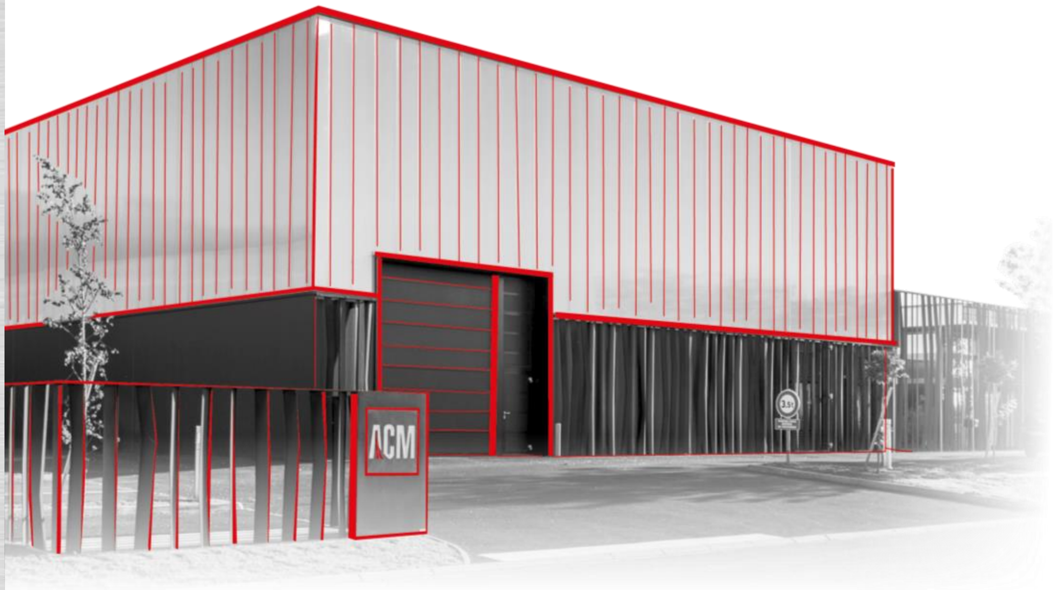
ABS CENTRE MÉTALLURGIQUE

ABSOLUTE STEEL QUALITY



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PSEVEN USER CONFERENCE 2022

October 12, 2022

Thermal exchange and friction coefficients optimization of the numerical modeling of hot rolling

Corentin PONDAVEN, R&D Engineer, ABS Centre Métallurgique

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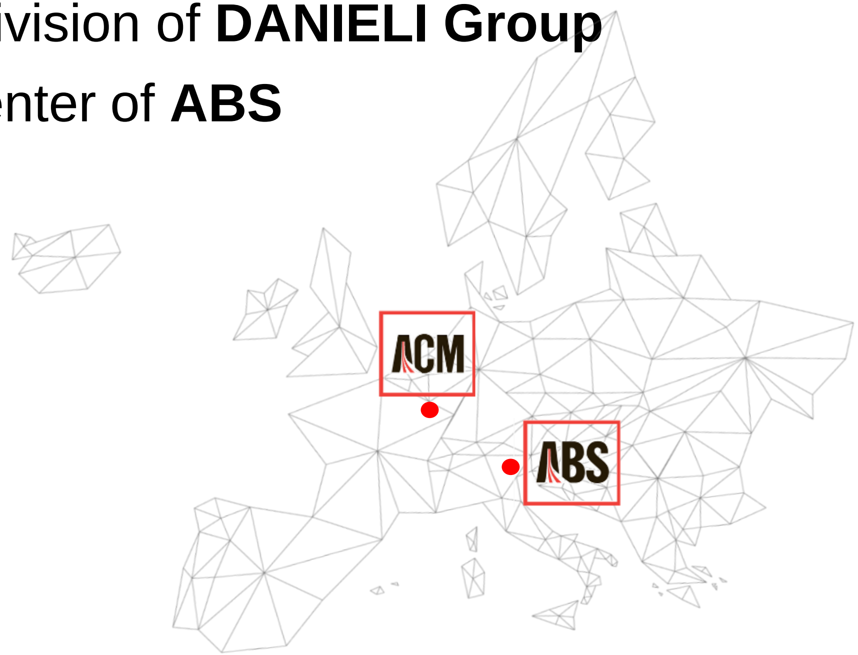
- **Acciaierie Bertoli Safau (ABS)** is the Steelmaking division of **DANIELI Group**
- **ABS Centre Métallurgique (ACM)** is the research center of **ABS**



- **ACM missions**:
  - Improvement of ABS processes
  - Development of new products
  - Technical support with ABS customers
  - External offer of technical services

Markets: Automotive & Trucks, Oil & Gas, Wind power, …

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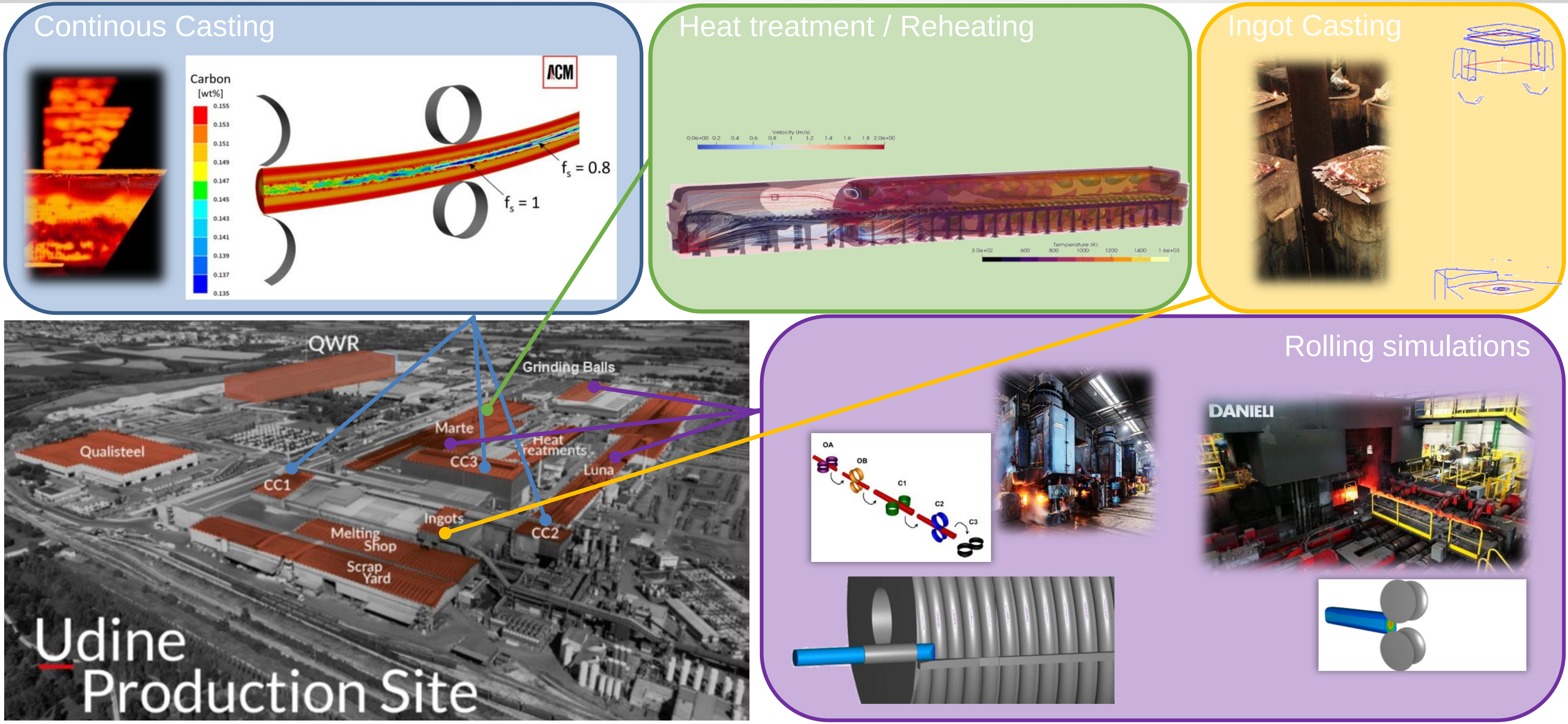
« DIGITAL TWIN » PROJECTS



