Temperature field evolution during flash-butt welding of railway rails

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CONTENT

- Introduction
- Outline work content
  - Experimental
  - Numerical simulation
- Results
- Discussion
- Outlook

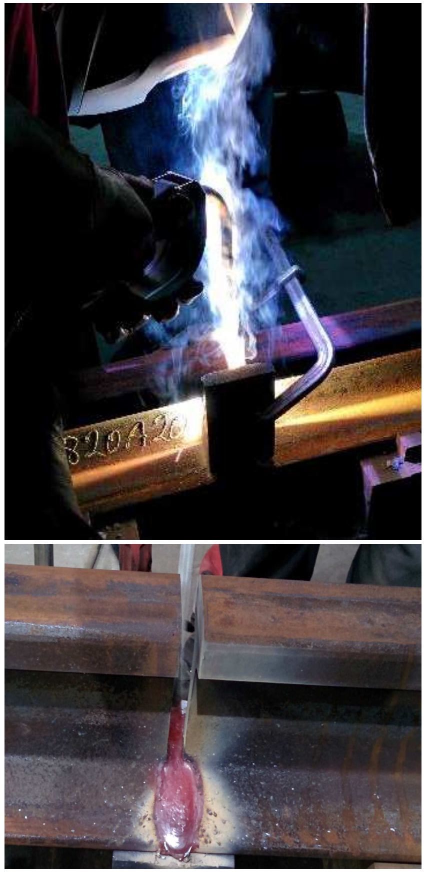
INTRODUCTION

- Rail welding processes:

Flash-butt welding stationary/ mobile

Aluminothermic welding

Manual arc welding

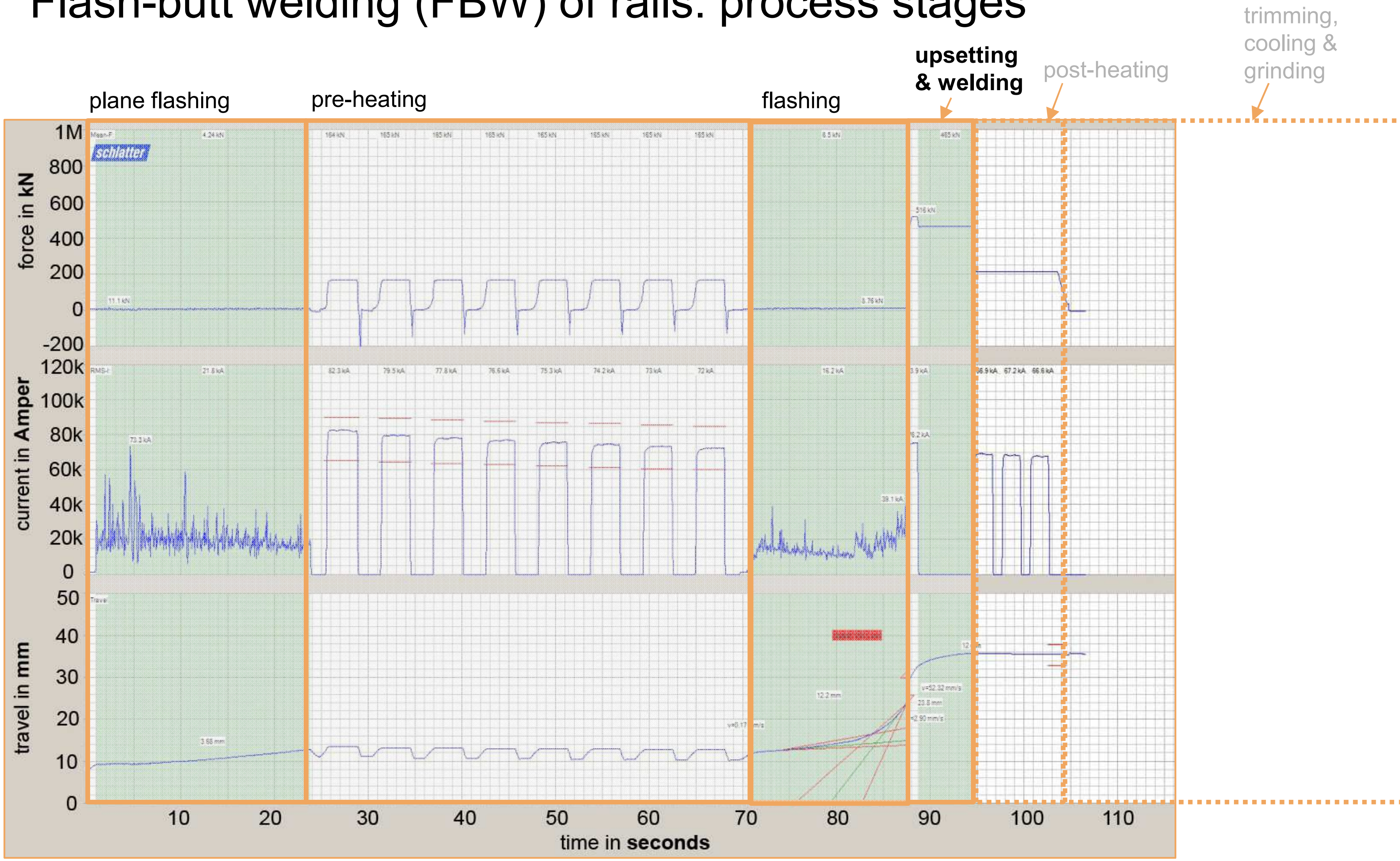


Gas pressure welding

source: [13,14]

INTRODUCTION

Flash-butt welding (FBW) of rails: process stages



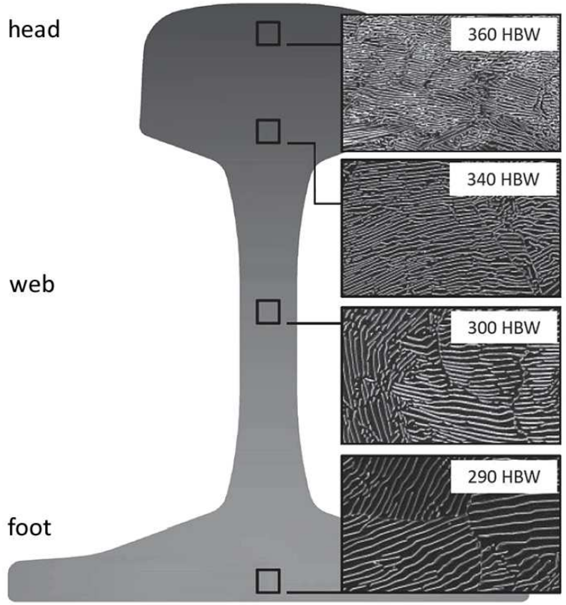
Welding diagram FBW. source: [1]

INTRODUCTION

Rail steels (pearlitic):

	main alloying elements in weight -%						
grade name acc. to standard EN 13674-1	**C**	**Mn**	**Si**	**Cr**	**P max.**	**S max.**	**HBW on running surface**
R260	0,62- 0,80	0,70- 1,20	0,15- 0,58	≤ 0,15	0,025	0,025	260- 300
R350HT	0,72- 0,80	0,70- 1,20	0,15- 0,58	≤ 0,15	0,020	0,025	350- 390
R400HT	0,90- 1,05	0,20- 0,60	1,00- 1,30	≤ 0,15	0,020	0,020	400- 440

source: [3]



