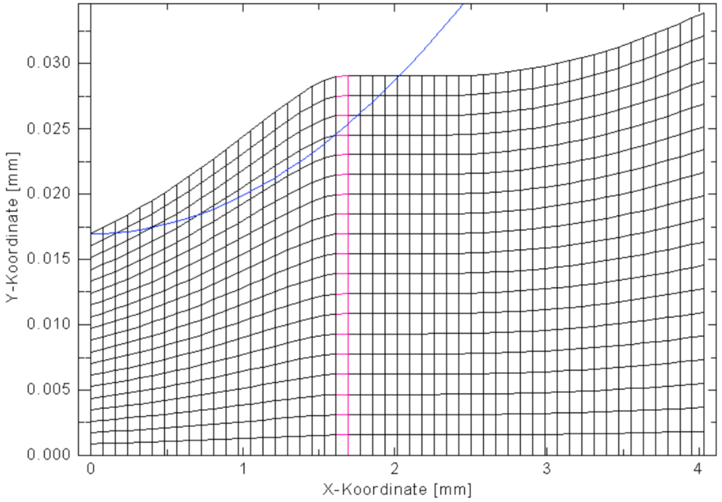


Simulations are performed by **ROSE** (**RO**lling **S**imulation **E**nvironment), an in-house development of Speira with a focus on fast solvers.

Pass 1 (Cold Rolling)



Pass 4 (Foil Rolling)