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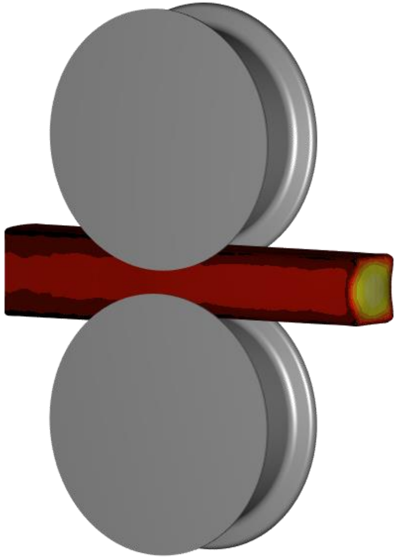
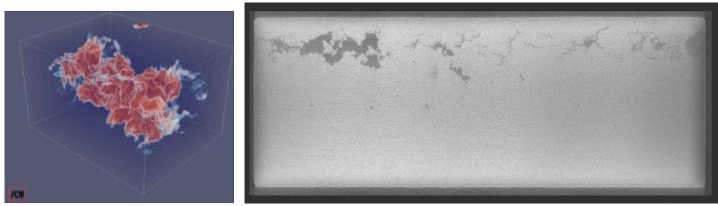
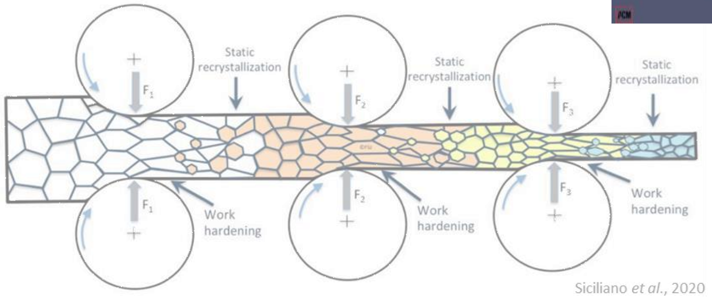
- **Section reduction of blooms**
  - Suited for further manufacturing process



- **Improvement of material properties**
  - Improvement of central soundness
    - Healing of shrinkage pores
    - Fracturing of inclusion clusters
  - Refinement of structure



Shrinkage pores (µCT)



Siciliano *et al.*, 2020

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- **A numerical model, why?**
  - To prepare the rolling of specific steel grades
  - To optimize the operating parameters
  - To limit the trials

- **A numerical model, how?**
  - Model needs to be calibrated/validated
  - Numerous material parameters needed
  - Computational power needed

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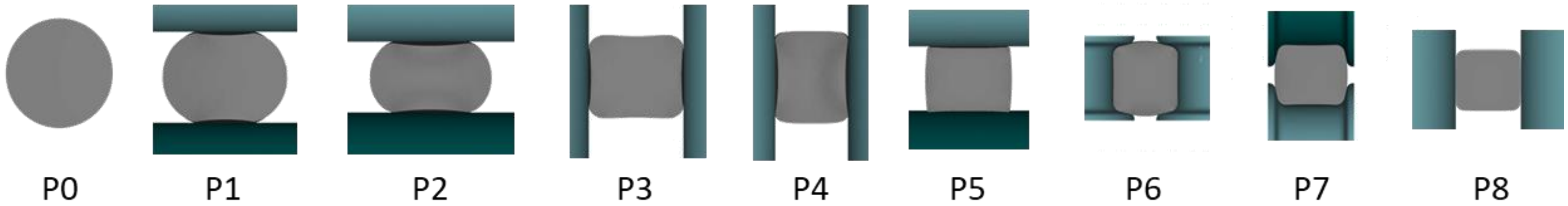
Rotoforgia mill of Marte line

- Large product rolling mill

- Studied rolling sequence : round bloom D750 mm to square ca. 440 mm
  - 35CrMo4 steel
  - 8 rolling stand with alternated loading direction



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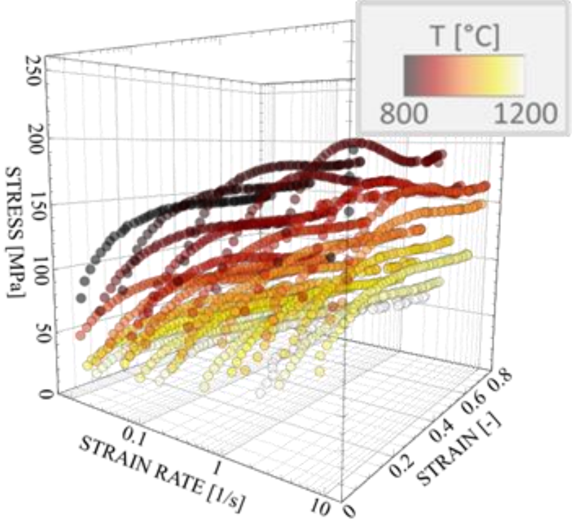
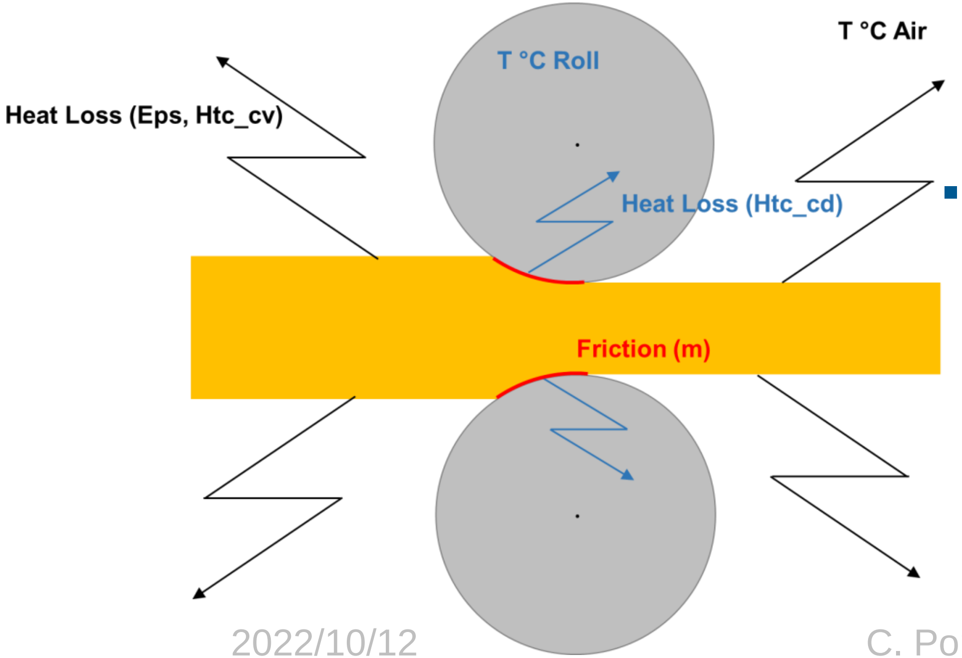
- Material behavior
  - **Compression test to calibrate phenomenological model**
    - Hensel-Spittel model
    - Ranges of identification
      - Temperature 1250 – 900°C
      - Strain 0 – 0.8
      - Strain rate 0.01 – 10 s^{-1}

