An effective model-calibration for polycarbonate impact simulations

<u>Marta Beltramo</u>
Lorenzo Peroni
Martina Scapin

Mechanical and Aerospace Engineering Department

Politecnico di Torino
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DYNLAB

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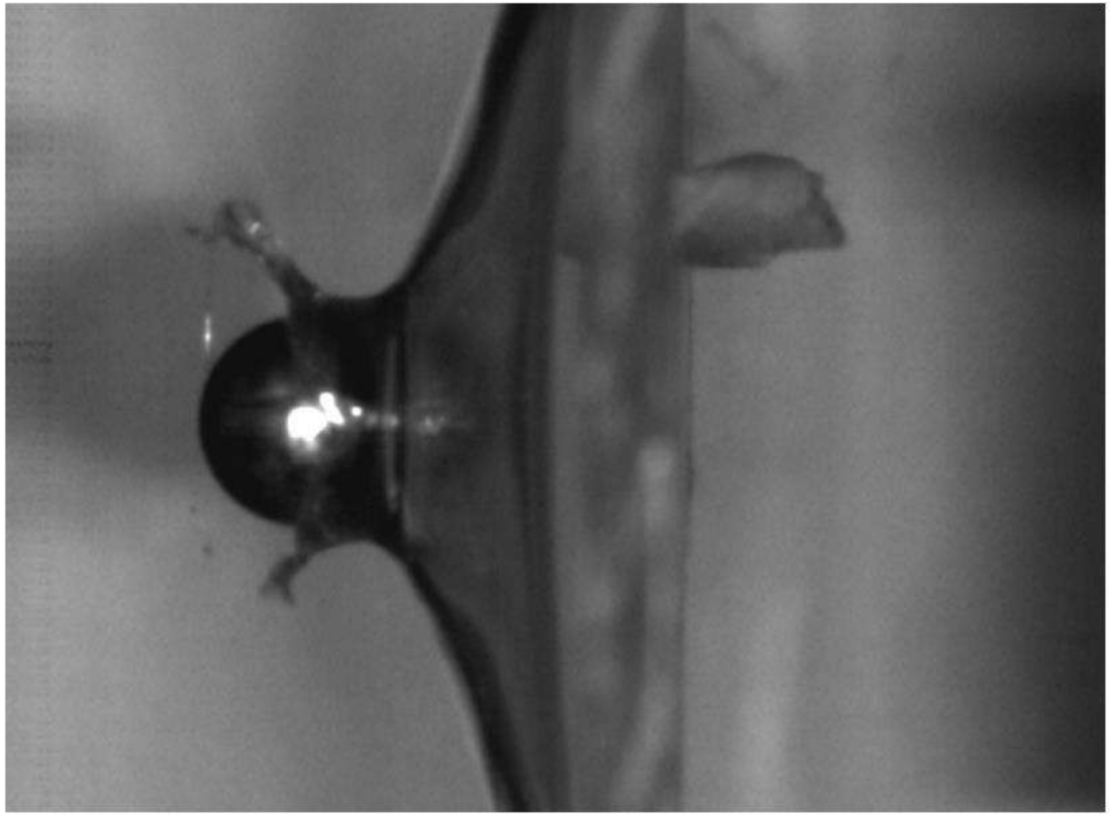
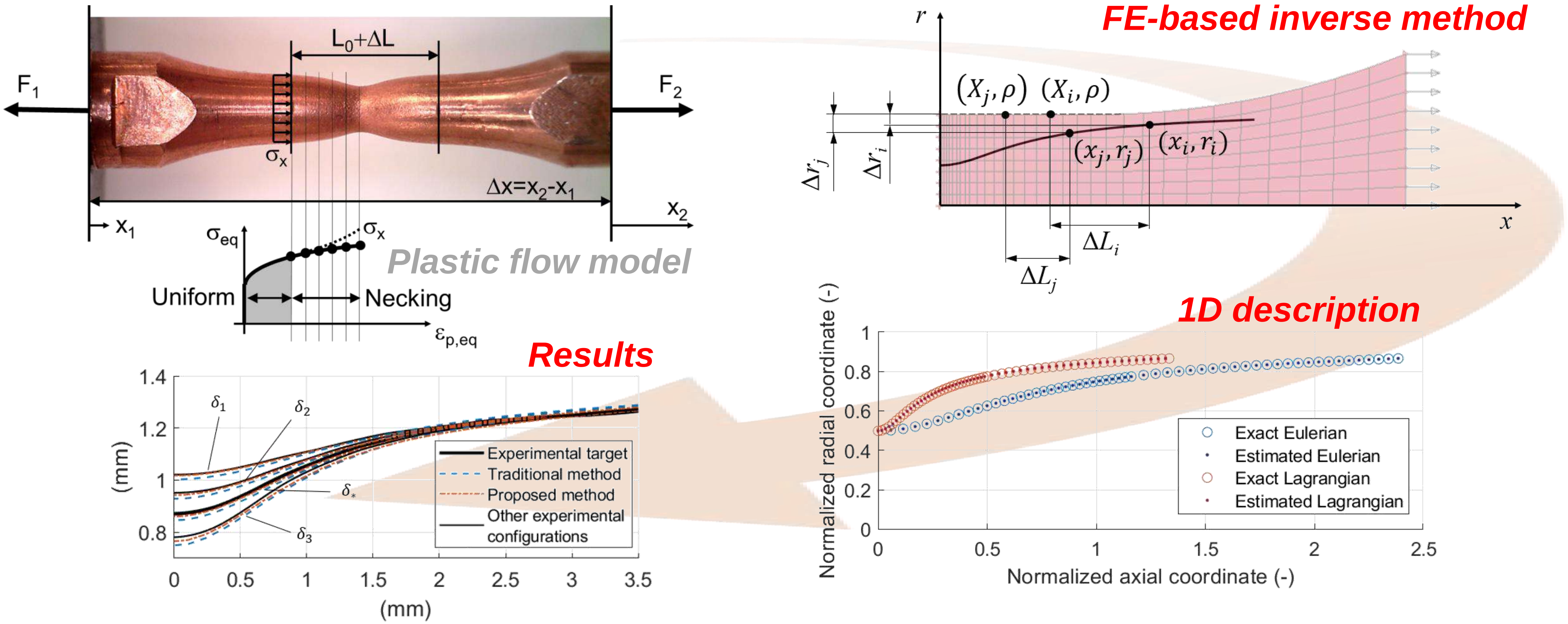