Rolling Simulation Environment - ROSE

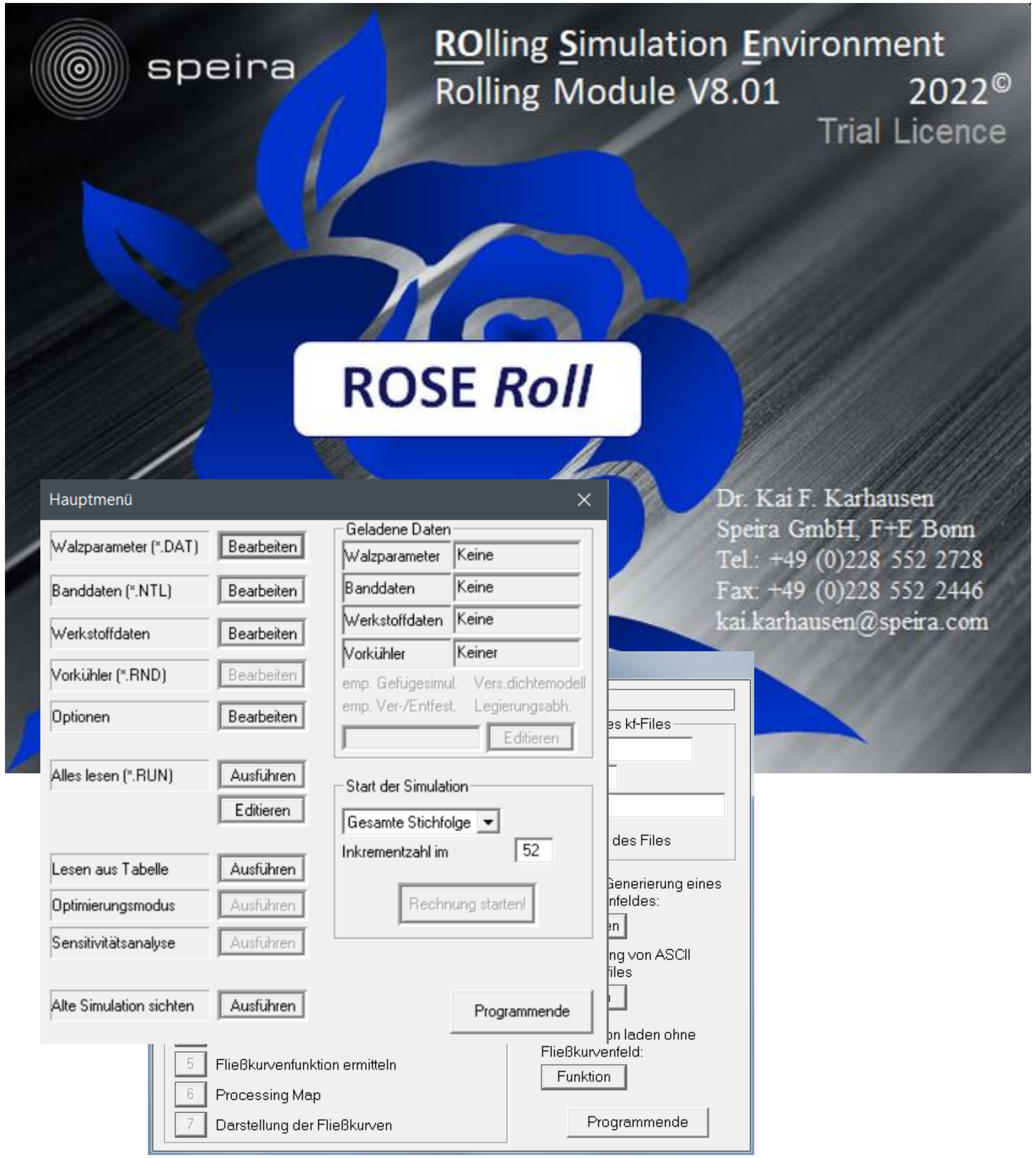
speira

Material Modules (limited texture information)

• **ClaNG***	Classical Nucleation and Growth
• **RoseRoll**	Thermomechanical Rolling
– 3IVM+*	dislocation based work hardening and recovery
– StrucSim	(partial) recrystallisation
• **RoseAnneal**	Thermal Treatments
– 3IVM+*	dislocation based recovery and recrystallisation
– StrucSim	(partial) recrystallisation
• **RoseWind**	Thermomechanical Coil Winding
– 3IVM+*	Creep

Material Modules (full texture information)

• **Gia***	Deformation Texture
• **Core***	Recrystallisation (Nucleation and Growth)



* In co-operation with IBF & IMM at RWTH Aachen and MPIE Düsseldorf

Physically based Statistical Material Model

Work hardening and Recovery:

- Assumption of a cellular structure
- 3 Variables:
  - ρ_m : Mobile Dislocations
  - ρ_w : Immobile Dislocations in Walls
  - ρ_i : Immobile Dislocations in Interior
  - $\dot{\rho}^+, \dot{\rho}^-$: Generation-/Annihilation Rates
- Kinetic eqn. of state:

3IVM+

Disl. Density

$$\tau_{i,w} = \alpha \cdot G \cdot b \cdot \sqrt{\rho_{i,w} + \rho_m} + \tau_{chem}$$

$$k_f = \overline{M}(f_i \cdot \tau_i + f_w \cdot \tau_w)$$

Solid Solution, Particles

ClaNG

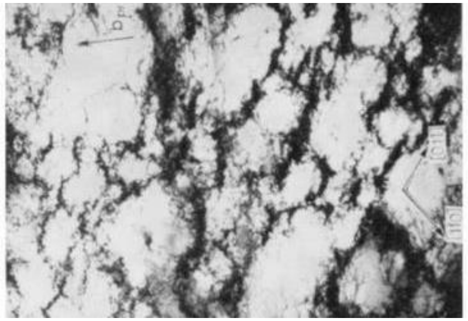
Recrystallisation:

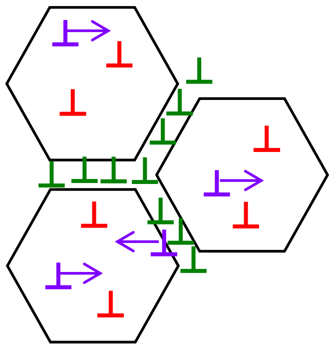
- kinetics

$$\frac{df_{RX}}{dt} = (1 - f_{RX}) \cdot 4 \cdot \pi \cdot N_0 \cdot r^2 \cdot \upsilon_{GB}$$

