Advances in thermo-mechanical characterization of steel using data fusion and inverse methods

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VForm-xSteels

This project has received funding from the Research Fund for Coal and Steel under grant agreement No 888153

Objective

VForm-xSteels

Material Testing 2.0: mechanical testing of materials that combines full-field deformation measurements (like DIC) and inverse identification to extract mechanical constitutive parameters from heterogeneous (non-statically determinate) stress states

Data fusion: process of integrating multiple data sources to produce more consistent, accurate and useful information than that provided by any individual data source

Objective: Use heterogeneous stress and temperature fields to identify the thermomecanical behavior of high strength steel

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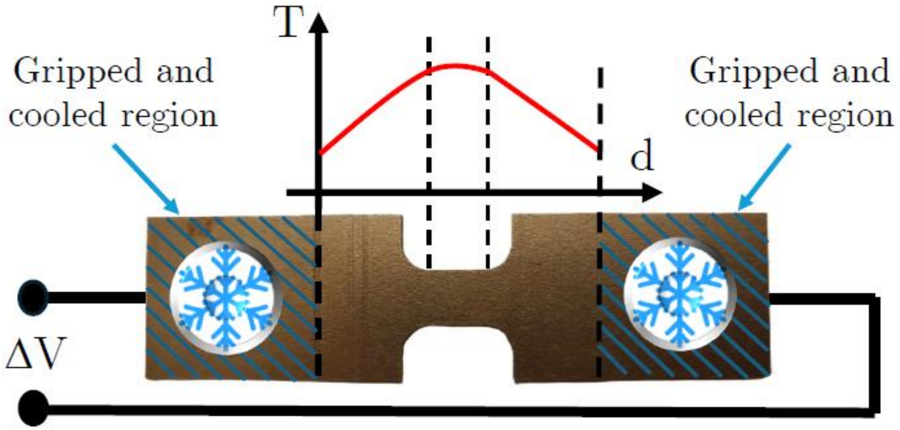
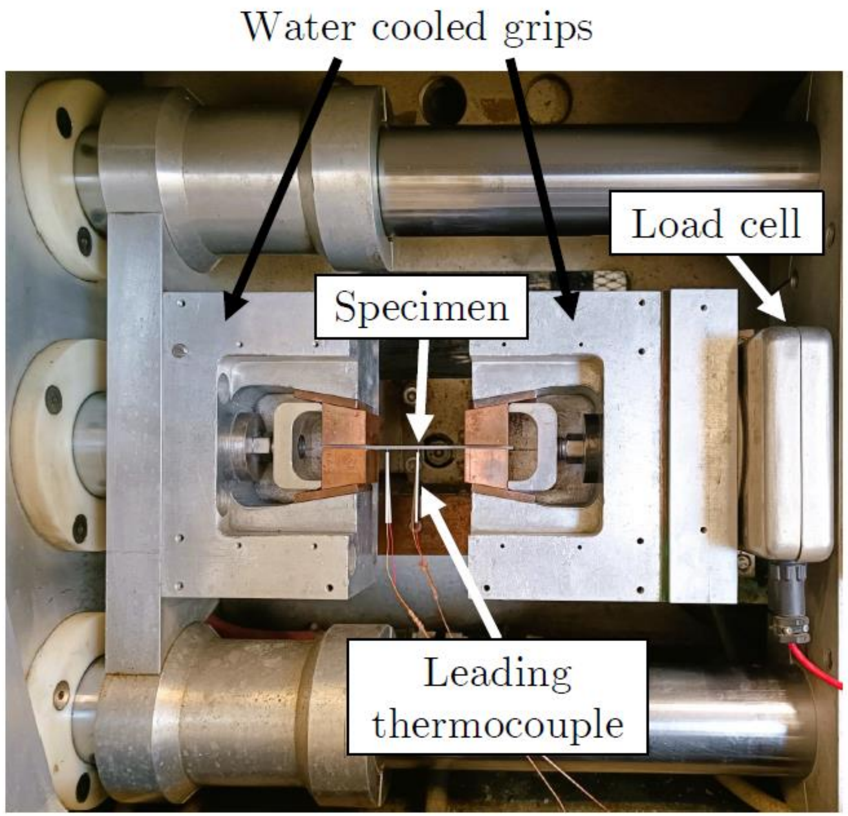
Gleeble system

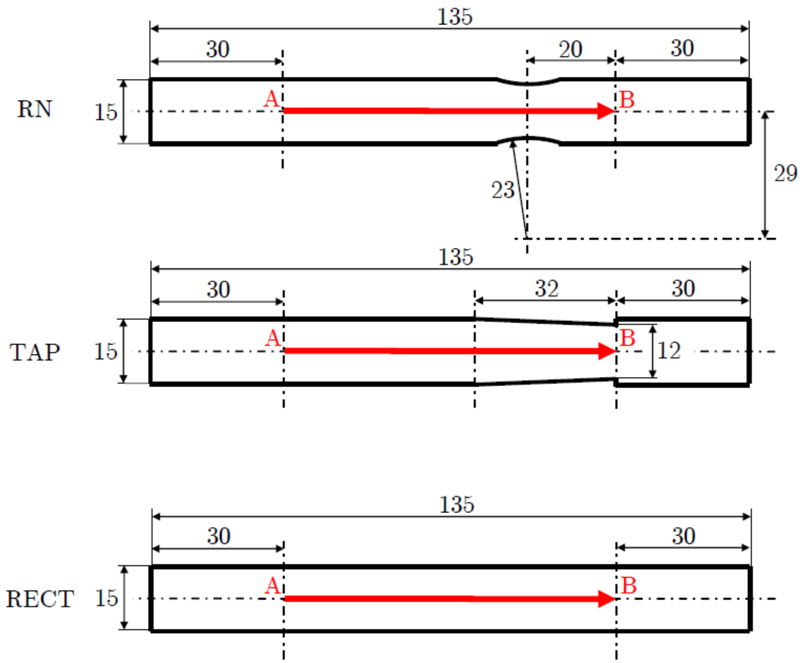
This system uses the Joule effect to heat a conductive specimen