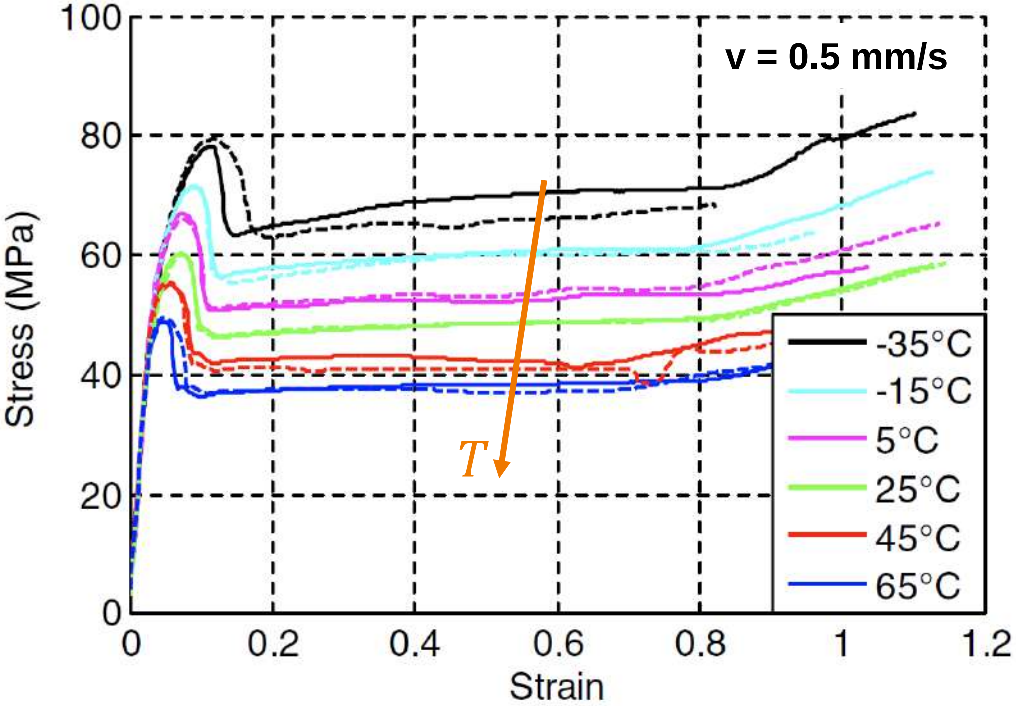
My PhD research

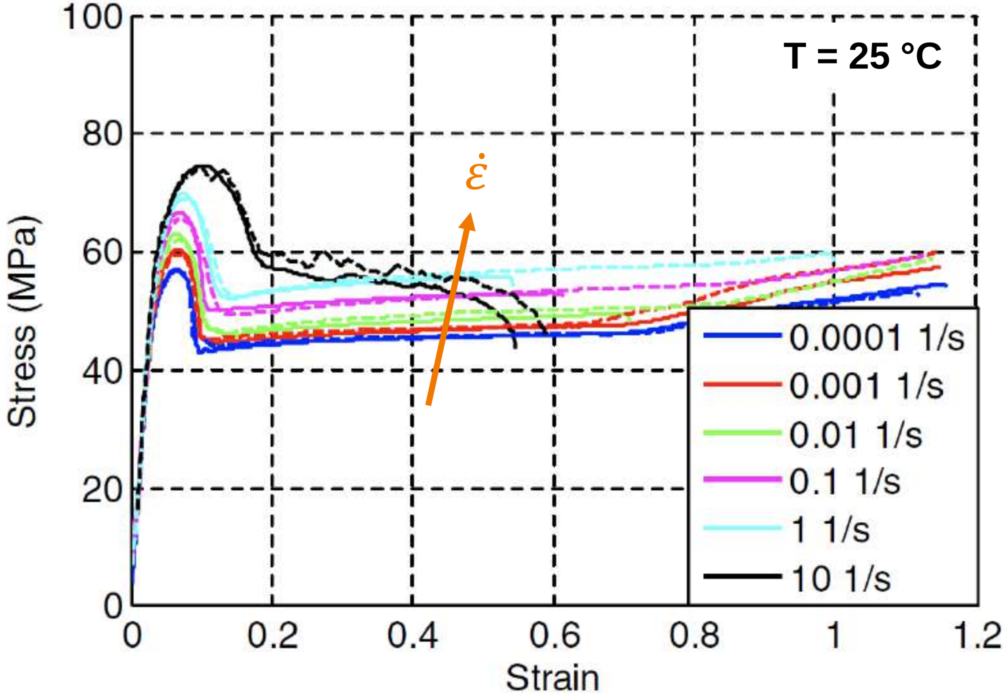
Advanced methods for **calibrating** elasto-plastic material models, with particular reference to the **post-necking** phase.

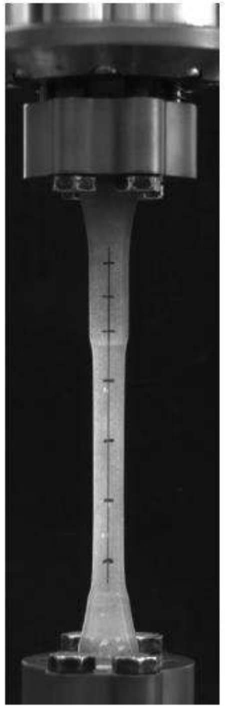


Starting point: experimental tests

In this preliminary phase, reference was made to already available experimental data*.







Future experimental investigation will be conducted with the **Hopkinson** bar.