Texture

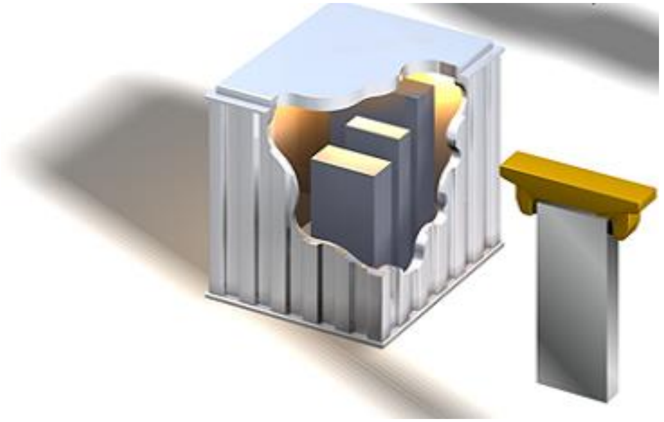
GIA



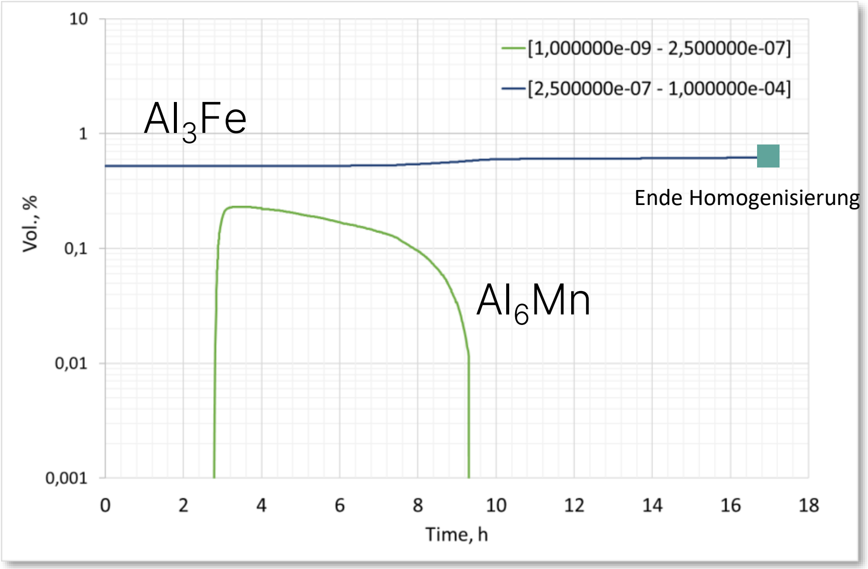


In Co-Operation with RWTH Aachen / MPIE Düsseldorf

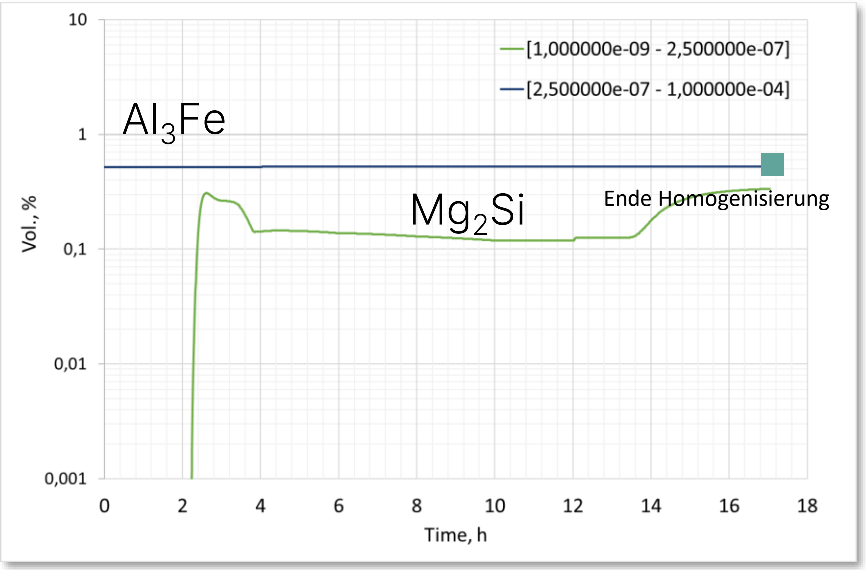
Simulation of μ-chemistry



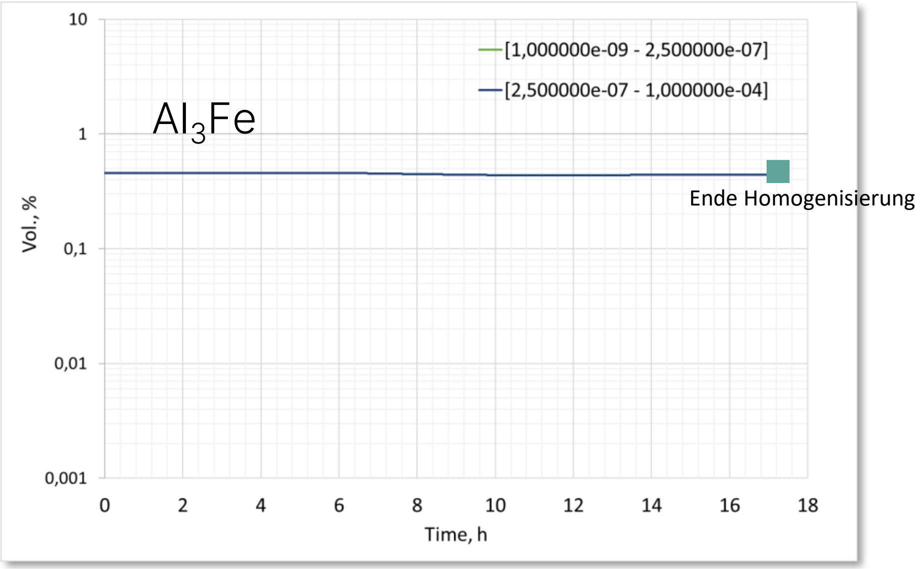