Thermo-mechanical characterization





- **Boundary conditions**
  - Thermal exchanges
    - Convection (Htc_cv)
      - Air Temperature
    - Conduction (Htc_cd)
      - Roll temperature
    - Radiation (Eps)
  - Friction (m)

Defined using optimization

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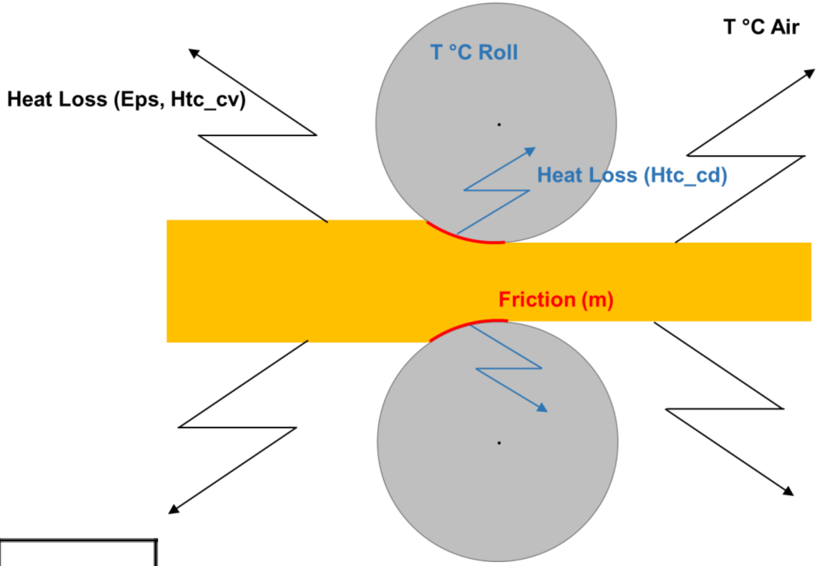
Parameters Optimization : range with physical meaning for hot-rolling

Parameters initial cooling (descaling)

	Text_cooling (°C)	Eps_cooling	Htc_cv_cooling ($W.m^{-2}.K^{-1}$)
Range	20-**200**	**0.65-0.95**	7-24



Parameters rolling and cooling

	Text (°C)	Tdie (°C)	Eps	Htc_cv ($W.m^{-2}.K^{-1}$)	Htc_cd ($kW.m^{-2}.K^{-1}$)	m
Range	20-50	**25-200**	**0.8**-0.88	7-24	1-25	0.65-1

→ **9 parameters to be defined during the optimization procedure**

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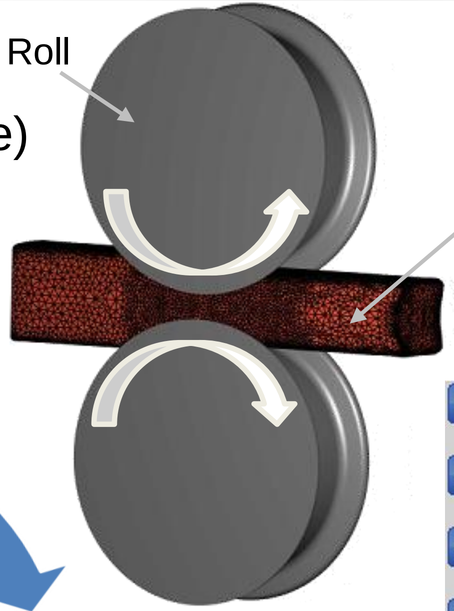
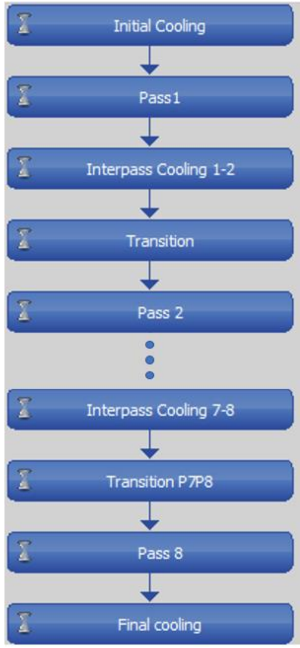
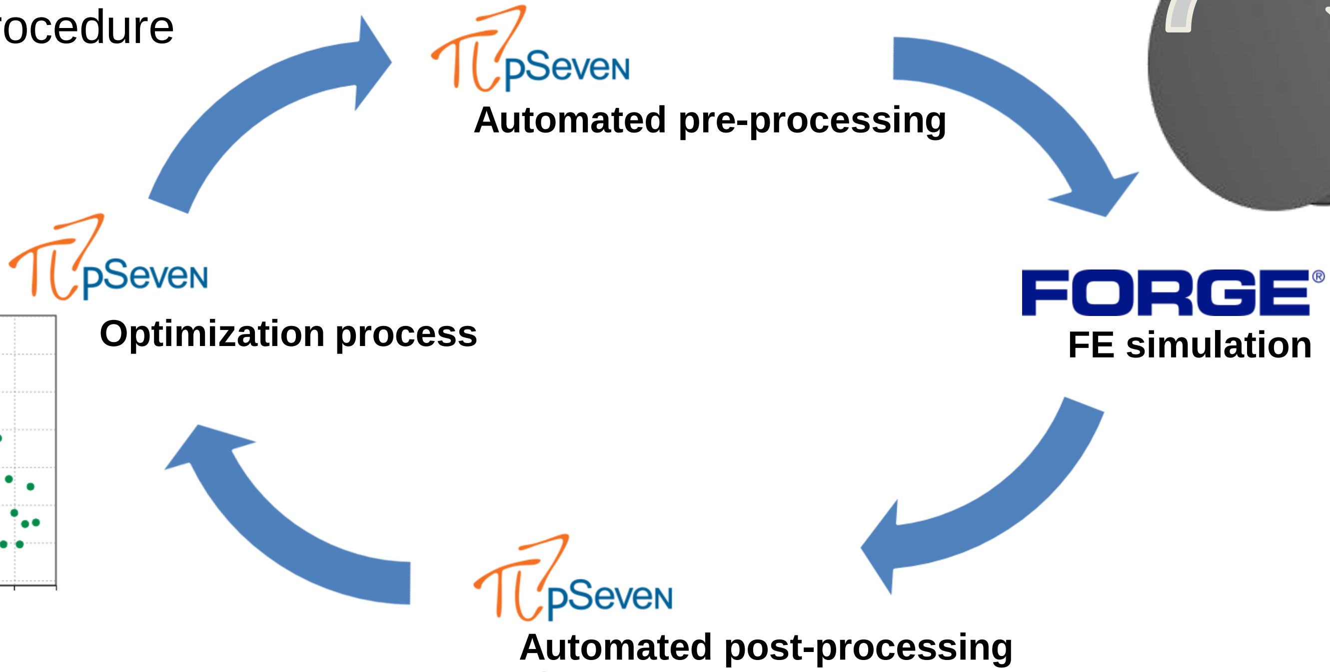
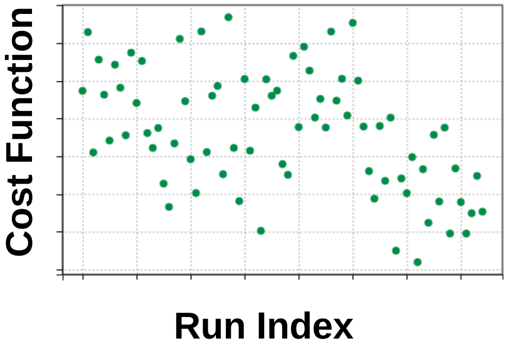
- **Optimization of friction and thermal exchange**
  - Improvement of the prediction of experimental results (rolling force)
    - Cost function $Fc = \sqrt{\sum_{i=1}^{9} \frac{\left(\overline{Frexp_i} - \overline{Fsim_i}\right)^2}{\|\overline{Frexp}\|^2}}$
  - Optimization procedure