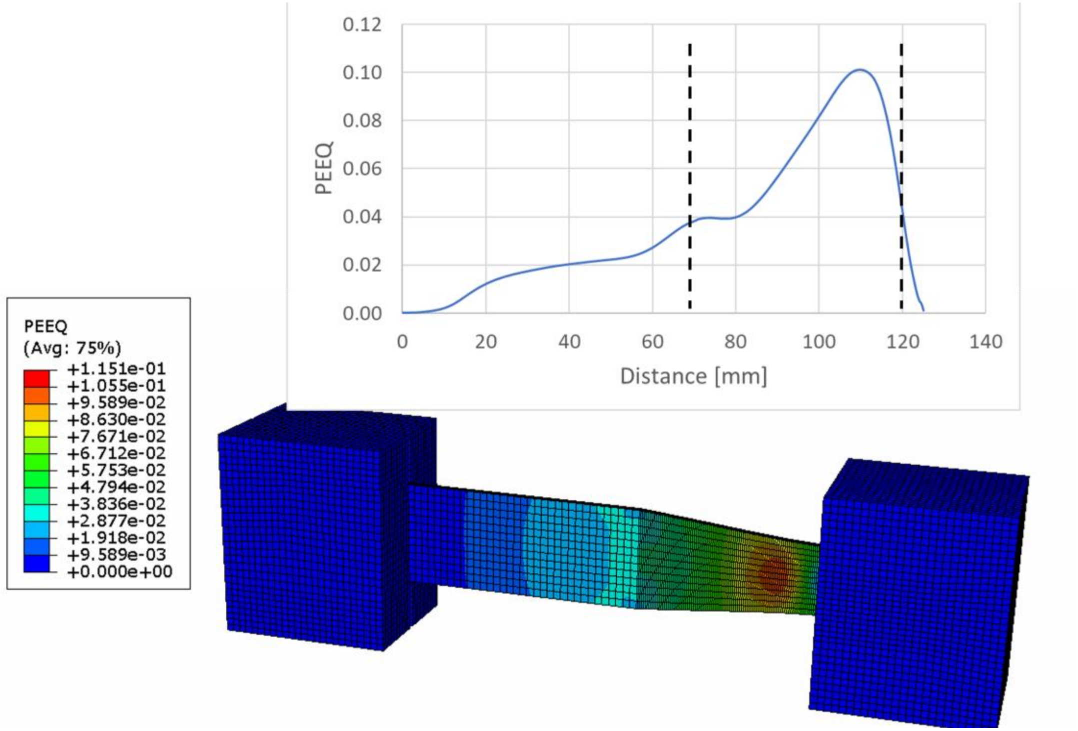




Specimen Optimization

The geometry of the specimen can be optimized to have both temperature and stress heterogeneity





Rossi M., Morichelli L., Cooreman S., Thermo-mechanical Characterization of High-strength Steel through Inverse Methods, Proceedings of SEM2023

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Constitutive Model

Hardening model: modified Johnson-Cook with no strain rate effect

$$\sigma(\varepsilon_p) = (A + B\varepsilon_p^n)(1 - \widetilde{T}^m) \ \text{with} \ \widetilde{T} = \begin{cases} 0 & T < T_t \\ \dfrac{T - T_t}{T_m - T_t} & T_t < T < T_m \\ 1 & T > T_m \end{cases}$$

Yielding model: Hill48 with normal anisotropy

$$\sigma_{eq} = \sqrt{\sigma_1^2 + \sigma_2^2 + \frac{2R}{1+R}\sigma_1\sigma_2 + (2+4R)\tau_{12}^2}$$

5 parameters to be determined from 1 test (A,B,n,m,R)

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Used Inverse Method: Virtual Fields Method

VFM exploits the equilibrium equation expressed using the principle of virtual work to identify *n* constitutive parameters $\boldsymbol{\xi} = [\xi_1, \cdots, \xi_i, \cdots, \xi_n]$

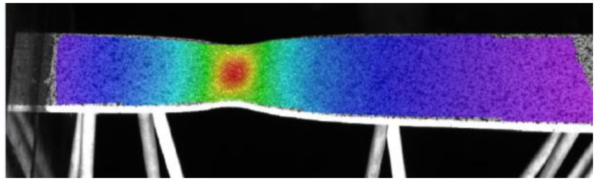
$T_j^{1PK} n$ = External forces measured with the load cells

Minimization algorithm (Iterative solution)

Solved! Correct material parameters

$$\Psi(\boldsymbol{\xi}) = \sum_{i=1}^{N_{VF}} \sum_{j=1}^{N_{step}} \left| \underbrace{\int_V T_j^{1PK} \cdot \delta F_i^* \, dV}_{\text{Internal Virtual Work}} - \underbrace{\int_{\partial V} \left(T_j^{1PK} n\right) \cdot \delta v_i^* \, dS}_{\text{External Virtual Work}} \right|$$

$$T^{1PK} = \det(F)\, \boldsymbol{\sigma} F^{-T} = \det(F_{\mathrm{DIC}})\, \boldsymbol{\sigma}\left(\epsilon_{\mathrm{DIC}}, T, \boldsymbol{\xi}\right) F_{\mathrm{DIC}}^{-T}$$