AA1110 Upper limit



AA1110 Standard



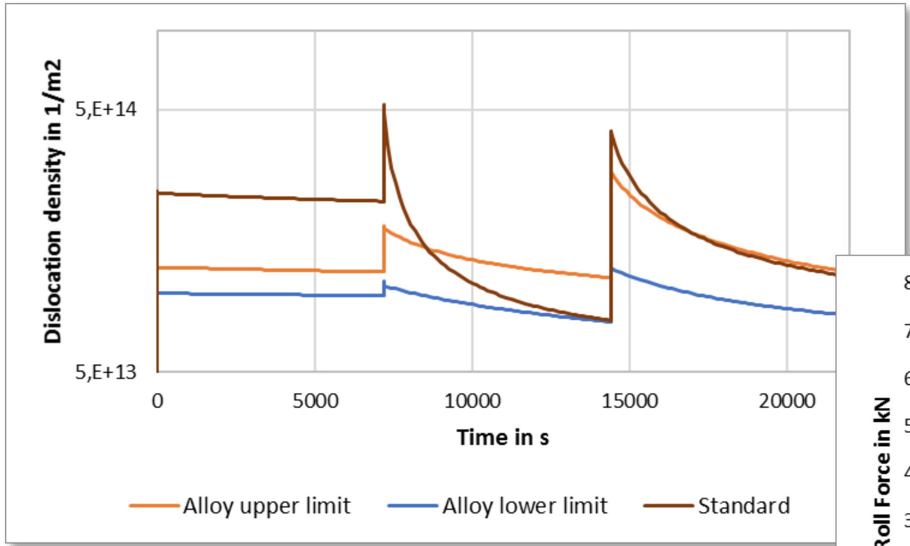
AA1110 Lower limit



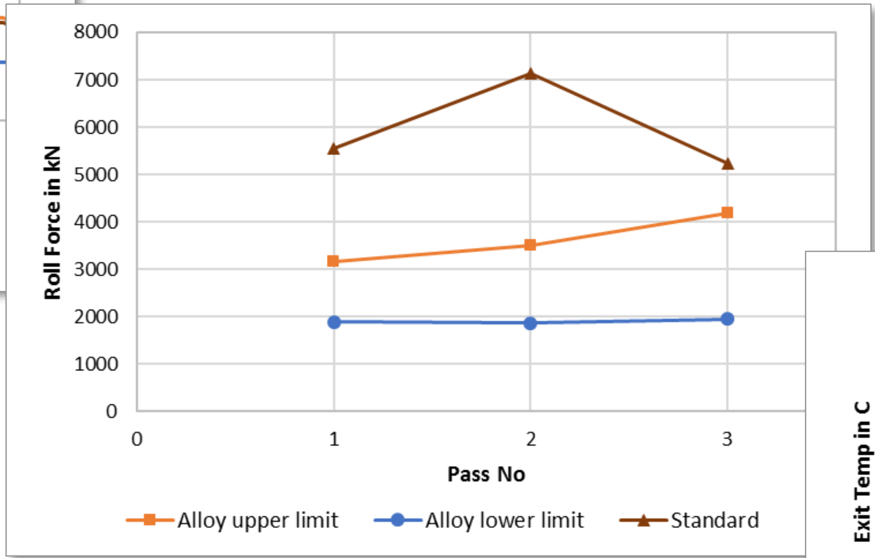
Content of intermetallic particles for different alloying content within the AA1100 specification after pre-heating in hot mill.