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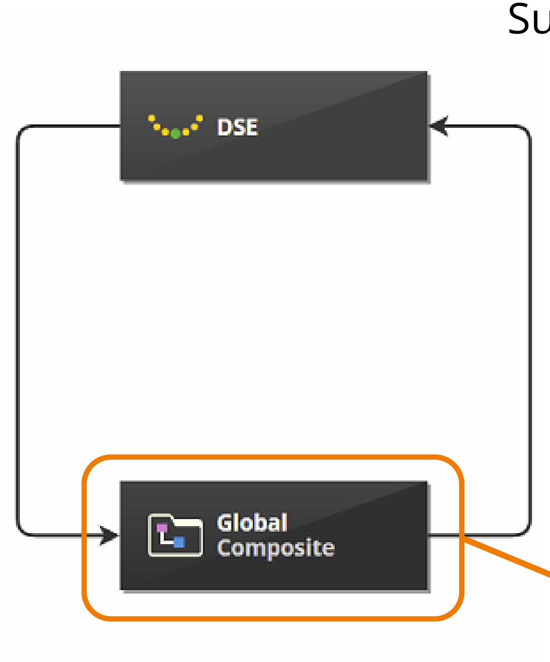
- Use of the DSE module of pSeven

DESIGN SPACE EXPLORATION

Surogate-based optimization with a population of 75 samples

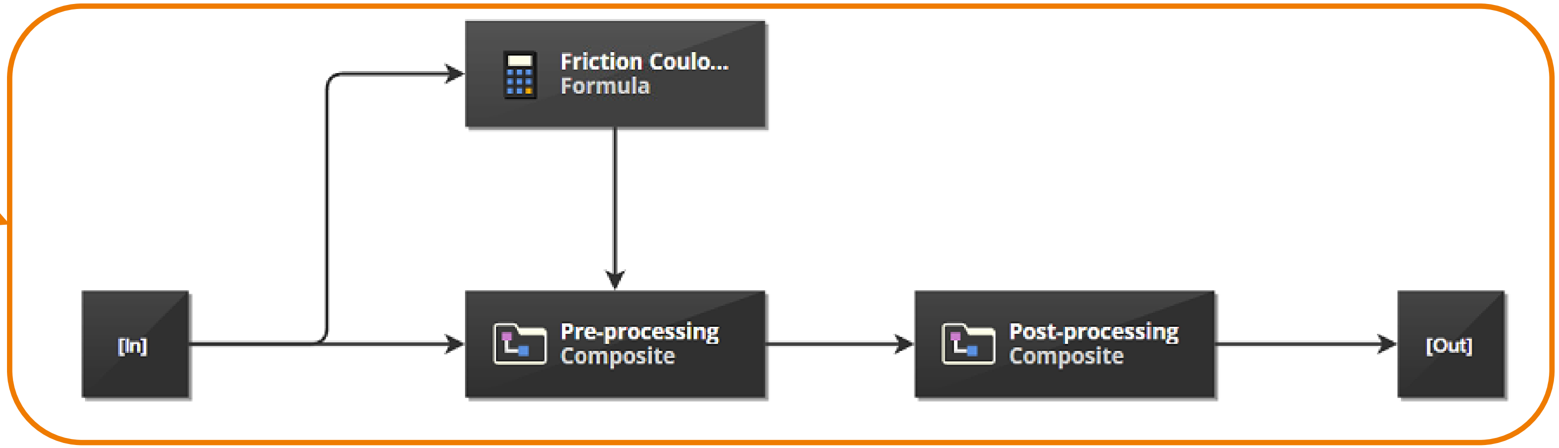
Objective : minimization of CF



COMPOSITE BLOCK

Configuration of the simulations

Post-processing of the results



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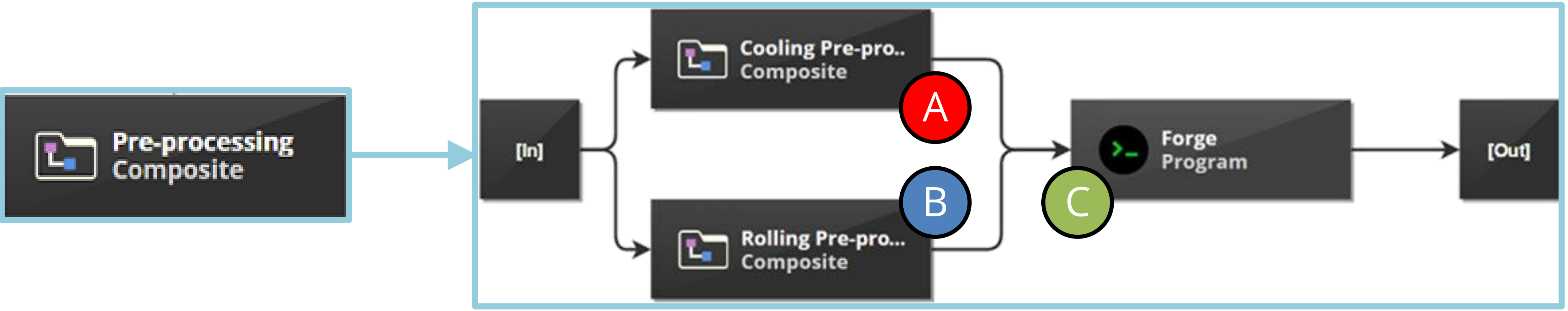
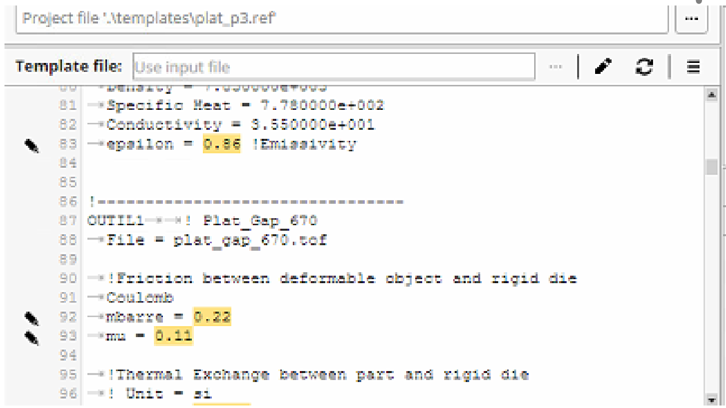
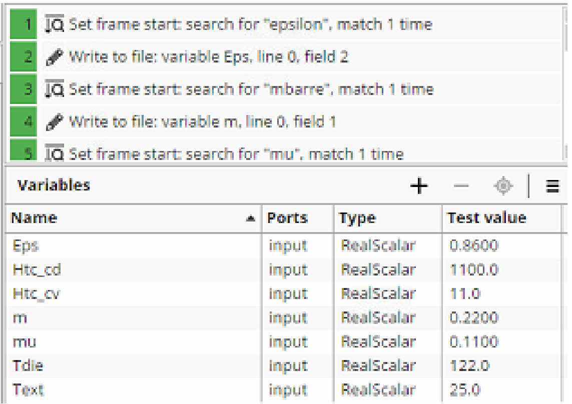