$\delta v^*, \delta F^*$ virtual fields (arbitrary functions)

Rossi M. et al., Int J Solids Struct, 2016

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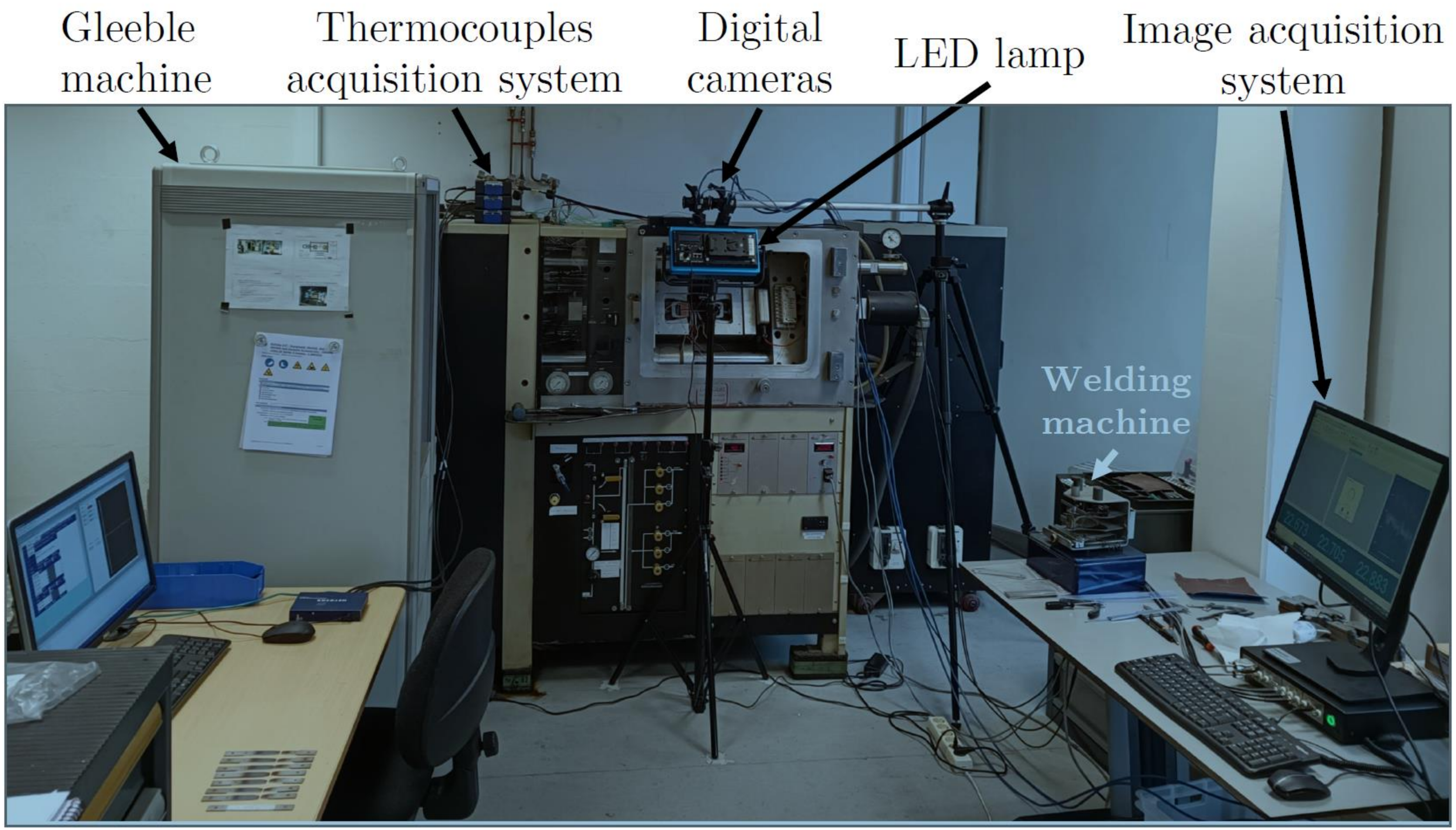
Exeprimental Set-up