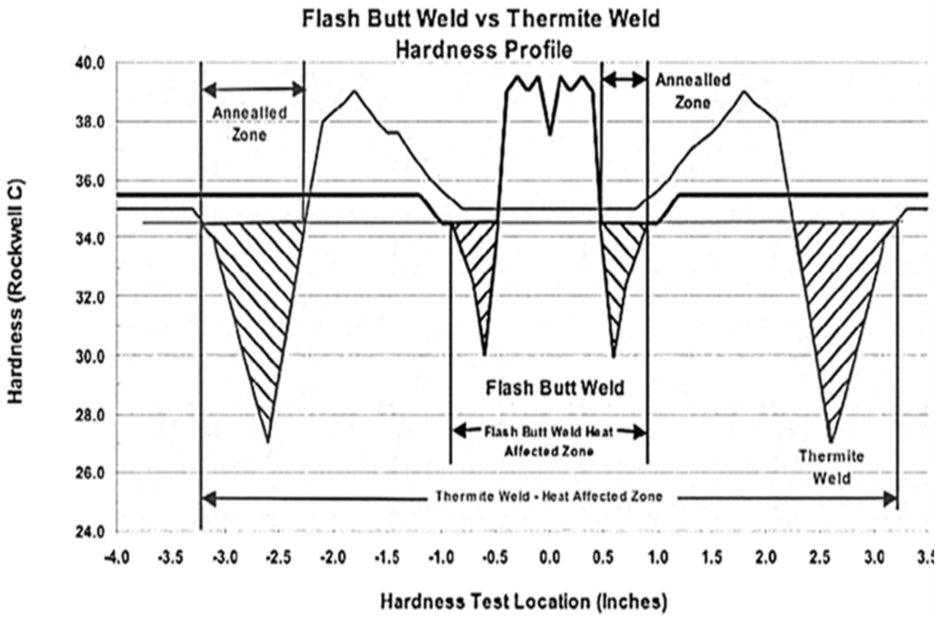
Microstructrue of R350HT vignol rail.
source: [2]

- head-hardened rails:
  - accurately adjusted, fully pearlitic microstructure
  - improved resistance against wear and rolling contact fatigue (RCF) source: [4, 5, 11]

INTRODUCTION

Motivation:

- Rail welding (FBW and AT) causes softening in HAZ



Hardness profile at rail head in longitudinal direction of rails welds.
source: [6]

Localized spalling damage at FBW in hypereutectoid rail.
source: [7]

- annealed microstructure → deterioration properties on running surface at weld joint
  → repair/ maintenance intervals shortened
  → **increased life-cycle costs of track $↑**

WORK CONTENT

Objectives:

- support improvement of rail welding processes, suitable for modern high hardness rail steel grades:
  - better process-knowledge for FBW for rails
  - experimentally validated, numerical tool
    - 3D- transient T-Field
    - relevant metallurgical transformations

→ tool, depict relevant weld joint properties numerically

- improve weldability through process optimization

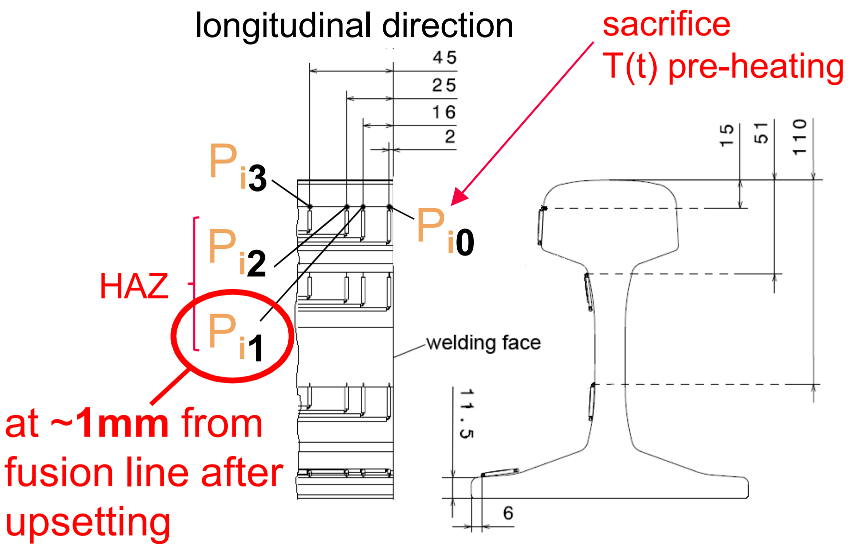
→ minimizing weakened areas of HAZ

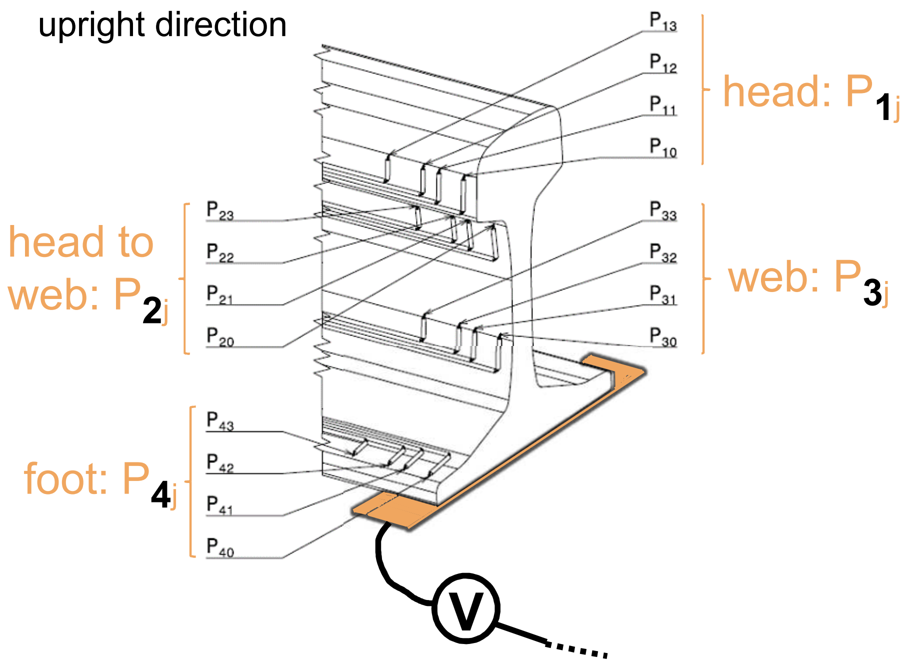
WORK CONTENT EXPERIMENTAL

- Welding experiments:
  - Schlatter GAA100 stationary Flash-Butt welding machine
    - DC current, up to 80 kA
    - up to 780 kN upsetting force
  - material: R260 rail steel. profile: 60E1, 750mm long
  - **Process characterization:**
    - **T(t):** 16 thermocouple measurement points

Schlatter GAA100 stationary FBW machine for rails. source: [8]

positioning and labelling:





- secondary welding voltage $U_S(t)$

WORK CONTENT EXPERIMENTAL

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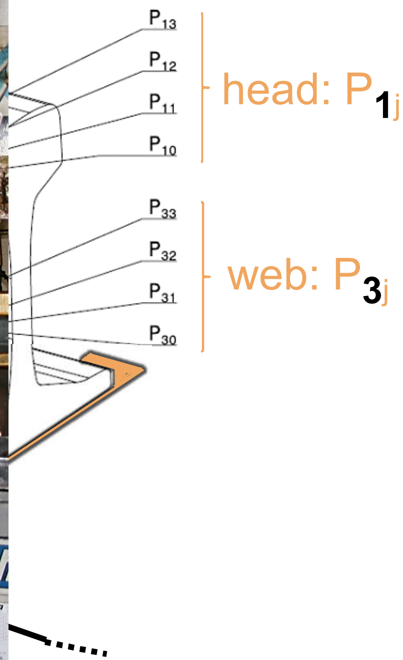
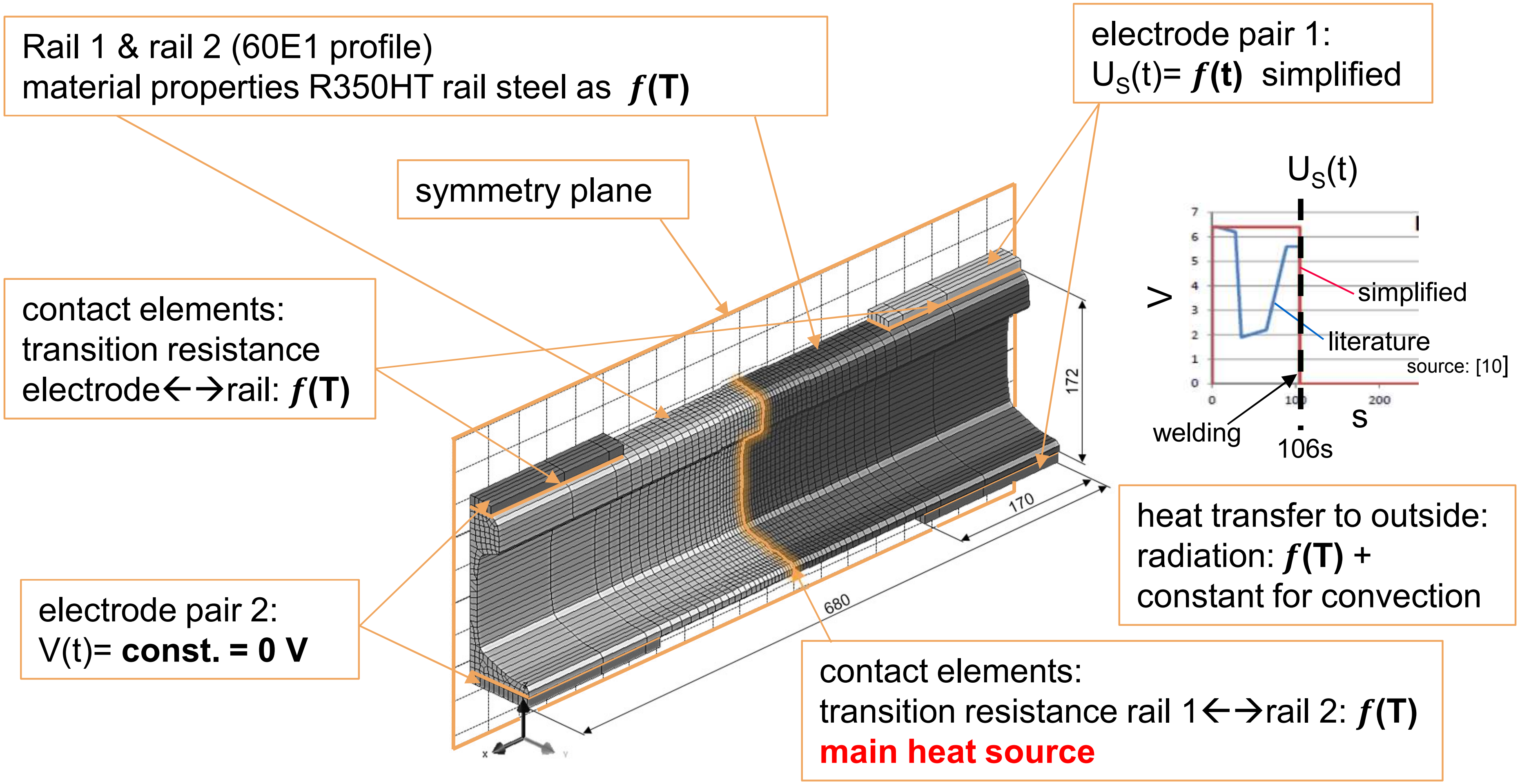
Schlatter GAA100 stationary FBW machine for rails. source: [8]