Simulation of Cold Rolling

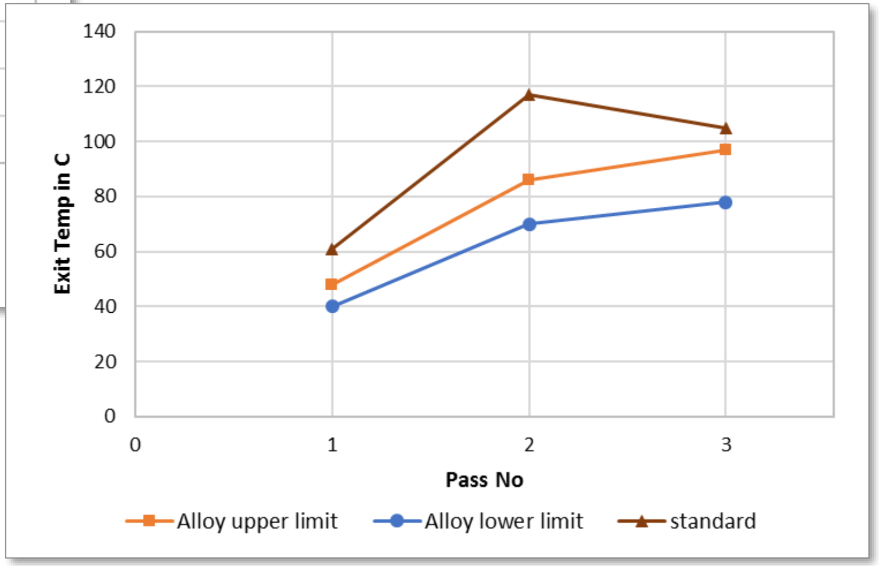
Dislocation Density



Roll Force



Exit Temperature



Effect of different µ-chemistry on cold rollling in 3 subsequent passes

03 Application in Foil Series 2

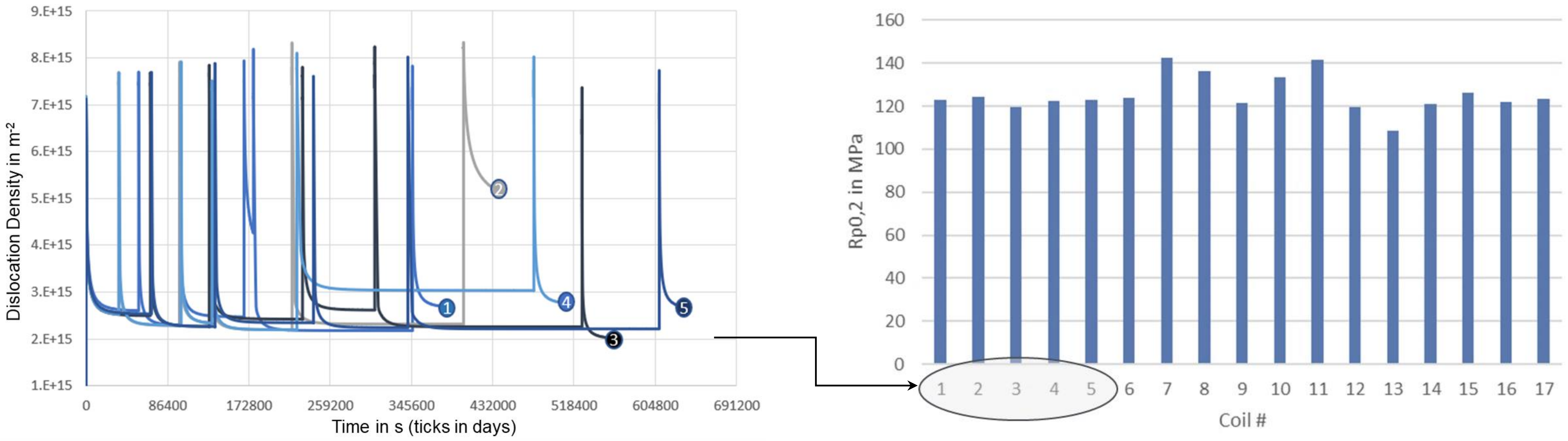
Soft sensor

Calculation of full material history with RoseRoll+RoseAnneal (incl. 3IVM⁺)
Tracing of Dislocation Densities and cell size
Calculation of strength at any point in time during processing