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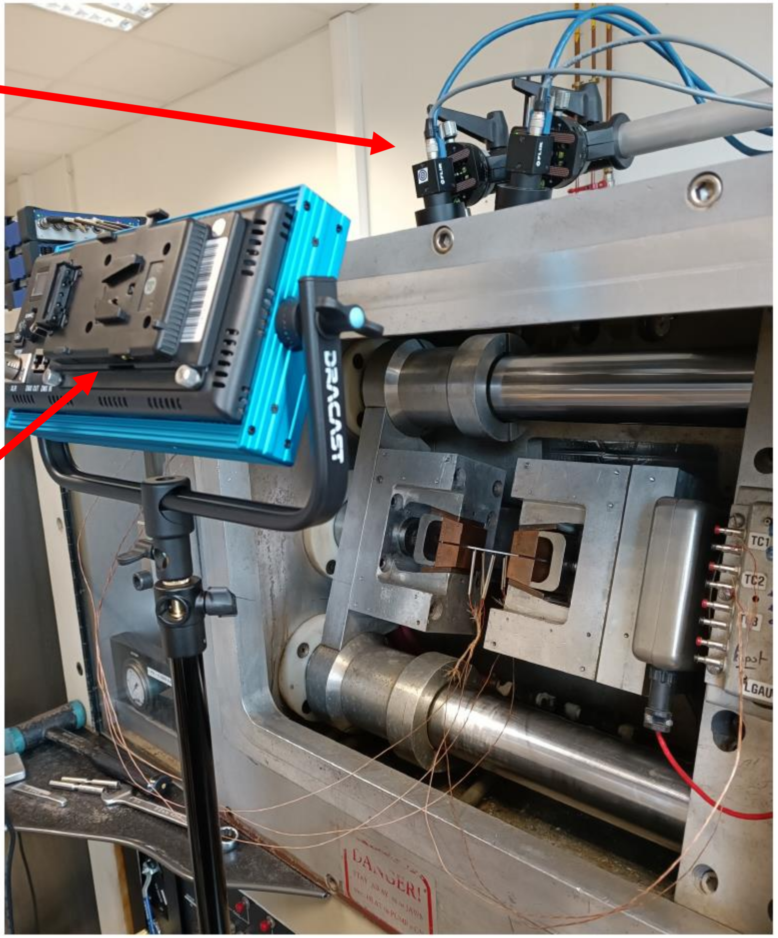
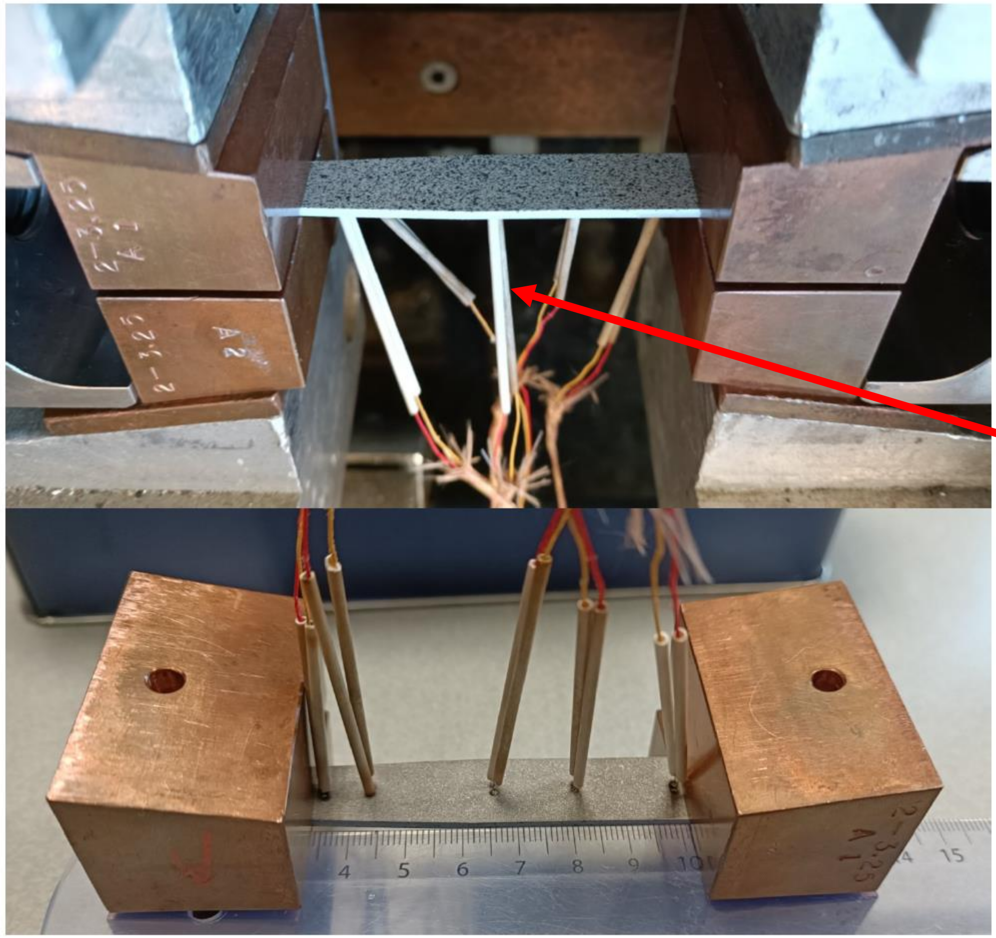
Exeprimental Set-up