* Peroni, M., Peroni, L., & Avalle, M. (2009). Advanced experimental investigation and numerical simulation of polycarbonate behaviour at different strain-rate and temperature. In *DYMAT-International Conference on the Mechanical and Physical Behaviour of Materials under Dynamic Loading* (Vol. 2, pp. 1383-1389). EDP Sciences.

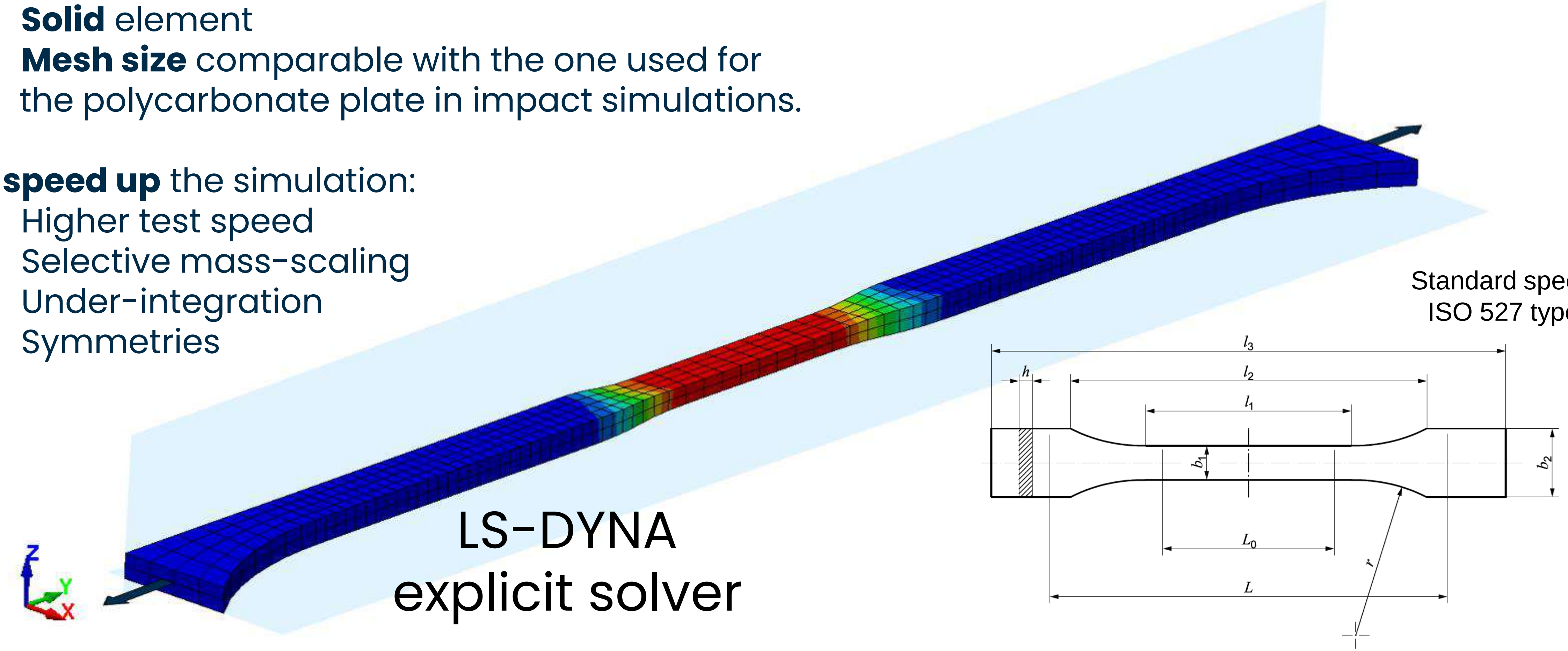
FE model: tensile specimen

The model-calibration is done through an **inverse numerical method** based on **FE simulations**. Since the calibrated material model depends on the FE model itself, its features must be similar to the ones of FE model used for the application.

- **Solid** element
- **Mesh size** comparable with the one used for the polycarbonate plate in impact simulations.