A. CONFIGURATION OF COOLING STAGES
Modification of thermal parameters in the initial simulation model

B. CONFIGURATION OF ROLLING STAGES
Modification of thermal and friction parameters in the initial simulation model

C. COMPUTATION RUN





Automated field recognition in text files using templates

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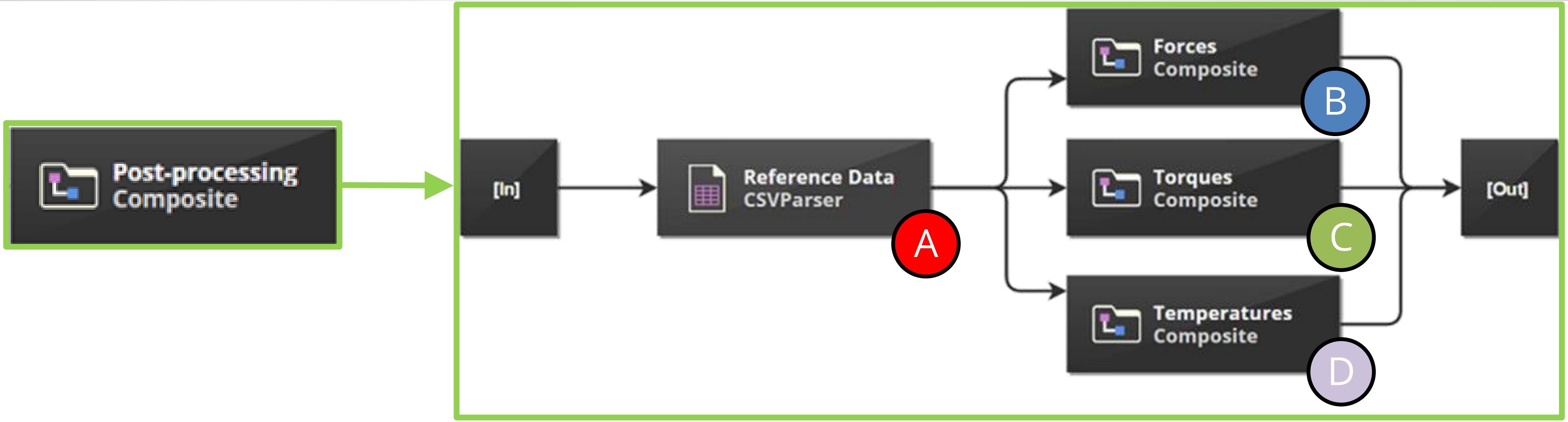
ROLLING SIMULATIONS – POST-PROCESSING AUTOMATION



A. EXTRACTION OF EXPERIMENTAL DATA
Torque, Surface Temperature, **Rolling Force**

B. EXTRACTION OF SIMULATED FORCES
Data extraction, computation of mean forces, computation of **cost function**

C. EXTRACTION OF SIMULATED TORQUES
Data extraction, computation of mean torques (monitoring)

D. EXTRACTION OF SIMULATED SURFACE TEMPERATURE
Automation of post-processing of Forge® (GLView), computation of mean temperature (monitoring)

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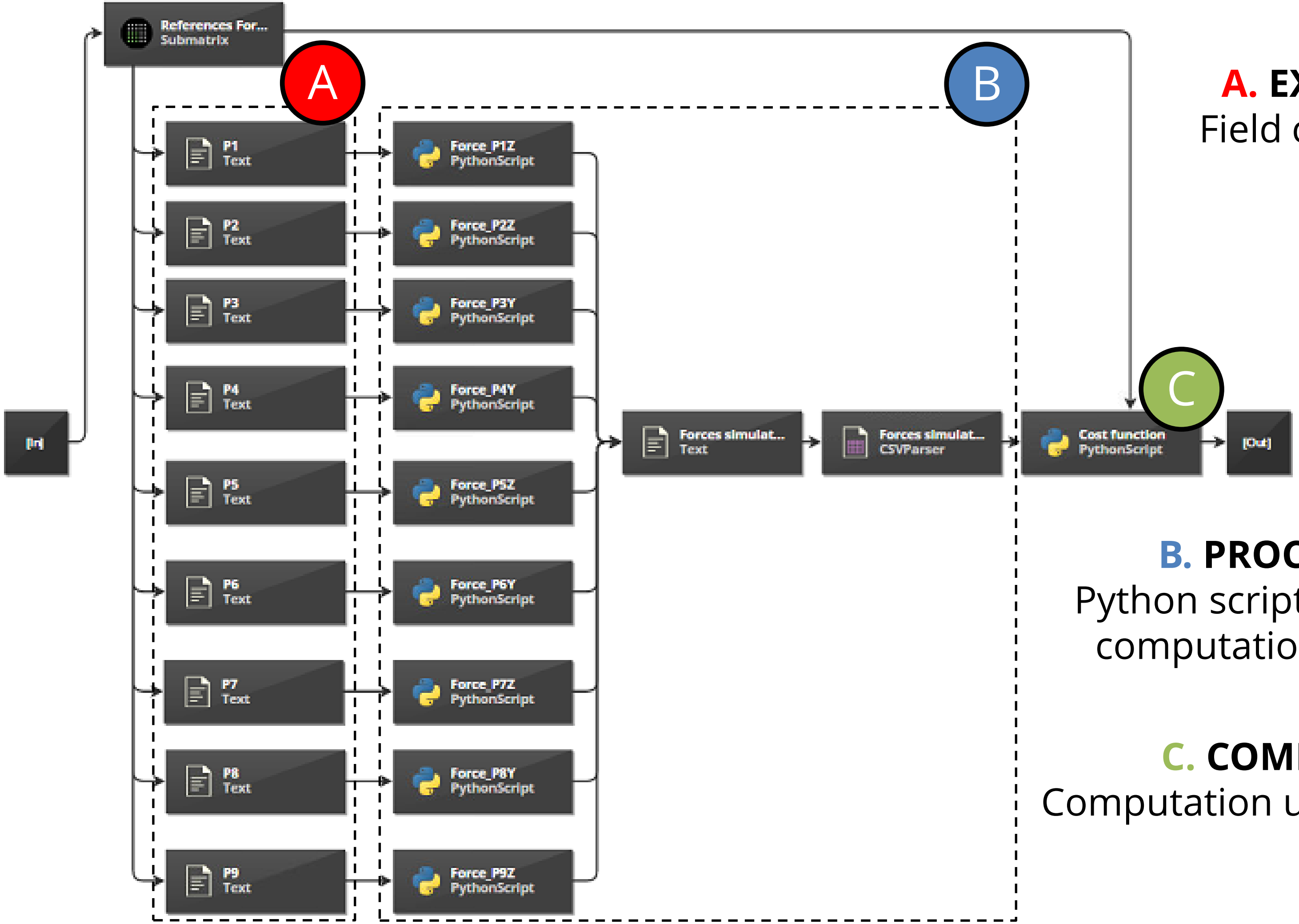
ROLLING SIMULATIONS – POST-PROCESSING FORCES