Cameras

Light





Thermocouples

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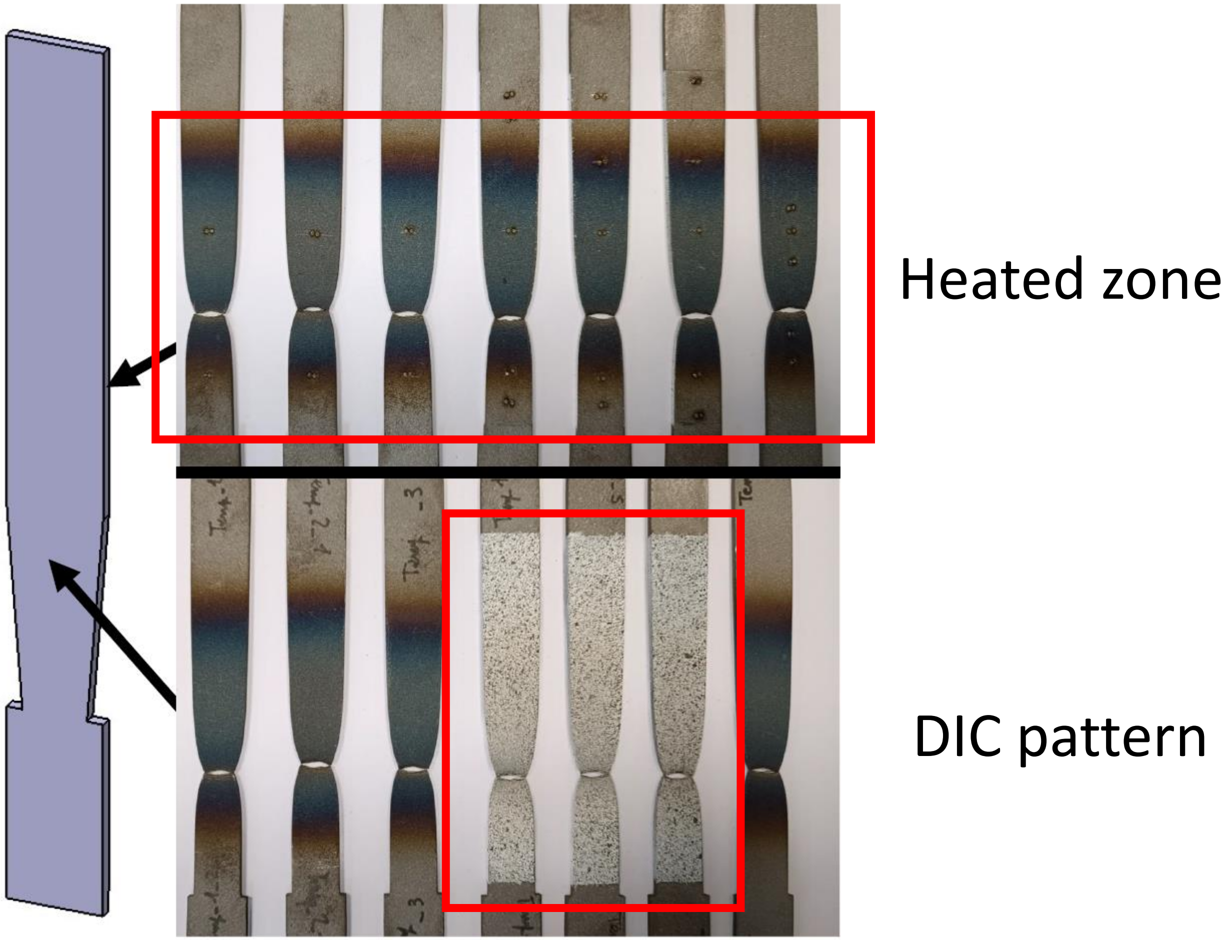
Tested Specimens



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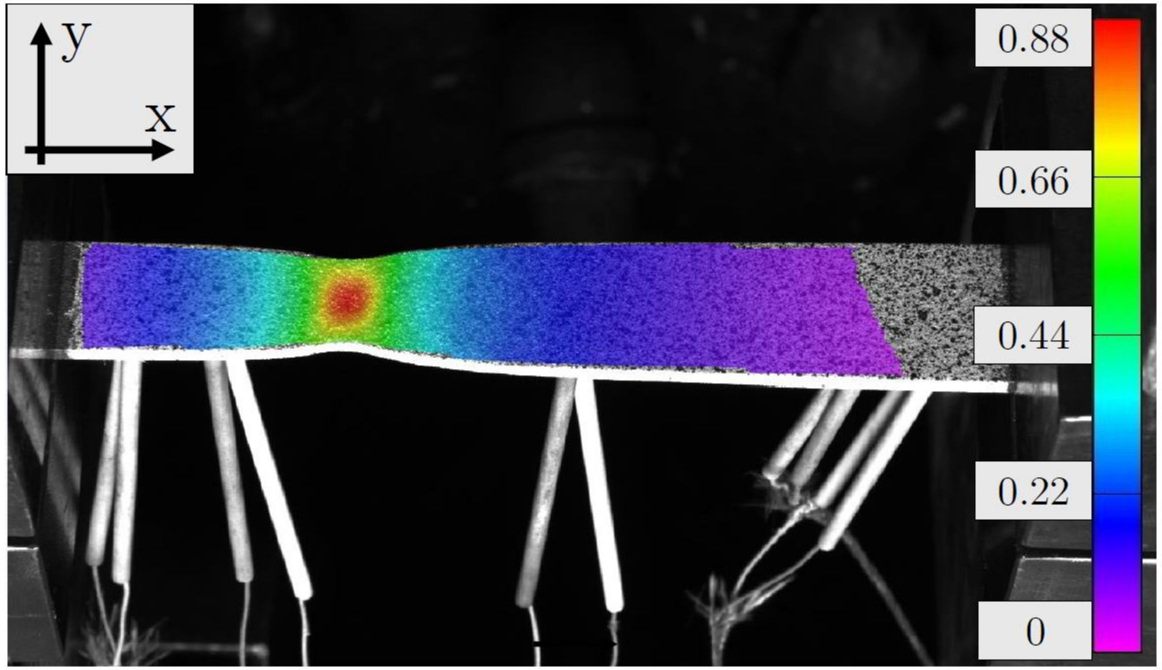
DIC measurements

Images were acquired with two Flir Backfly S BFS-U3-51S5M-C



DIC measurement were conducted using MatchID (v2023.1), with stereo correlation, subset size: 27 pixels, step size: 10 pixels, no spatial smoothing (gradient function)