Alloy: AA 8079

Dislocation Density of 5 coils

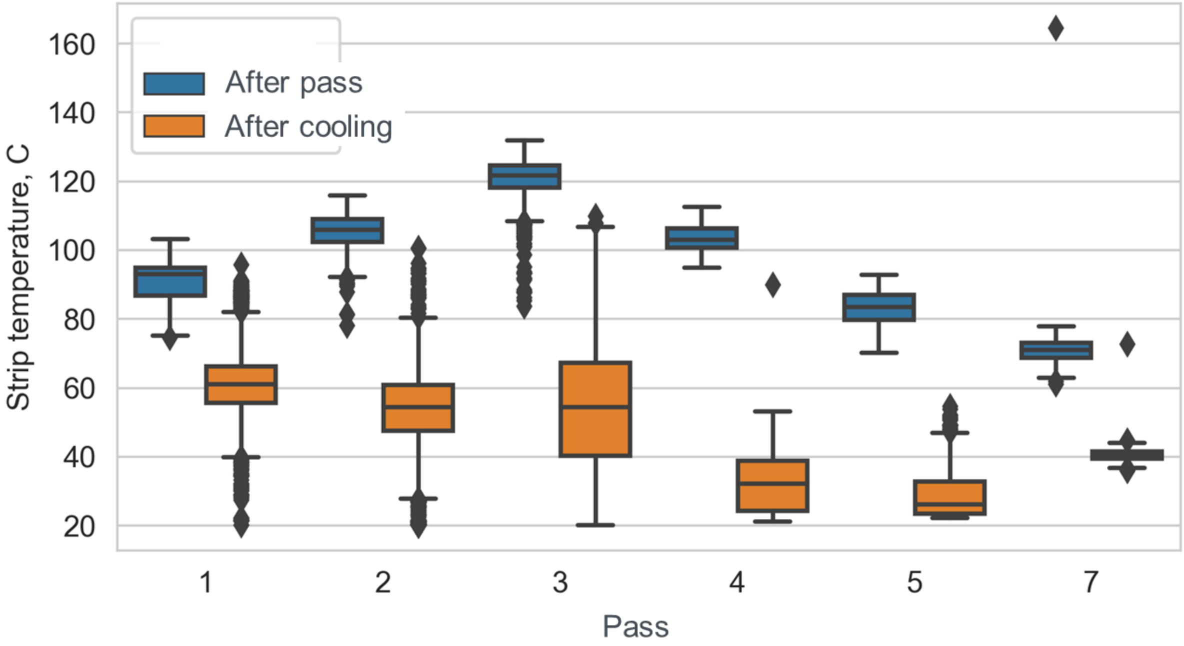
Final yield strength



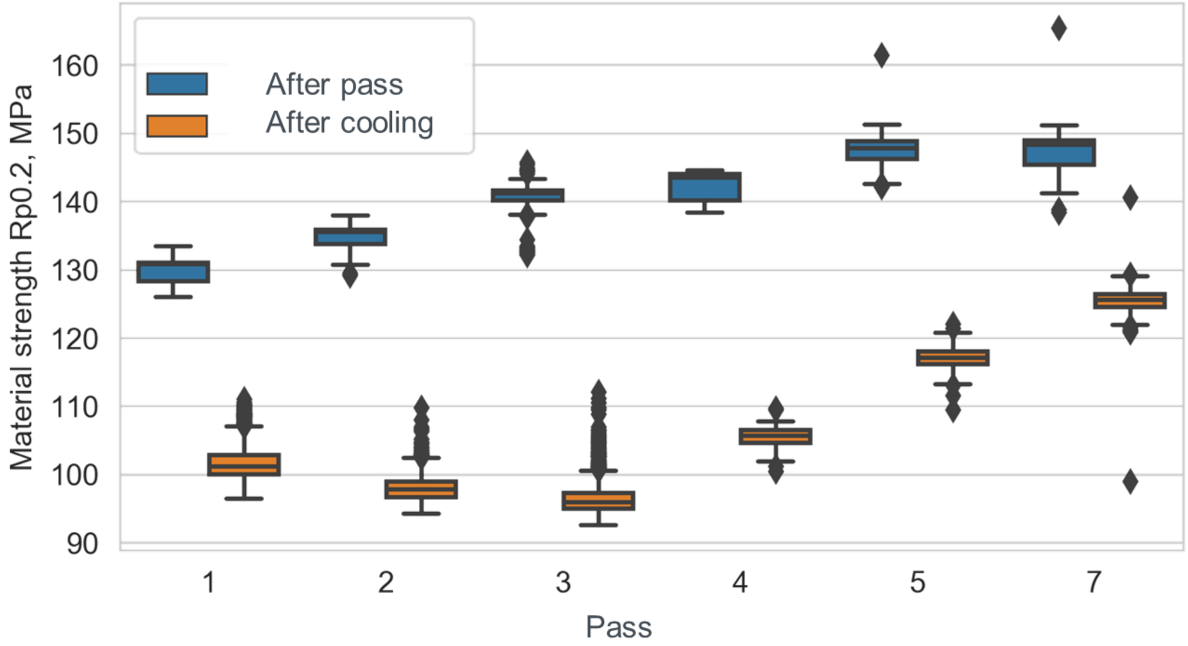
Use of Digital Twin as “Soft Sensor”