WORK CONTENT NUMERICAL

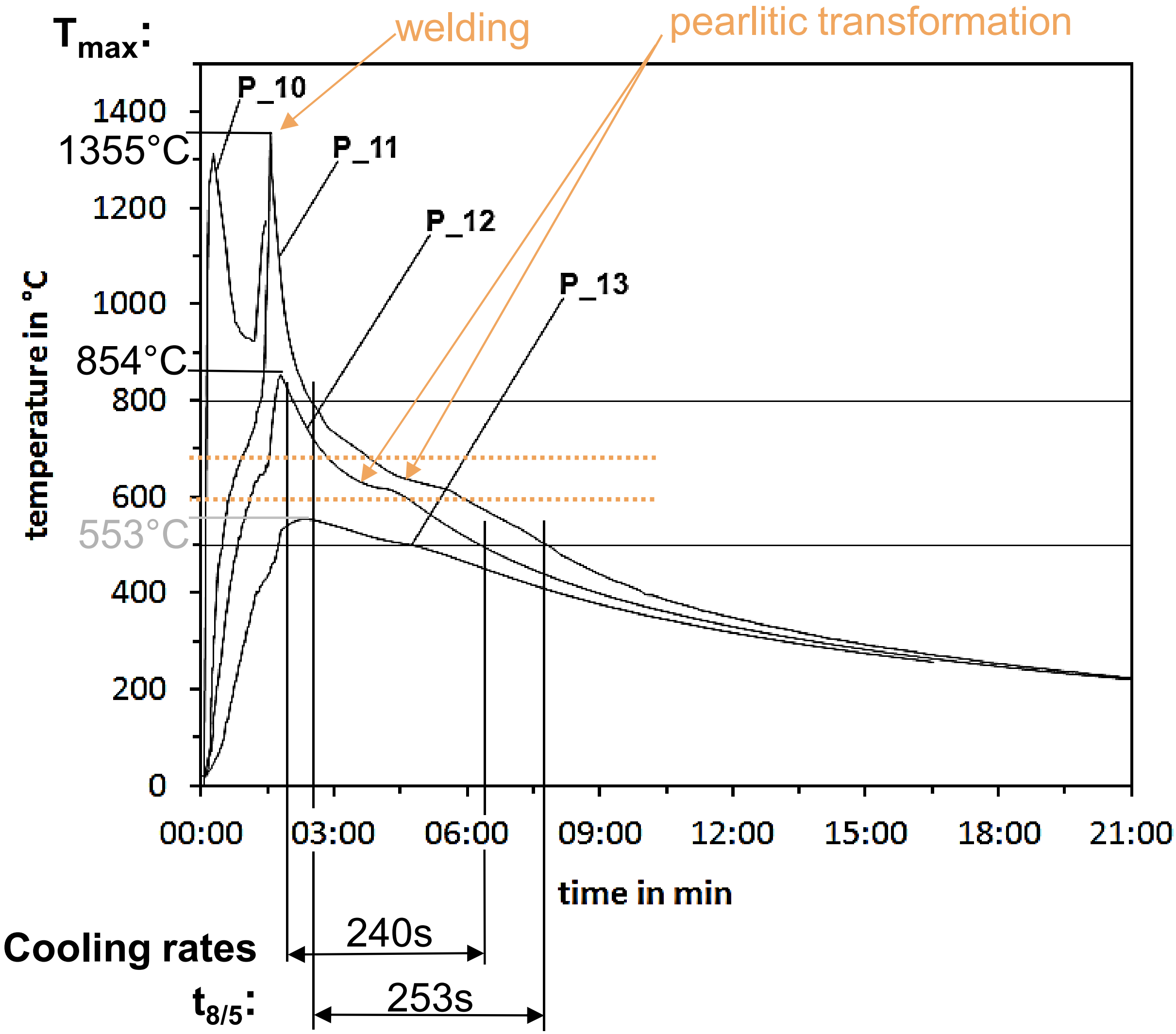
FE-Model in SYSWELD

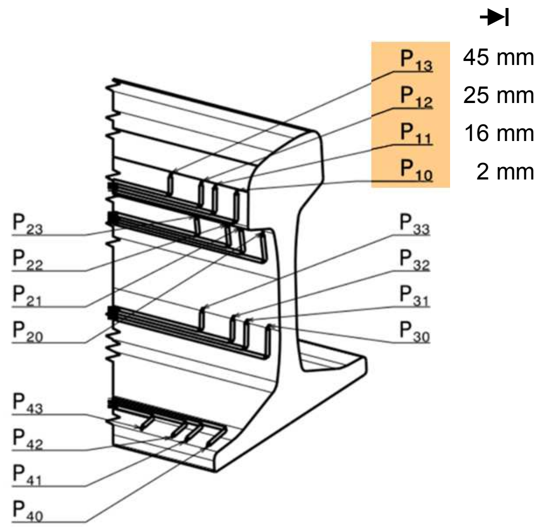
- 3D-electrokinetic-thermally coupled calculation option
- Metallurgy database based on CCT-diagram of R350HT rail steel source: [9]



RESULTS

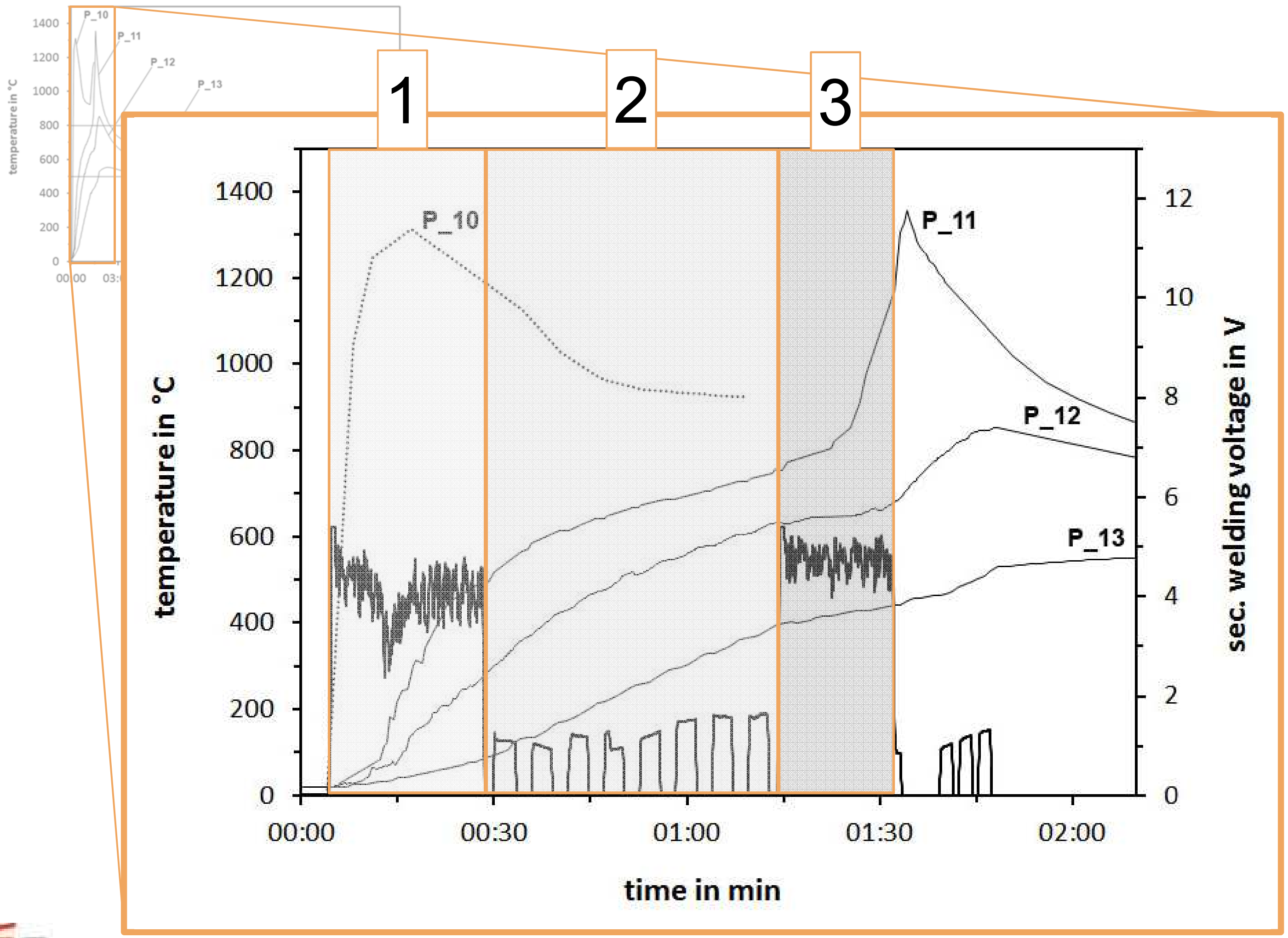
- Temperature evolution at rail head (P_{1j}):

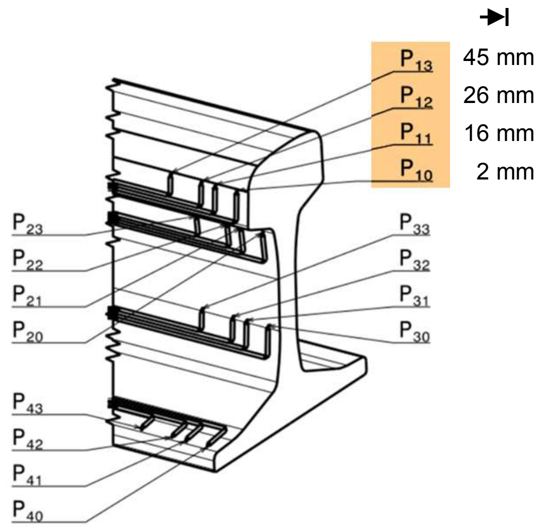




RESULTS

- Temperature evolution at rail head (P_{1j}) + $U_S(t)$:





stages heat-up phases:

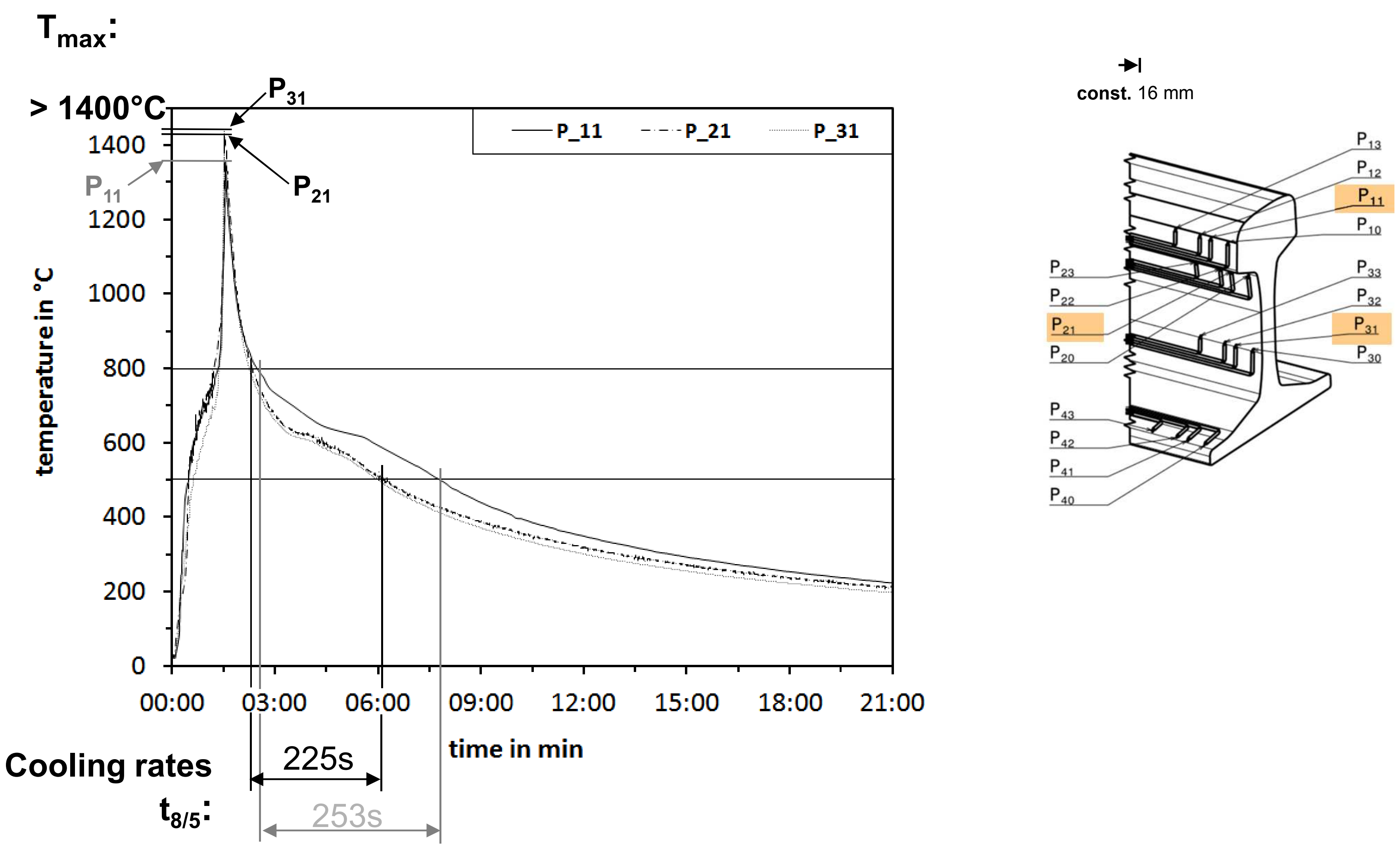
1… plane-flashing

2… pre-heating

3… flashing

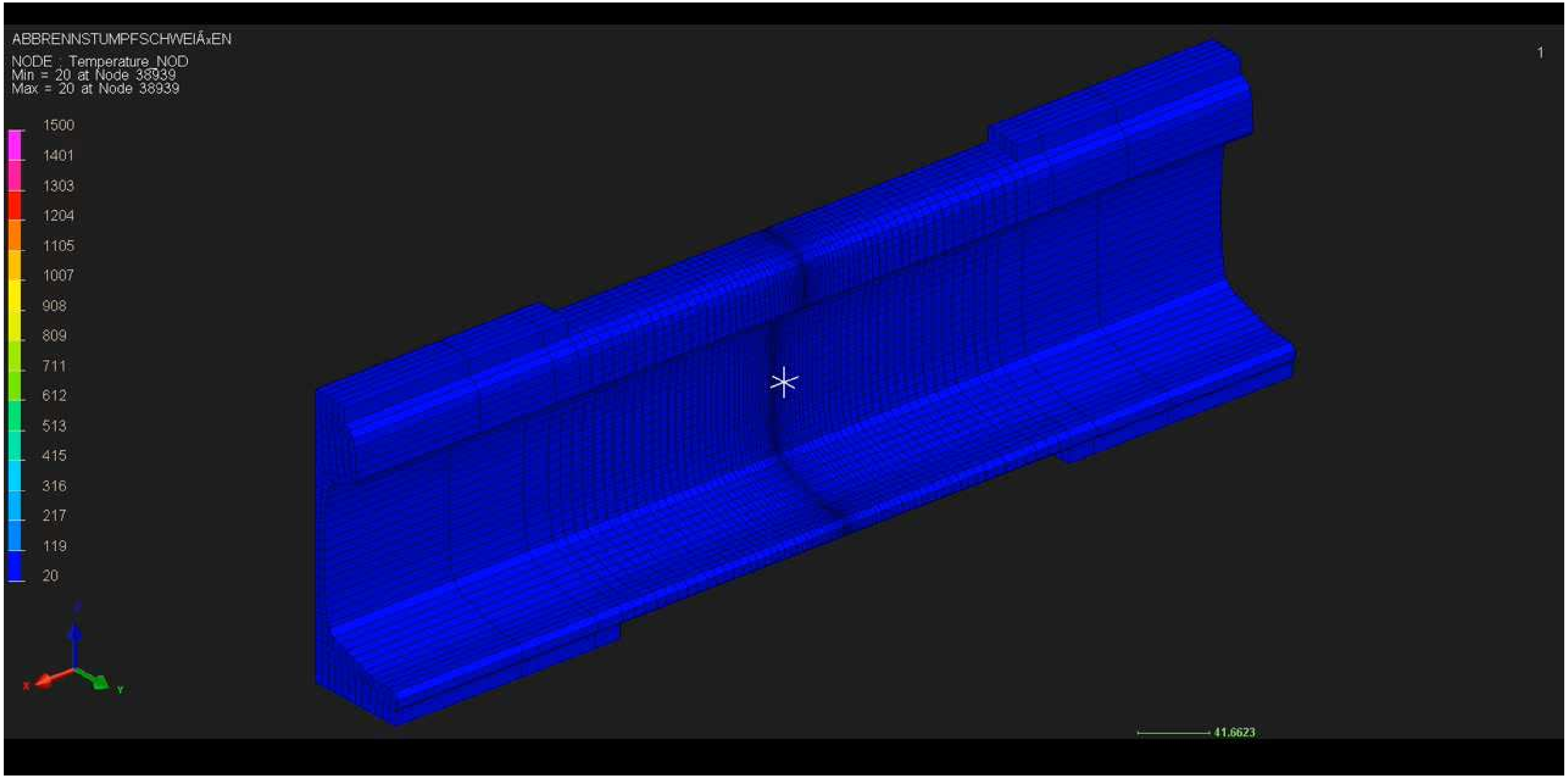
RESULTS

- Temperature evolution closest to welding face (P_{i1}) :