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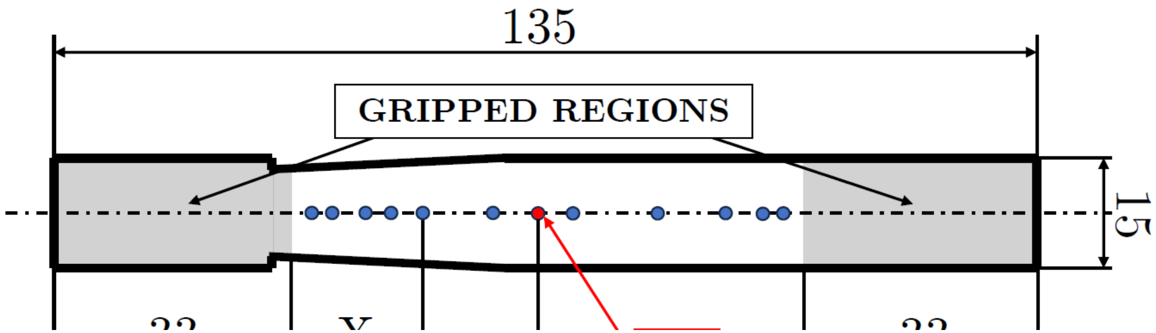
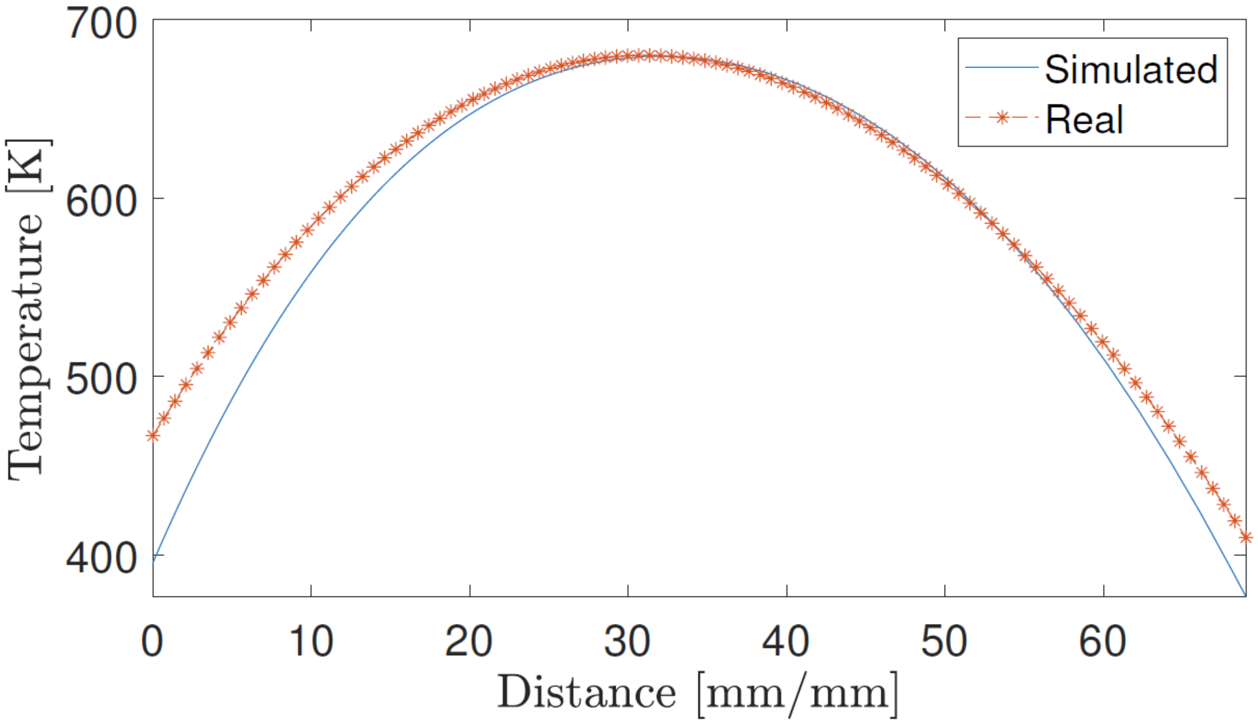
Temperature measurement





X [m

TC11

67

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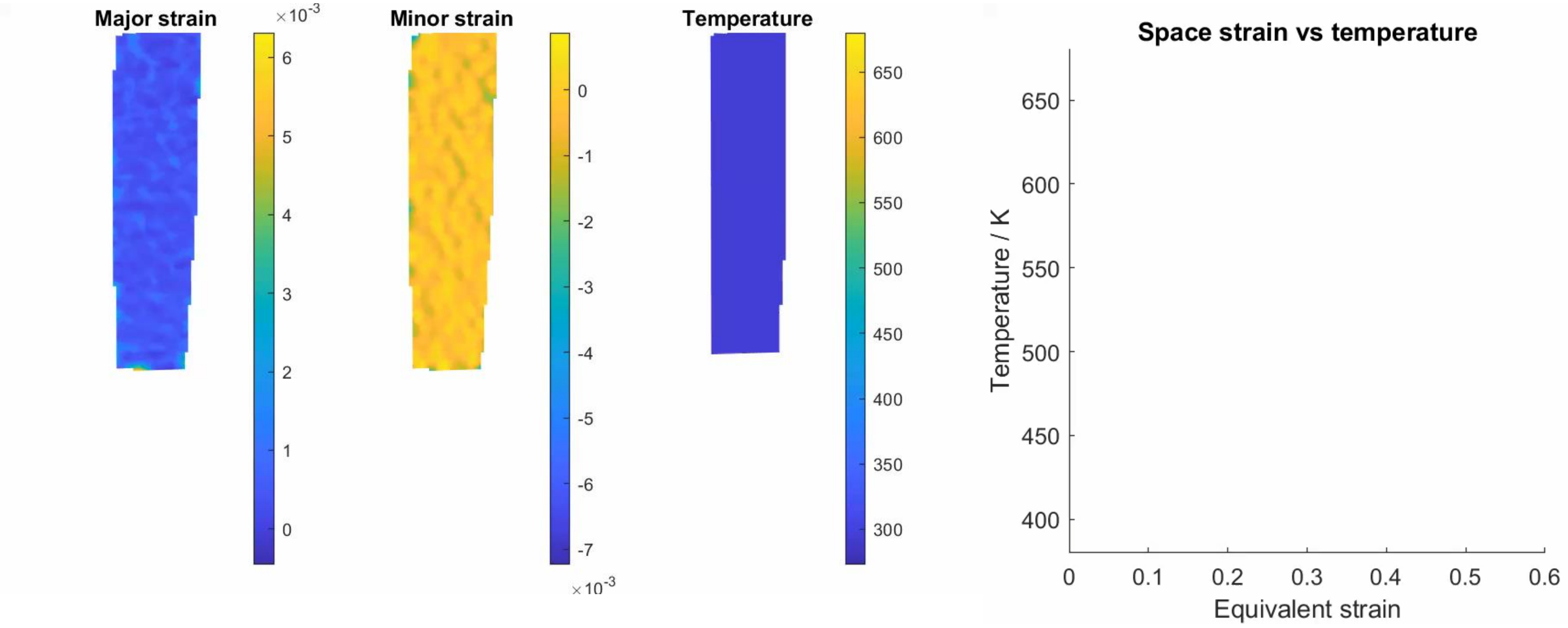
Strain and temperature fields