Re-Simulation of 3500+ Coils

Coil Temperature

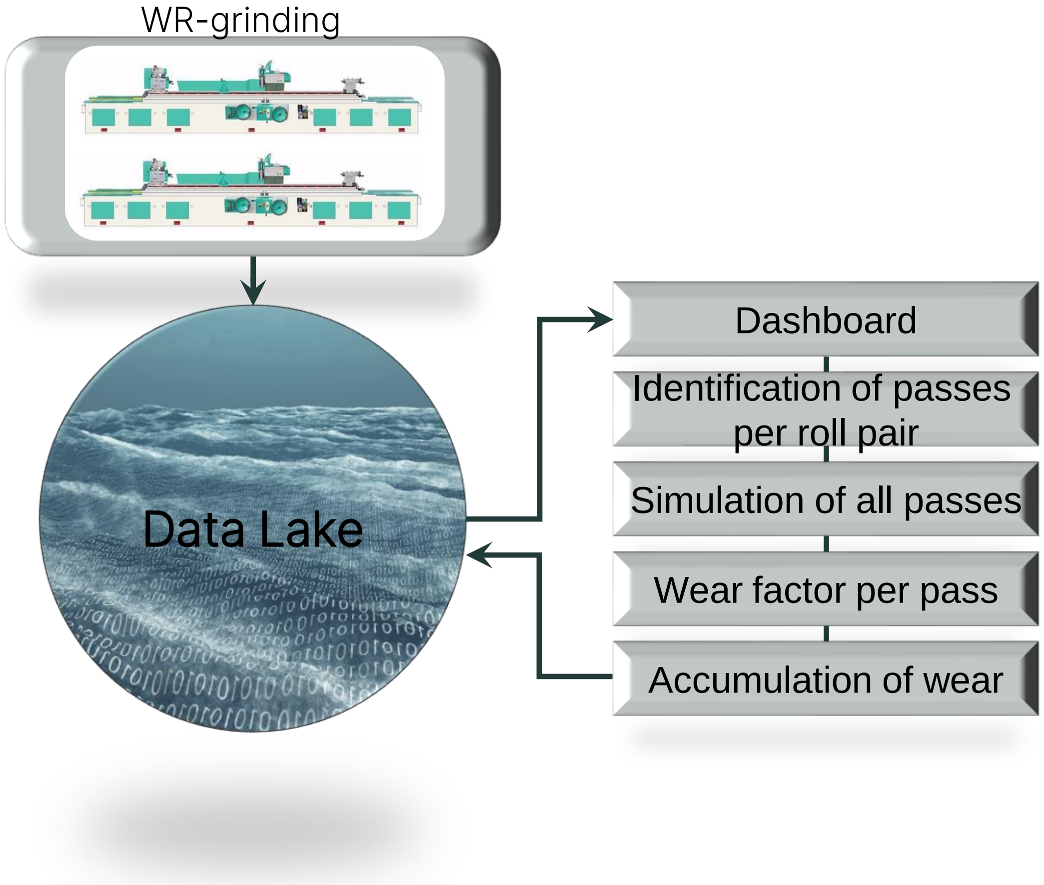


Material Yield Strength



Digital Twin of Rolls

speira



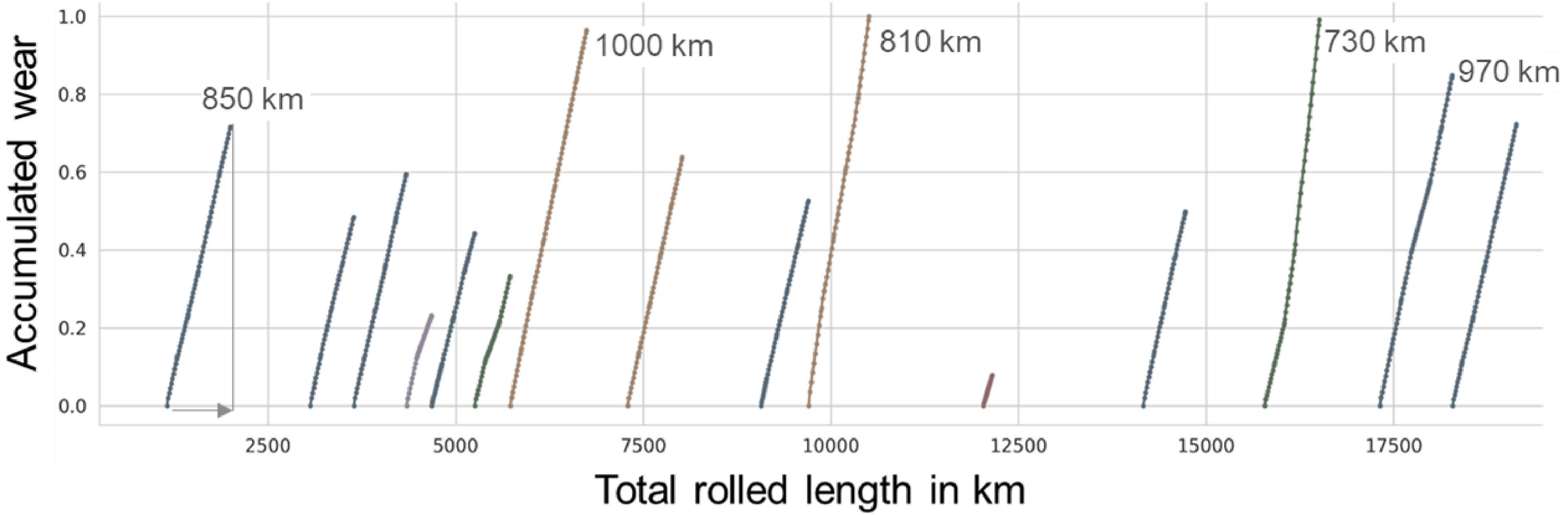
Wear, defined as change in radius with rolled length, is calculated within the process model