A. EXTRACTION OF SIMULATION DATA
Field computed in rolling roll (extraction of simulation results in text files)

B. PROCESSING OF SIMULATION DATA
Python scripting, extraction of the needed forces, computations of mean value, storage of values

C. COMPUTATION OF COST FUNCTION
Computation using experimental and simulation data

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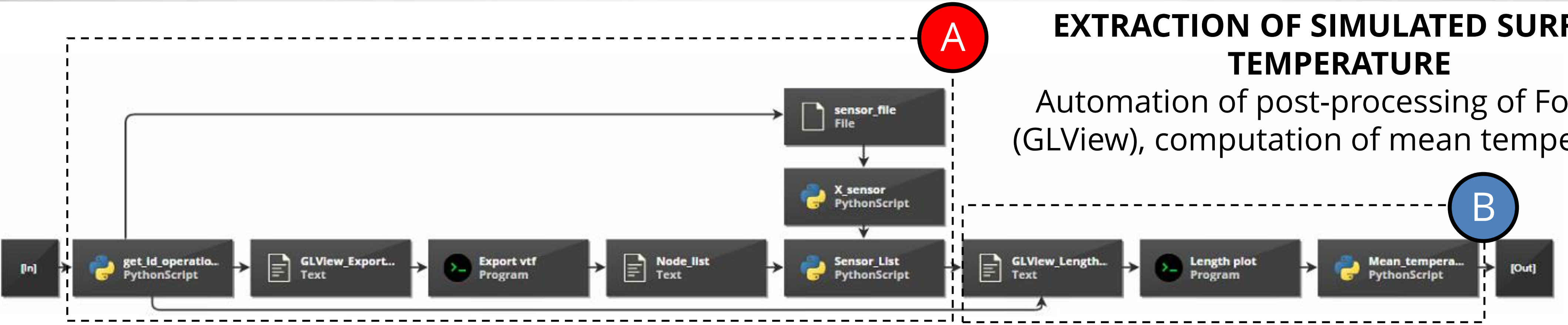
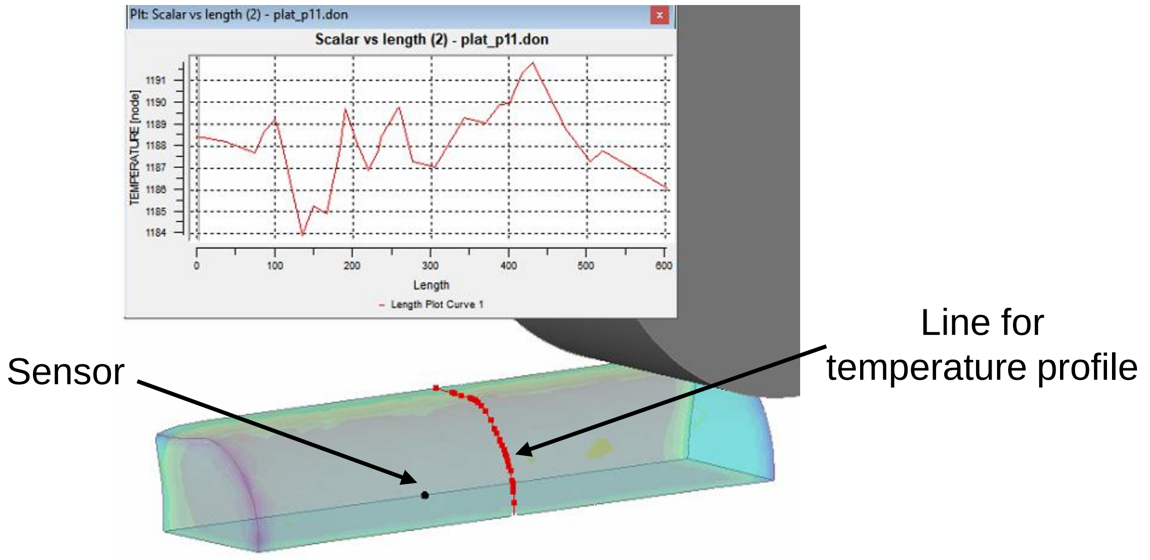
EXTRACTION OF SIMULATED SURFACE TEMPERATURE

Automation of post-processing of Forge® (GLView), computation of mean temperature



A. EXTRACTION OF RESULTS
Extraction of sensor coordinate, export of the node list of the rolled bloom at final state

B. GENERATION OF SURFACE TEMPERATURE
Draw of the temperature profile on a line located on the bloom surface on the section containing the internal sensor and mean temperature computation



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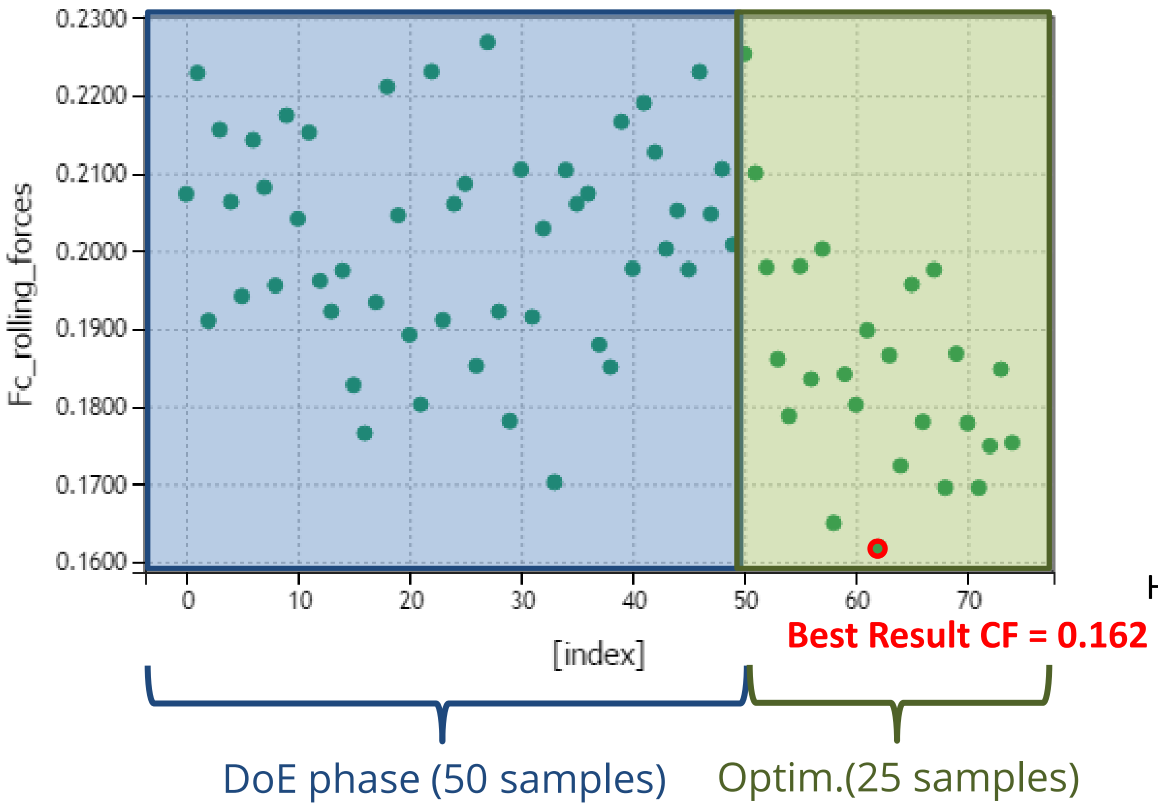
- **Cost-function evolution**
  - 75 run in approx. 25 days