RESULTS

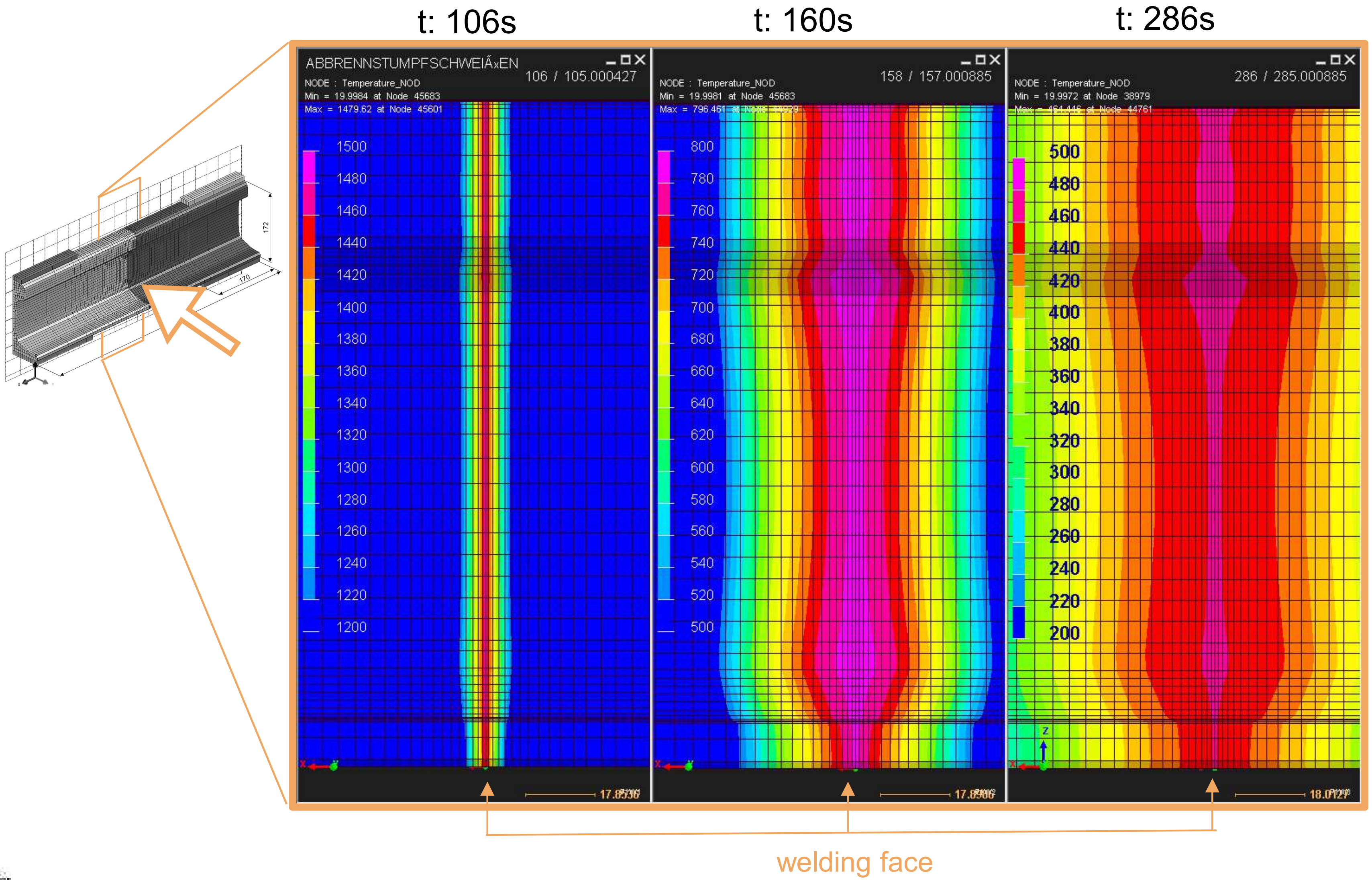
- Animation of simulation results T(t) in °C:



Link to animation…

RESULTS

- Simulation results T(t) in °C, temperature profile evolution:



DISCUSSION

Experimental results:

- T_{max} closest to weld face not homogenous over cross section
  - at rail head: T_{max} = 1355°C
  - at transition head→web, and web: T_{max} > 1400°C

- heating phase: 3 stages of the of FBW show characteric T(t) and welding voltage $U_S(t)$
  - clear allocation T(t) to known stages in :
    1. plane flashing
    2. pre-heating
    3. Flashing

- cooling rates ($t_{8/5}$): relatively slow
  - **at rail head:** ~4min, similar inside HAZ ($\Delta t_{8/5}$ ~ 13s)
  - **closest to welding face**: faster cooling at web ($\Delta t_{8/5\ head \leftrightarrow web}$ ~ 30s)

- fully pearlitic transformation

- steep ΔT_{max} / Δx : ~55 C°/mm → narrow HAZ

DISCUSSION

- Experimental results:
  - Temperature evolution for FBW at each stage of the welding cycle is understood as a result of complex interaction of the following aspects:
    - varying heat conduction conditions over the rails' cross-section due to the specific geometry (mass accumulation)
    - different heat transfer mechanisms due to given temperature dependencies and differences in surface/mass volume relation caused by rail geometry
    - varying heat input due to changing transition resistance at the welding surface (partly intently process driven, partly stochastic due to flashing mechanisms)

DISCUSSION

Simulation results:

- 3D-electrokinetic-thermally coupled + metallurgical simulation implemented in SYSWELD → depict FBW process
  - results T(t) of same magnitude
  - metallurgic calculation: fully pearlitic microstructure
  - good working numerical 'baseline' model

- comparison numerical ←→ experimental: differences remain
  - faster cooling rates in simulation

    experiment: $t_{8/5}$ ~ 250s

    simulation: $t_{8/5}$ ~ 110s
  - detailed variation of heat source not depicted
  - pearlite formation not depicted accurately enough

OUTLOOK

- planed further enhancements of the numerical model:
  - optimization 3D-T(t):
    - $R_T(T)_i$ … depict varying condition at weld surface for each stage of heating phase
    - optimization of cooling parameters
  - enhanced metallurgical model (pearlitic transformation)
  - implementation of mechanical FEM
    → depict up-setting at welding stage

ACKNOWLEDGMENTS

Thank you for your attention. Questions welcome.

The K-Project Network of Excellence for Metal JOINing is fostered in the frame of COMET - Competence Centers for Excellent Technologies by BMWFW, BMVIT, FFG, Land Oberösterreich, Land Steiermark, Land Tirol and SFG. The programme COMET is handled by FFG.