To **speed up** the simulation:

- Higher test speed
- Selective mass-scaling
- Under-integration
- Symmetries



LS-DYNA
explicit solver

Standard specimen
ISO 527 type 1A

FE model: material model

The material model must be able to represent:
- **strain-rate** hardening
- **thermal** softening
- **necking propagation** → **stiffening** model (e.g., Voce)

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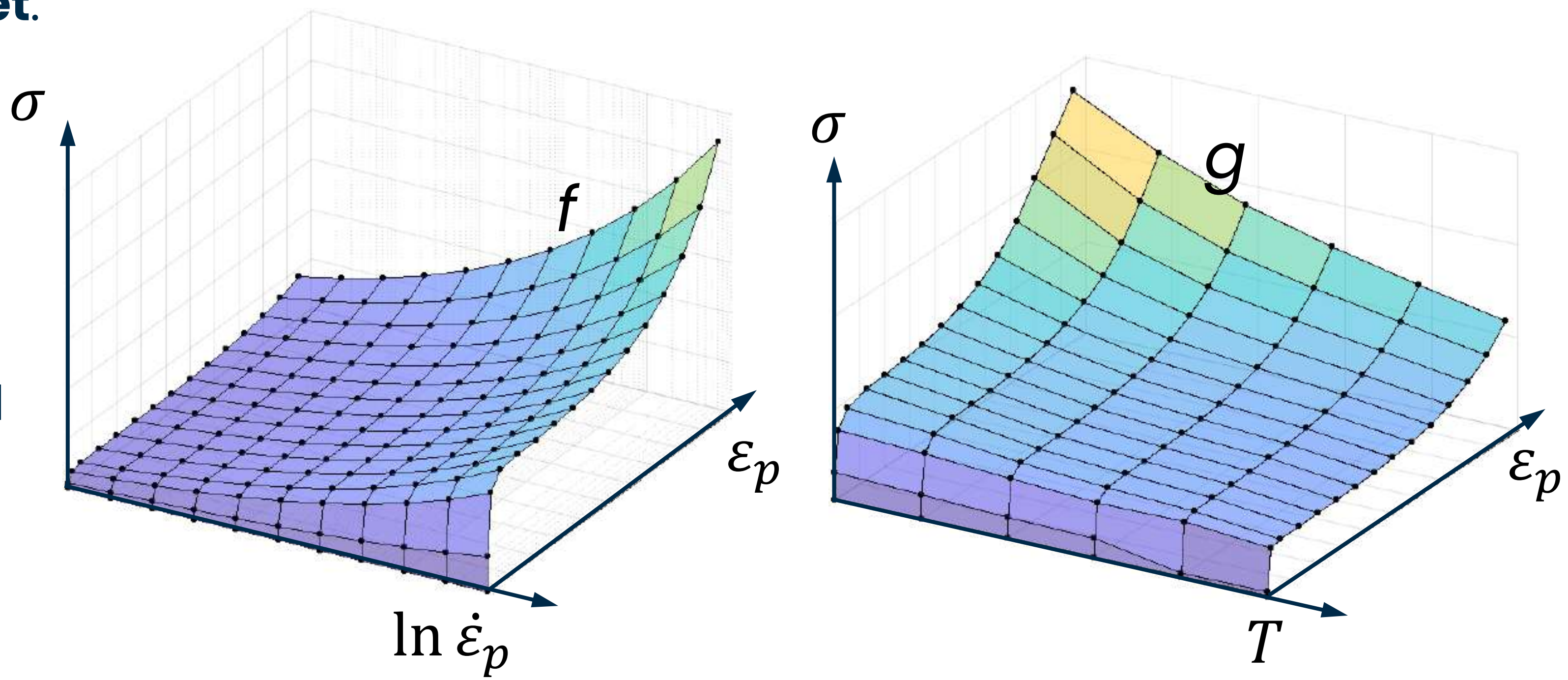
A tabular plastic flow curve allows to correctly predict the **necking onset**.

*MAT_106: **elasto-viscoplastic** material with **thermal** effects.