- **Correlation Diagram**

HTC Convection		0.12 0.32	0.064 0.587	0.19 0.105	-0.026 0.823	-0.03 0.8	-0.27 0.0189	0.26 0.0262	0.033 0.782	0.49 0.00000432
HTC Conduction	0.12 0.32		0.18 0.12	0.26 0.0221	0.047 0.69	0.12 0.29	-0.14 0.249	0.058 0.62	0.11 0.346	0.45 0.0000331
Emissivity	0.064 0.587	0.18 0.12		0.18 0.122	-0.14 0.231	0.062 0.598	-0.026 0.827	0.21 0.0715	0.092 0.435	0.53 5.47e-7
Friction coeff.	0.19 0.105	0.26 0.0221	0.18 0.122		0.005 0.966	0.11 0.337	-0.13 0.254	0.098 0.403	0.16 0.183	0.37 0.00112
T°C die	-0.026 0.823	0.047 0.69	-0.14 0.231	0.005 0.966		-0.14 0.239	0.17 0.136	-0.022 0.853	-0.24 0.0406	-0.13 0.275
T°C air	-0.03 0.8	0.12 0.29	0.062 0.598	0.11 0.337	-0.14 0.239		0.00091 0.994	-0.01 0.93	-0.056 0.637	0.052 0.662
T°C air (ini. cool)	-0.27 0.0189	-0.14 0.249	-0.026 0.827	-0.13 0.254	0.17 0.136	0.00091 0.994		-0.1 0.384	-0.14 0.235	-0.28 0.0146
Emissivity (ini. cool)	0.26 0.0262	0.058 0.62	0.21 0.0715	0.098 0.403	-0.022 0.853	-0.01 0.93	-0.1 0.384		0.21 0.0751	0.77 2.67e-18
HTC Conv. (ini. cool.)	0.033 0.782	0.11 0.346	0.092 0.435	0.16 0.183	-0.24 0.0406	-0.056 0.637	-0.14 0.235	0.21 0.0751		0.36 0.00128
Cost Function	0.49 0.00000432	0.45 0.0000331	0.53 5.47e-7	0.37 0.00112	-0.13 0.275	0.052 0.662	-0.28 0.0146	0.77 2.67e-18	0.36 0.00128	
										CF

- Strongest impact of emissivity of initial cooling on forces
- Strong impact of thermal parameters in general

→ **Necessity to model the initial cooling with high precision**

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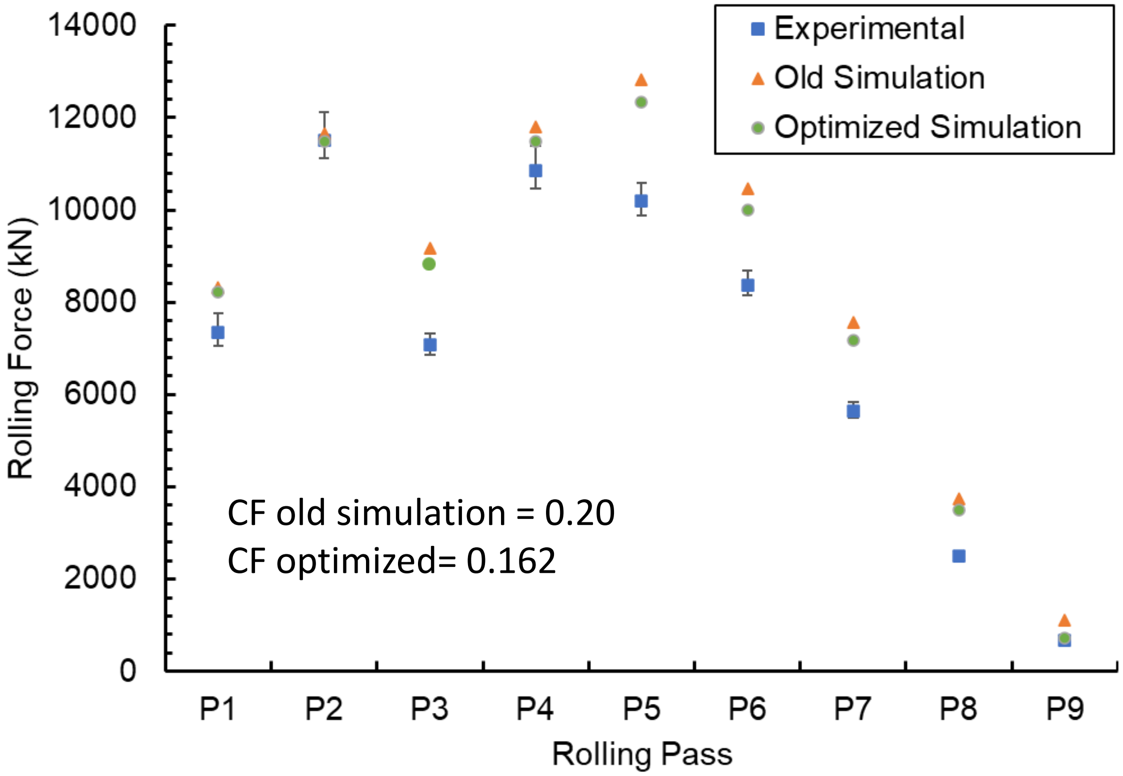
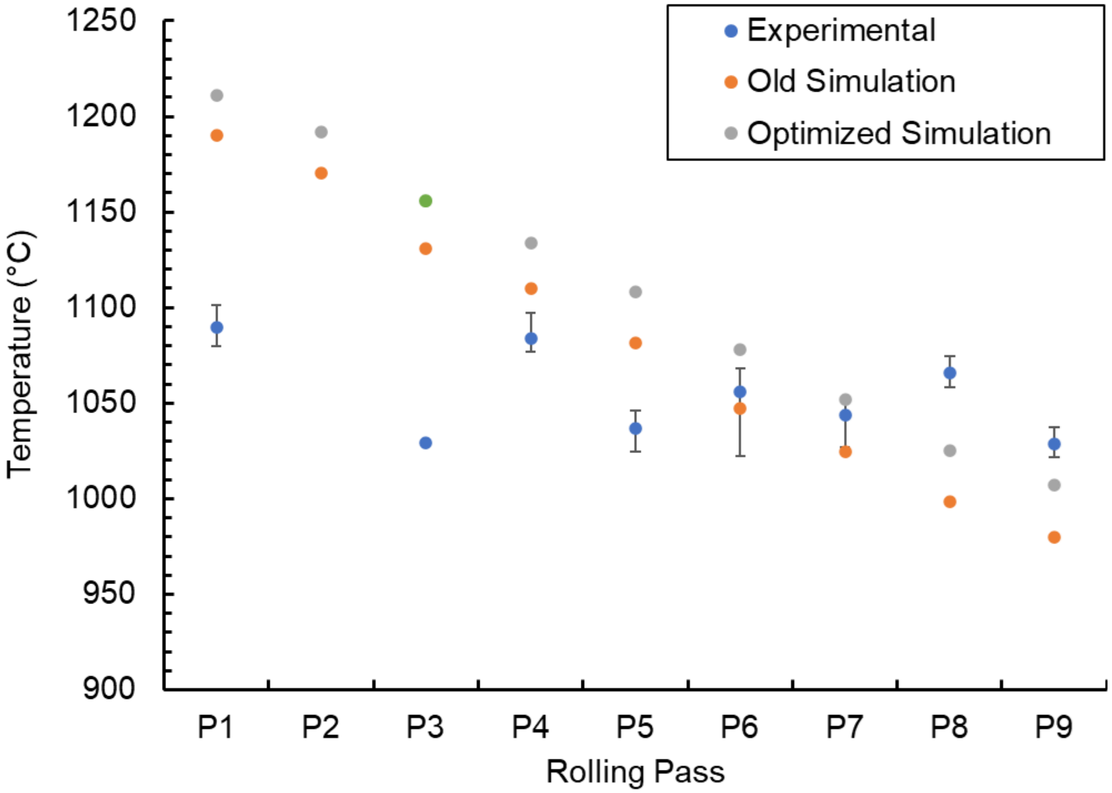
- **Rolling simulation results**





