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# 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



#### speira **Consequences of fixed production recipies** precold casting hot rolling annealing heating rolling properties **Process Parameter Range** Quality Upper limit Lower limit **Process Parameter Range** Quality Upper limit Lower limit Kai Karhausen, AMAP Colloquium, Feb. 2023

### **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)



#### Foil rolling Series 2 (Grevenbroich)

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# **Production Foil-Series 2**



Definition of the Cyber Physical System CPS

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



#### speira Data Organisation of i4.0 (Series 2) Foil production (mills, doubler, test center) WR-grinding Machine Data (Level 1) Production Planning Sensors, off-line measurements, etc. SQL/NoSQL – Coil Query Logistics simulation Data Lake **Process Simulation** Analytics **Property Simulation** Vizualisation SQL/NoSQL – Queries SQL/NoSQL – Database

### **Demonstration Digital Twin prototype**



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# **Digital Twin of Coil**





> Transformation of time oriented data to location oriented data

### **User Interface: Dashboard**

crosoft Azure							PORTAL	6 speira			
1. Filter by alloy :       8079-L       2. Filter by start date :       03.07.2019       3. Filter by end         5. Plot Coil ID :       8476204000       Raw data out of bounds :       (true,true,true)				oard_v4				Upo	date		
				nd date : 21.09.2019 4. Select Material_Id_red : 8476106000, 8476105000, 8476104000 •							
Digital Twin Coil - Foil Series 2 in GV				Approximate number of distinct CoildIDs in s2							
			approx. number of coils in Data Lake								
Rolled coils - ALL -			Rolled coils - FILTERED -								
Material_Id_red	Alloy	SoP	Passes	Material_Id_red	Alloy	SoP	Passes	-			
7726504000	1100-L	30.07.2019	▶ [1,5,2,6,3,7,4]	8041502020	8079-L	13.07.2019_	► <u>[5 7 4]</u>			 	
8041502020	8079-L	13.07.2019	▶ [5,7,4]	8111802000	8079 L	Spec. r	oll force p	er pass			
8041702000	8079-D	04.07.2019	▶ [1,2,3,7]	8139802020	8079-L	(					
8111802000	8079-L	12.08.2019	▶ [5,2,3,7,4]	8139803020	8079-L	3					
8112501000	8079-D	04.07.2019	▶ [1,2,3,7]	8139804010	8079-L						
8112502000	8079-D	04.07.2019	▶ [1,2,3,7]	8139804020	8079-L	2.5					
8139603010	8079-L	13.11.2019	▶ [1,2,3,7]	8183508000	8079-L						
8139802020	8079-L	03.07.2019	▶[7]	8184204000	8079-L	2					
8139803020	8079-L	03.07.2019	▶ [7,4]	8226902000	8079-L	8 15					
8139804010	8079-L	03.07.2019	▶ [7,4]	8226903000	8079-L	OILFO					
	8079-L	04.07.2019	▶ [5,7]	8226904000	8079-L						

### **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 4 (Foil Rolling)





# **Rolling Simulation Environment - ROSE**

#### Material Modules (limited texture information)

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

#### Material Modules (full texture information)

•	Gia*

Core\*

Deformation Texture Recrystallisation (Nucleation and Growth)

\* In co-operation with IBF & IMM at RWTH Aachen and MPIE Düsseldorf Kai Karhausen, AMAP Colloquium, Feb. 2023

	) sp	eira	R	ROlling Sin tolling Mo	mulation <u>E</u> n odule V8.01	ovironment 2022© Trial Licence
	Hauptmenü		ROS	E Roll		ai F. Karhausen
1	Walzparameter (*.DAT) Bearbeiten		Geladene Daten Walzparameter	Keine	Speira Tel : +	GmbH, F+E Bonn
	Banddaten (*.NTL)	Bearbeiten	Banddaten	Keine	Fax: +	-49 (0)228 552 2446
	Werkstoffdaten	Bearbeiten	Werkstoffdaten	Keine	kai.ka	rhausen@speira.com
	Vorkühler (*.RND)	Bearbeiten	emp. Gefügesimu	I. Vers.dichtemodell		
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# Physically based Statistical Material Model

#### Work hardening and Recovery:

- Assumption of a cellular structure



In Co-Operation with RWTH Aachen / MPIE Düsseldorf



### Simulation of µ-chemistry



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



AA1110 Lower limit



AA1110 Upper limit





### **03** Application in Foil Series 2





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

# Soft sensor





Final yield strength

### Use of Digital Twin as "Soft Sensor"



Re-Simulation of 3500+ Coils



#### Coil Temperature

#### Material Yield Strength



# **Digital Twin of Rolls**





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

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

Roberts (1983)

# **Digital Twin of Work Rolls**



Simulated wear for several campaigns on one set of work rolls



- $\Rightarrow$  Determination of optimum time to change WRs in the mill
- $\Rightarrow$  Characterisation of WR life cycle
- $\Rightarrow$  Correlation to griding practices

# **Data Consistency**

Digital Twins rely on complete and consistent data of <u>all</u> sensors



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**Production Statistics** 

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 !



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<u>Kontakt:</u> 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