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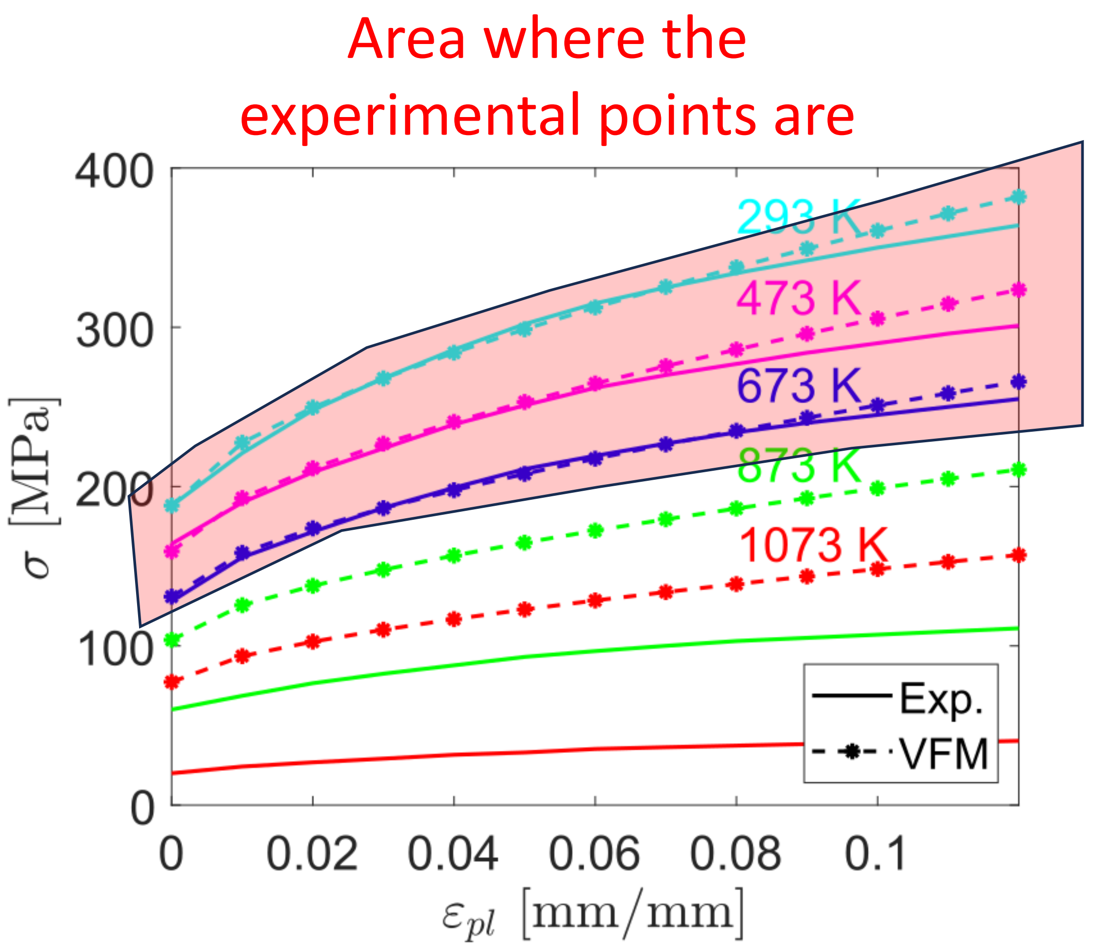
Identification results

	B [MPa]	n	m	R
Initial guess	500	1	1	1
Identified	754	0.64	0.92	1.98



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Conclusions

- A single specimen with a heterogeneous temperature fields can be used to calibrate the thermal exponent of a J-C model and the anisotropy parameter *R*
- Gleeble system was used with a specifically designed specimen type
- VFM was used to extract the parameters
- The identification is robust within the explored temperature range

Future development

- Measure the temperature field with a IR-camera
- Extend the test to higher temperatures
- Try different constitutive models