$$\frac{\Delta R}{\lambda} = \frac{K\mu L^2 r\bar{\sigma}\exp\left[\frac{\mu L}{h_{\mathrm{entry}}(2-r)}\right]}{D^2\sigma_{\mathrm{roll}}}$$

Roberts (1983)

Digital Twin of Work Rolls

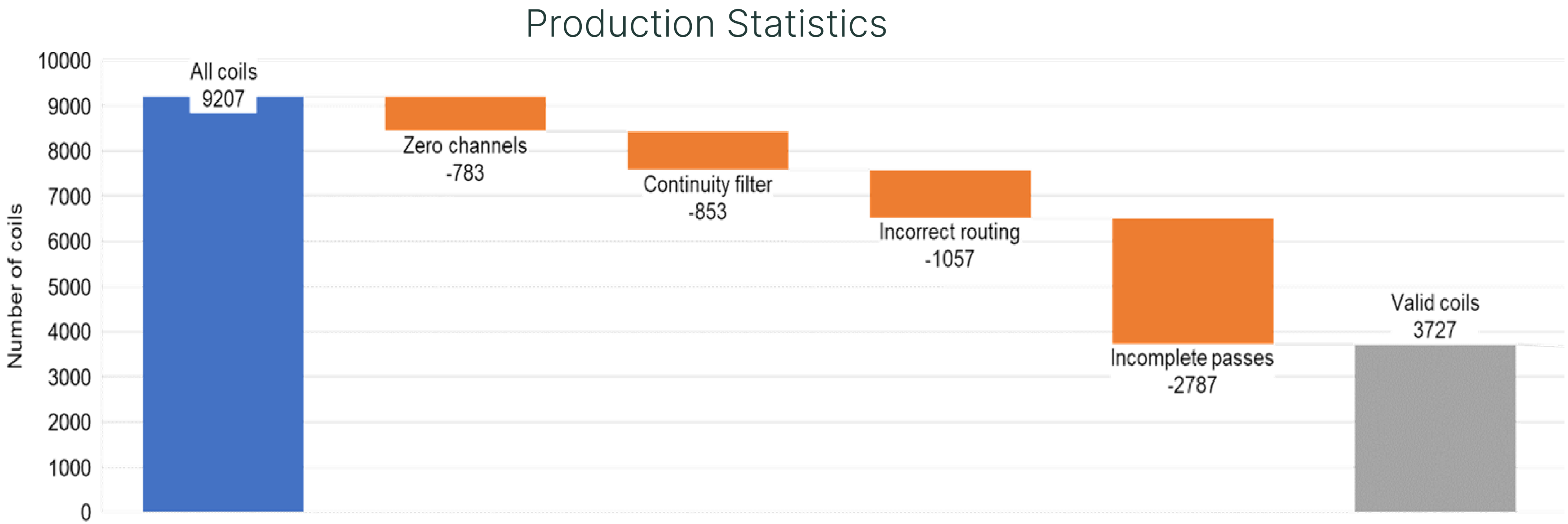
Simulated wear for several campaigns on one set of work rolls



⇒ Determination of optimum time to change WRs in the mill
⇒ Characterisation of WR life cycle
⇒ Correlation to griding practices

Data Consistency

Digital Twins rely on complete and consistent data of all sensors



Main causes for data losses:

- “0” channels due to maintenance
- Data logger system outages
- Coil tracing errors due to reasons like strip breakage
- Failure in data conversion between logger and data lake

Summary

- A digital representation of the main components of a foil plant has been set-up in a cloud system consisting of digital twins of:
  - Coils
  - Machines
  - Work Rolls
- Digital Twins are mandatory to predict the effect of process changes on product quality.
- The Digital Twins must be based on physical process and material models. They are applied as „soft sensors“ in addition to the physical sensors.
- Data-Quality and reliability is a most crucial issue.

Thank you for your attention !

speira

Kontakt:
Dr. Kai F. Karhausen
Speira GmbH, F&E Bonn
Georg-von-Boeselager-Str. 21
53117 Bonn
Tel: +49 (0)228 552 2728

kai.karhausen@speira.com