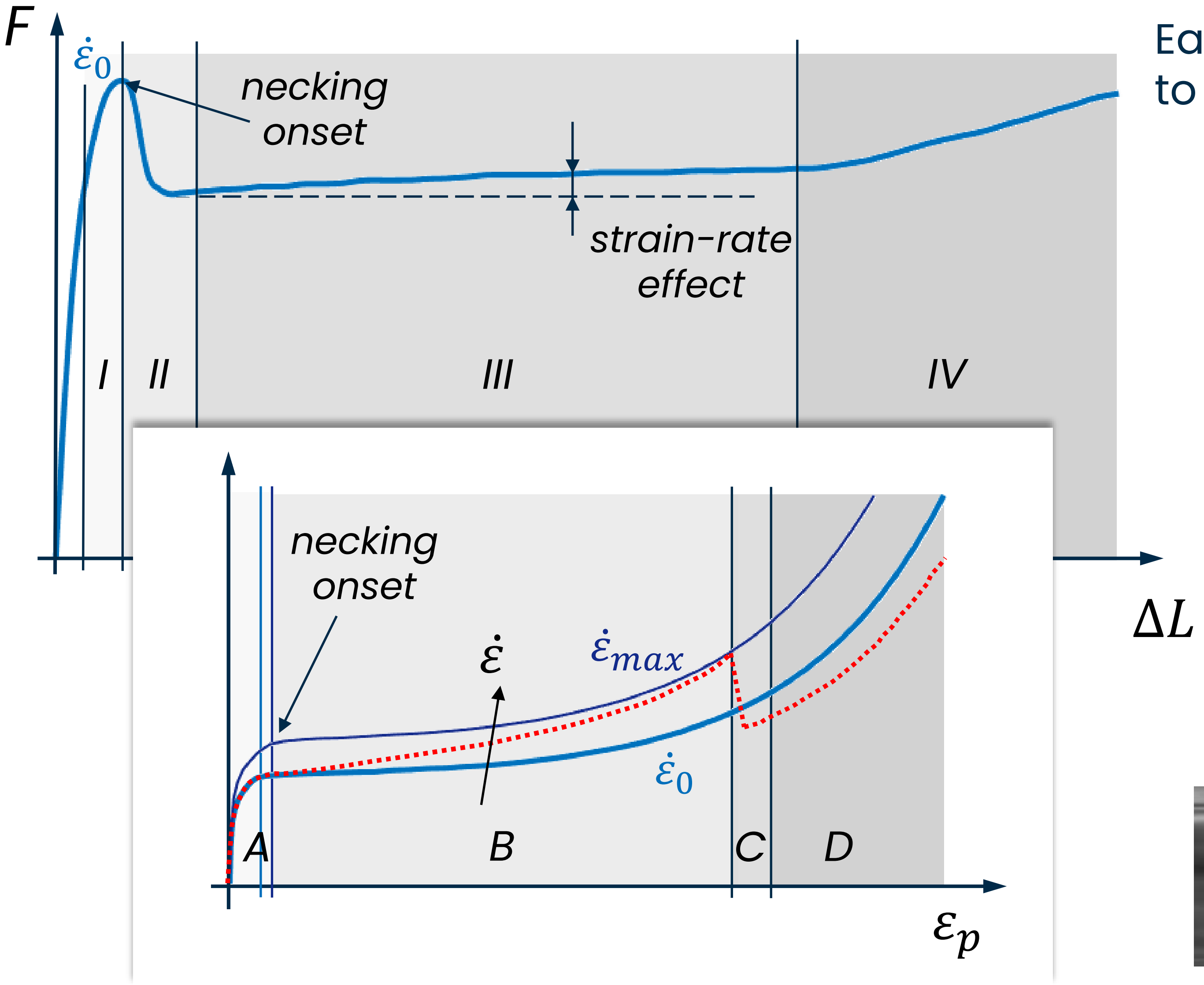
$$\sigma = \tilde{f}(\varepsilon_p, \dot{\varepsilon}_p, T)$$

*MAT_224: **tabulated Johnson-Cook**, elasto-viscoplastic material model.