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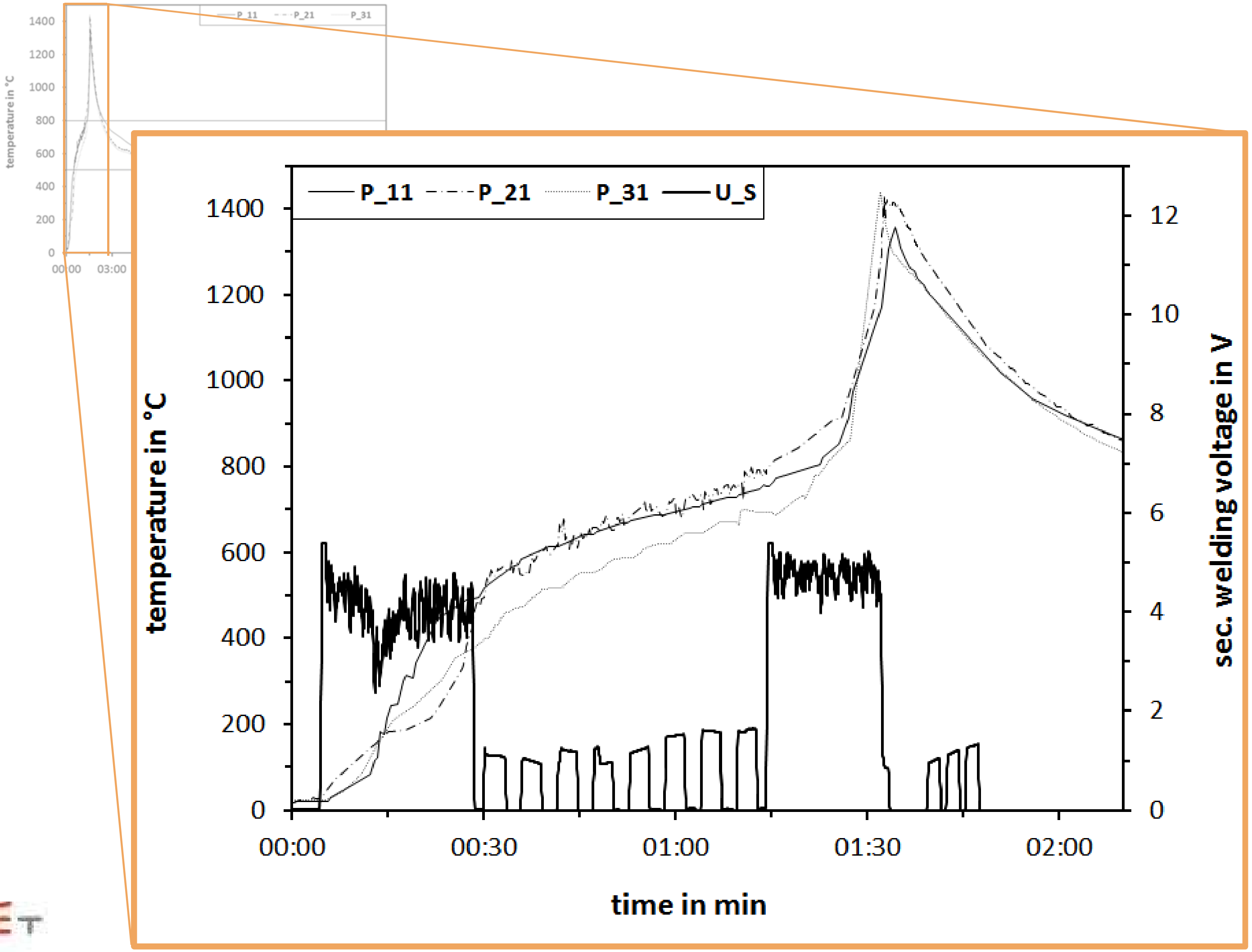
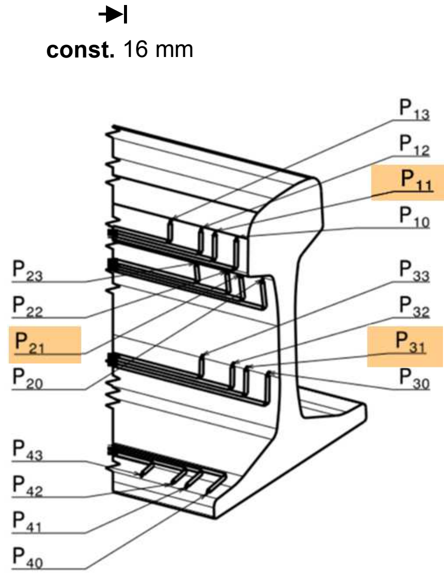
RESULTS

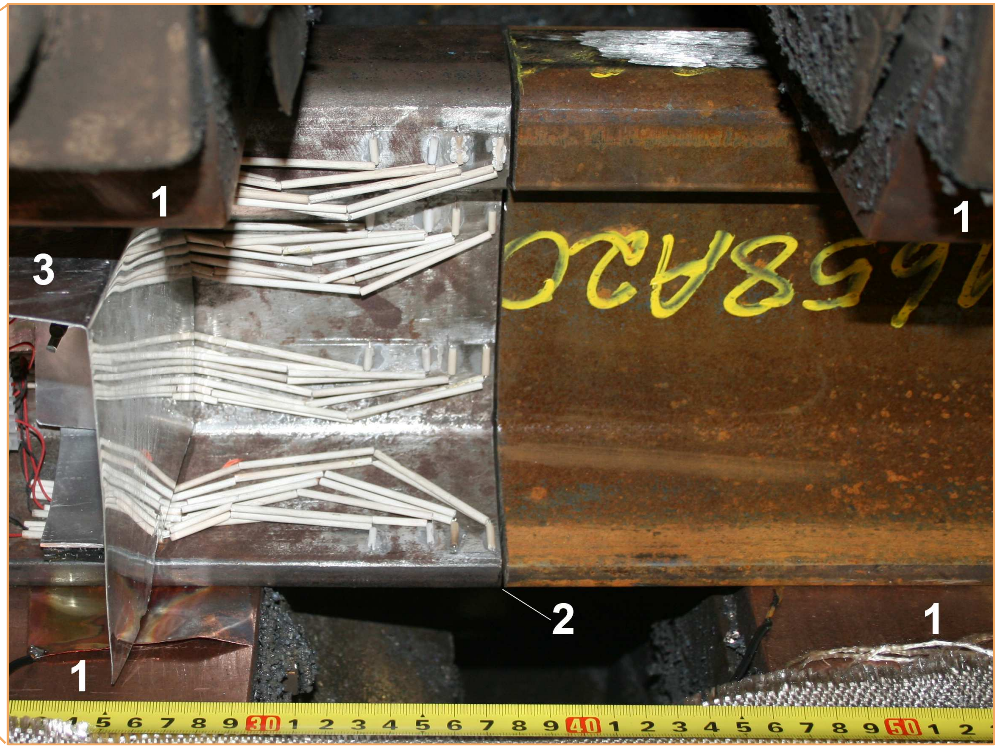
- Temperature evolution closest to welding face (P_{i1}) :





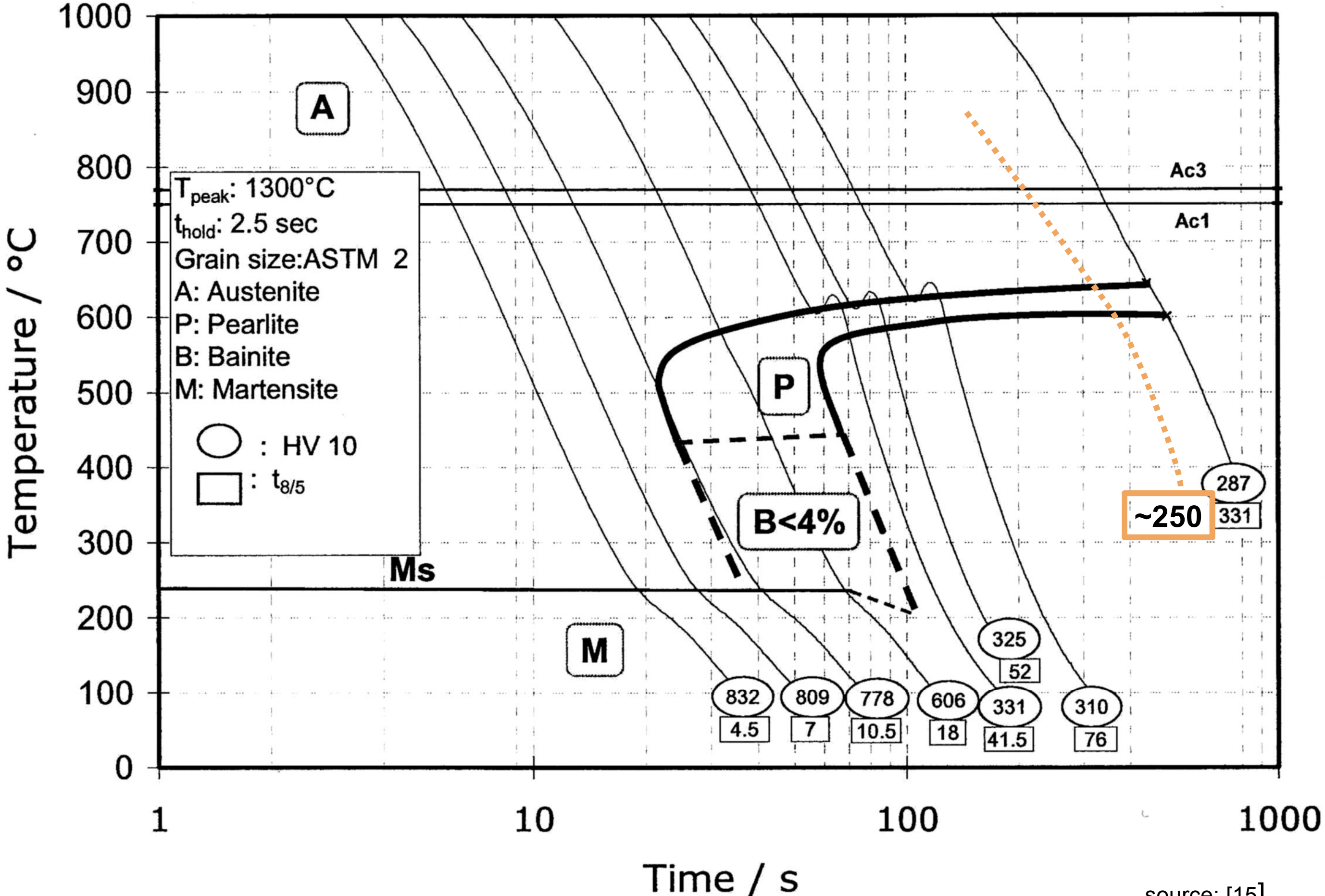
EXPERIMENTAL

- Instrumented welding experiments:



1… welding and clamping electrode of FBW machine
2… welding gap
3… protection cover for thermo-couple connection lines

WELDING-CCT R260 RAIL STEEL

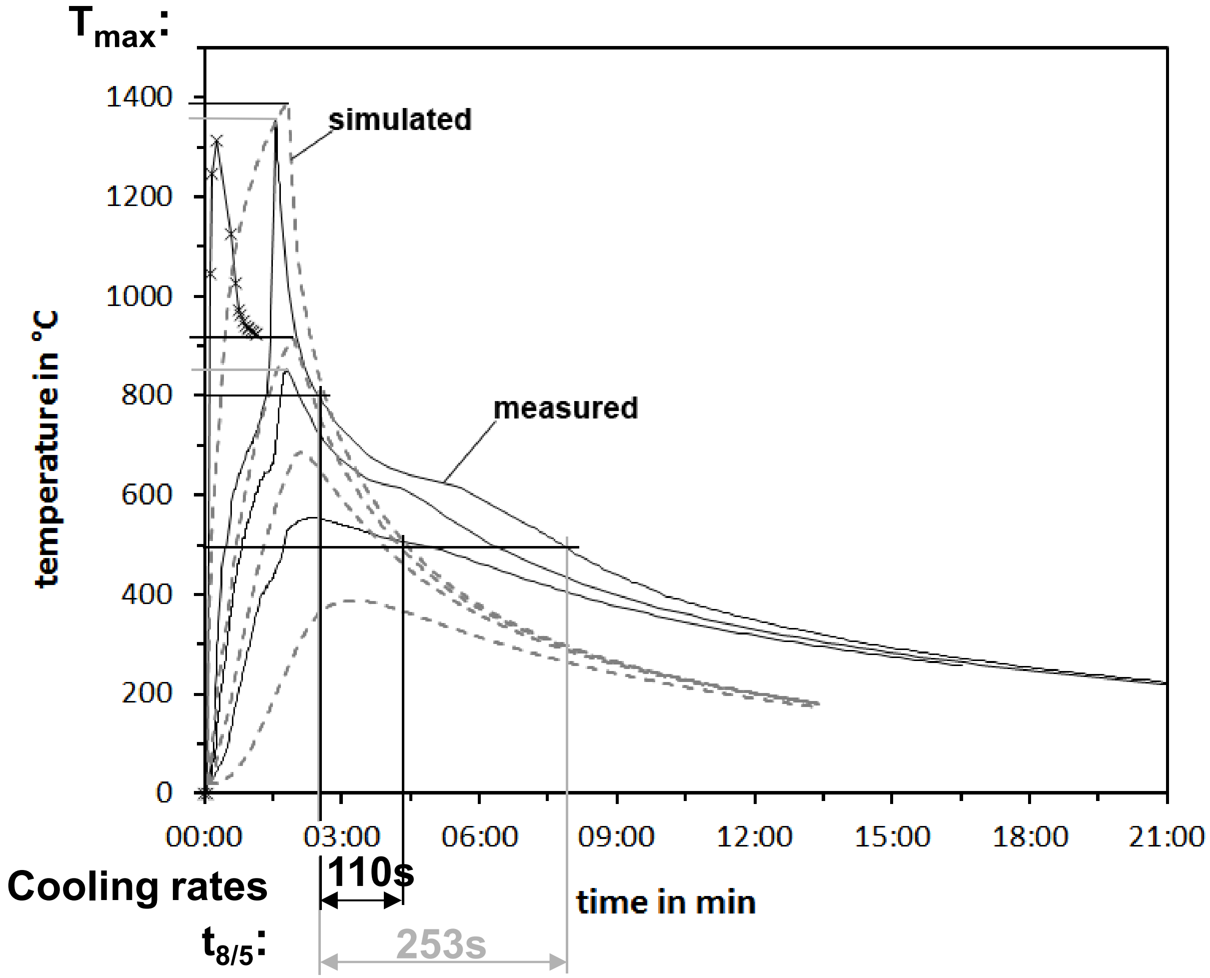


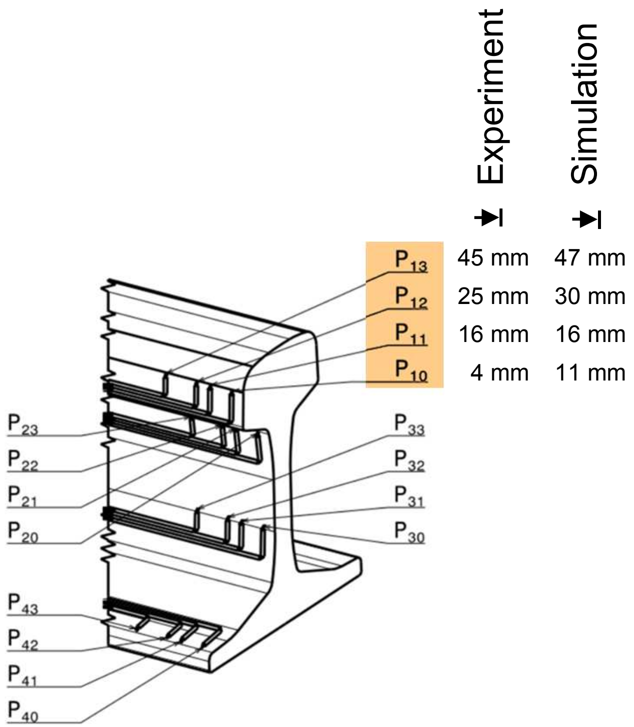
source: [15]

RESULTS

T(t) at rail head:

- experiment ——— vs. simulation ------





SUMMARY

- **instrumented FBW experiments on a stationary machine**
  - R260 rail steel, 60E1 profile
  - multiple T(t)-curves → temperature field over time
  - secondary welding voltage $U_S(t)$

→ characterization of stages at heat-up phase by T(t) and $U_S(t)$
→ in-depth process-knowledge for FBW welding of rails

- **numerical simulation of FBW-process**
  - 3D electrokinetic-thermally coupled calculation in SYSWELD
  - metallurgical model of 350HT based on CCT-diagram
  - results of same magnitude

→ accuracy of model expandable, relevant aspects not clearly derivable yet

OUTLINE WORK CONTENT

- **experimental:** characterization of FBW-process of rails:
  - **T(t)-curves** heat-up and cooling phase
  - multiple locations: head, head-to-web, web and foot (temperature field)
  - **heat-source:** secondary welding voltage **U_s(t)**

- **numerical:** implementation of **simulation model** of the FBW-process for rails:
  - 3D transient T-field
  - validation based on experiments
  - metallurgical transformations

→ depict relevant aspects that influence properties of welding joint in simulation