→ Improvement of rolling force prediction (in comparison with old trial/error technique)

→ Optimization of final temperature prediction

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- **Conclusions**
  - **Improved rolling modelling using optimization performed by pSeven**
    - Automated procedure of calibration
      - Wide population tested
    - Identification of the most impacting physical phenomenon / stage of the process
  - **Built pSeven workflow**
    - Use of template to modify/extract configurations/results file of Forge
    - Use of relative file path in pSeven workflow
    - Convention of process stage naming in the simulation

      → Fast adaptation of the workflow to other rolling sequences
- **Perspectives**
  - **Model improvement (initial cooling phase)**
  - **Model exploitation**
    - Analysis of thermomechanical fields (damage criterion evaluation …)
    - Internal pore closure analysis

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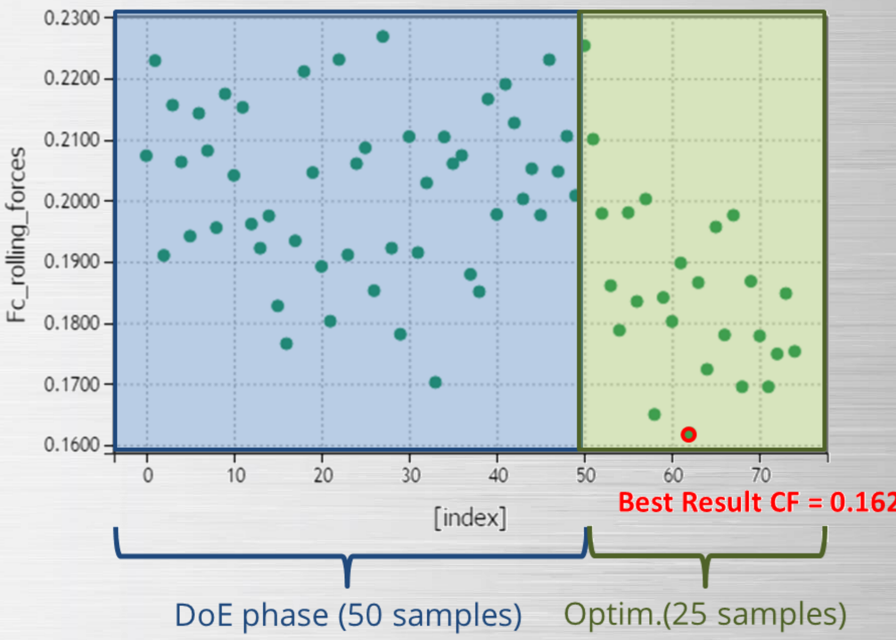

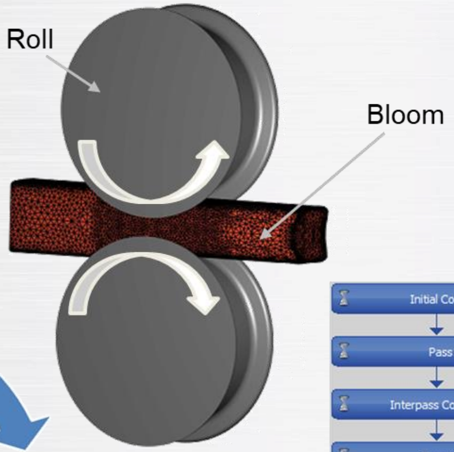

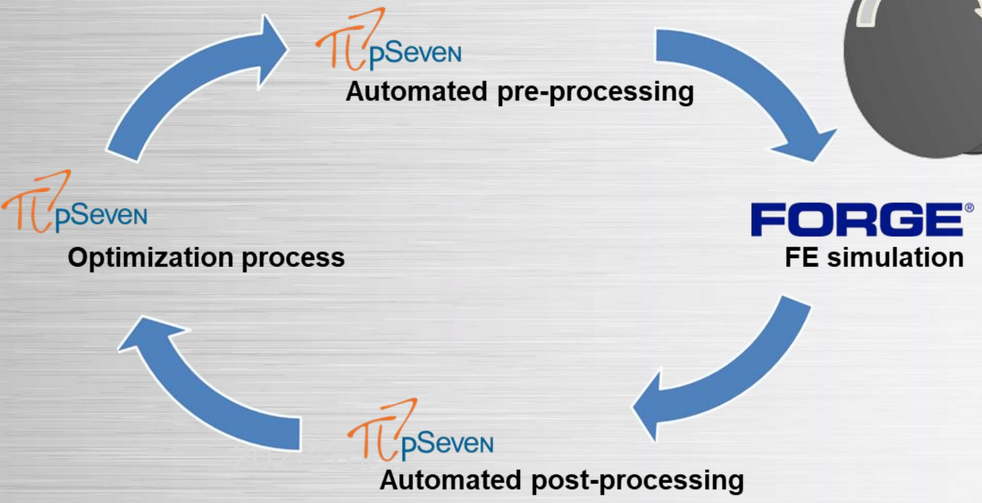

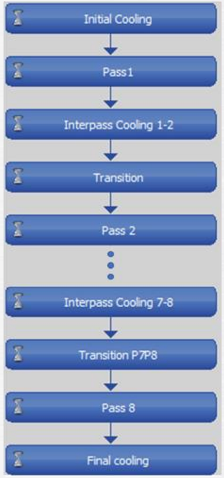

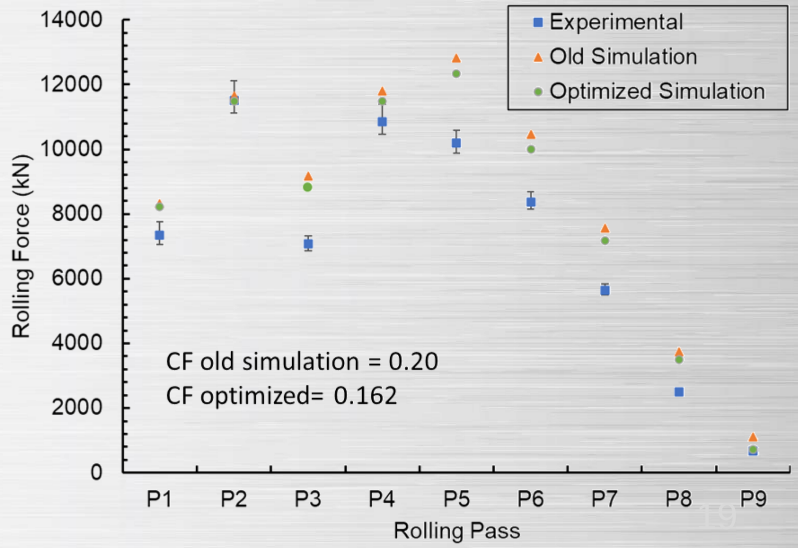

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