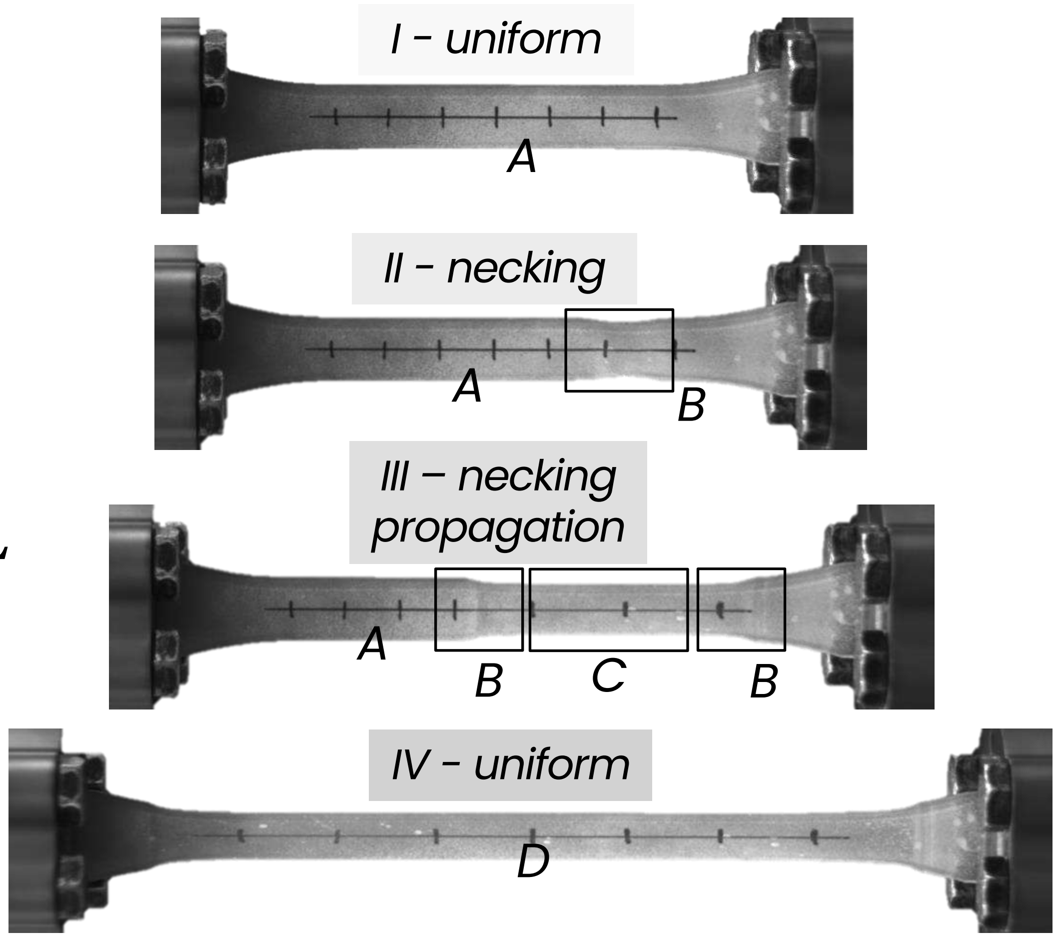
$$\sigma = f(\varepsilon_p, \dot{\varepsilon}_p) \frac{g(\varepsilon_p, T)}{g(\varepsilon_p, T_{ref})}$$