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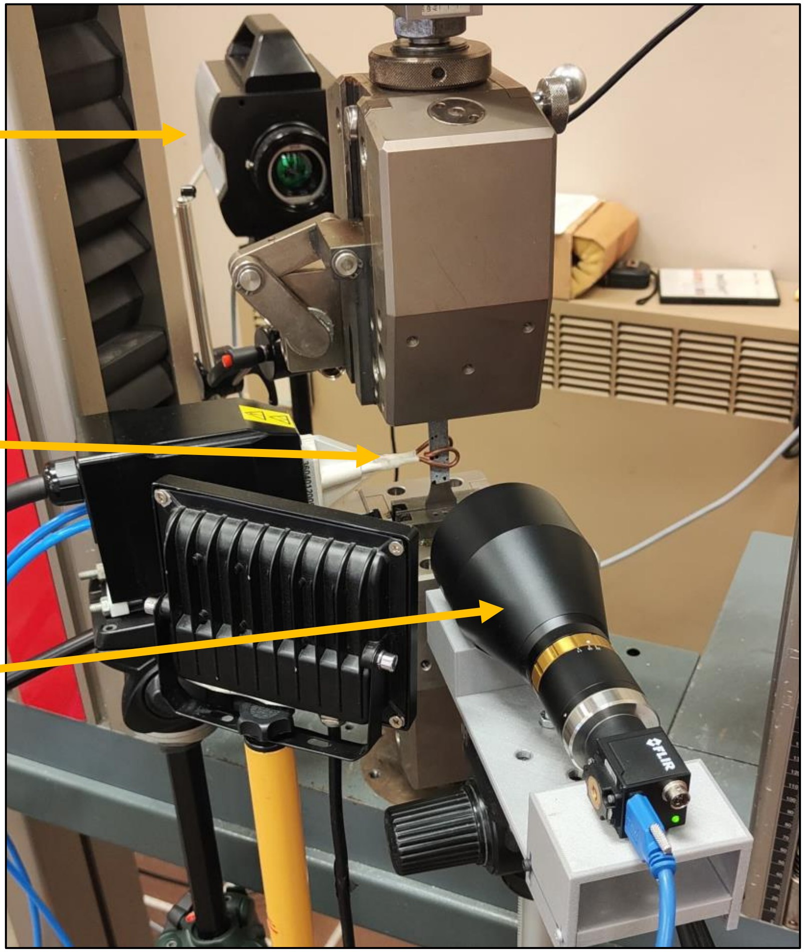
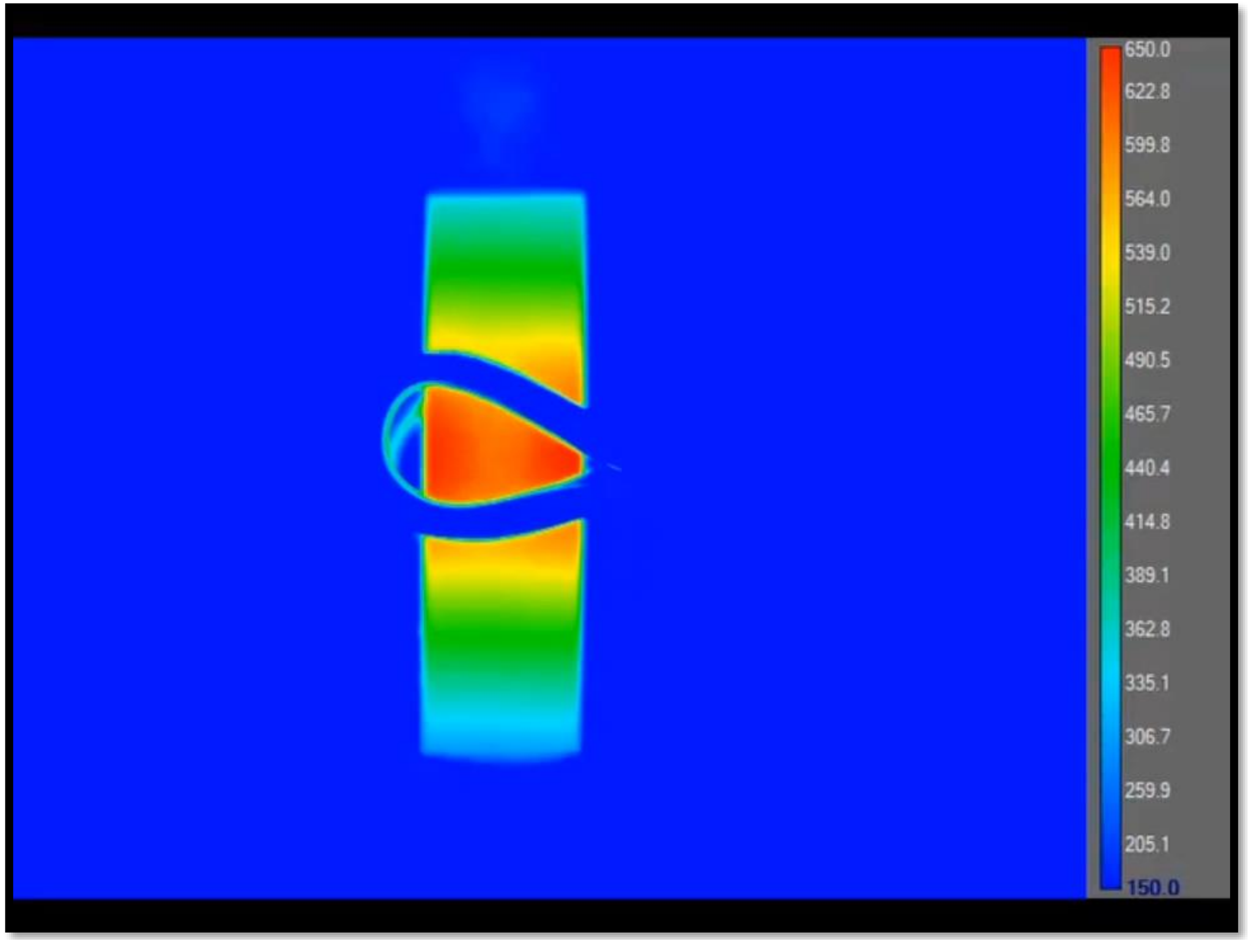
Simplified experimental set-up

IR-camera

Inductor

Camera (with Telecentric lens)





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