Material behavior: key aspects

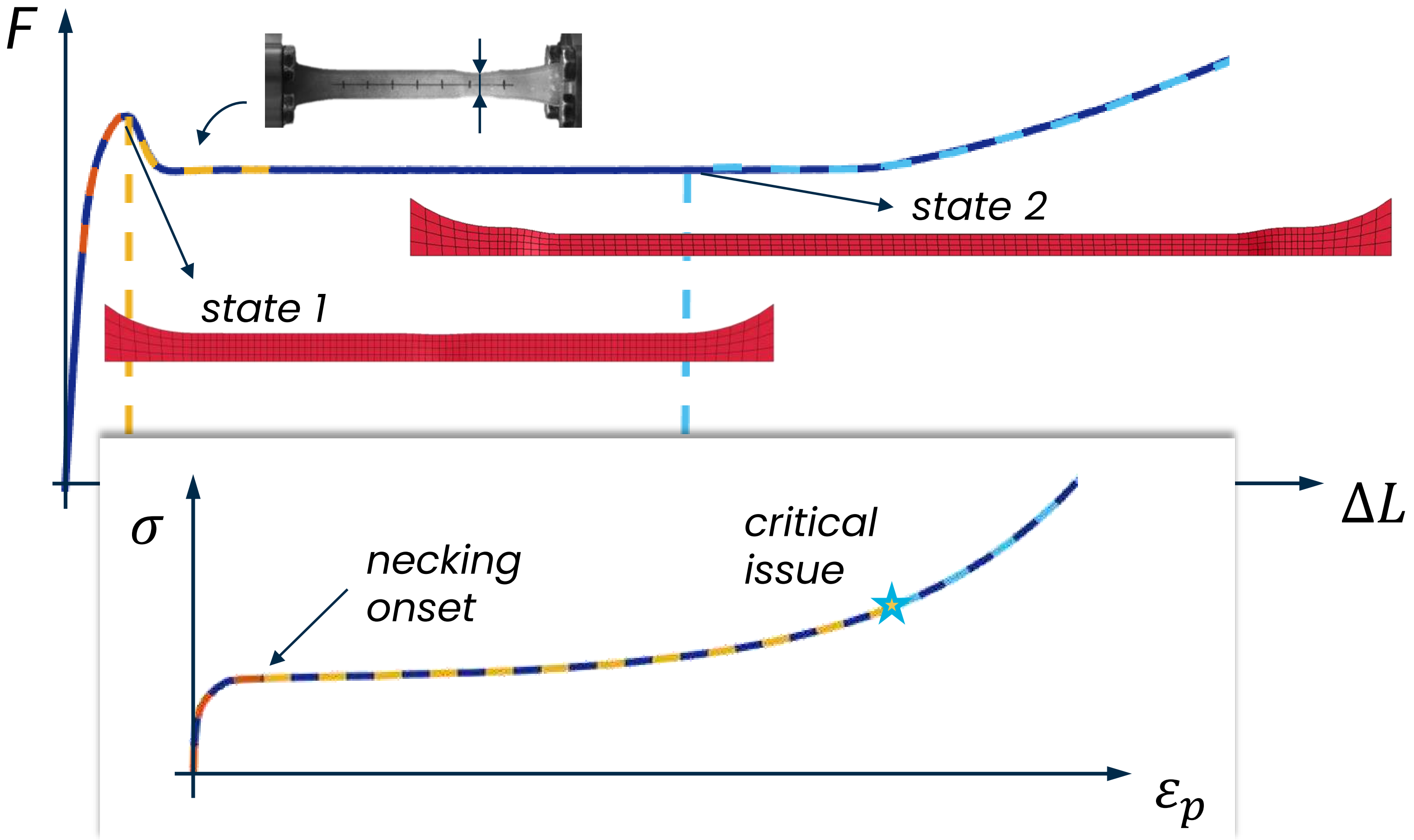


Each part of the **force-stroke** curve is related to a specific part of the **plastic flow** curve.



Calibration method

At first a **strain-rate insensitive** material model is considered, and the efficiency of the optimization is improved by **partitioning** the identification process.



- Split a simulation in sub-simulations, save the final state of a simulation and use it to initialize the next simulation.
- Each sub-simulation can be used to identify a part of the flow stress curve.
- **Save time and computational effort**, because the necking propagation is simulated just once outside the optimizer.

Calibration method: optimization

- The **variables** to be optimized are the points $(\varepsilon_{p,i}, \sigma_i)$ of the curves. The values $\varepsilon_{p,i}$ are fixed and the optimization variables are the **slopes** of each increment $\Delta\varepsilon_{p,i}$.
- A **multi – case optimization** is required: each test condition is a case with its own objective.

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Considering that both the strain-rate and temperature dependence should be identified, the computational effort is high.

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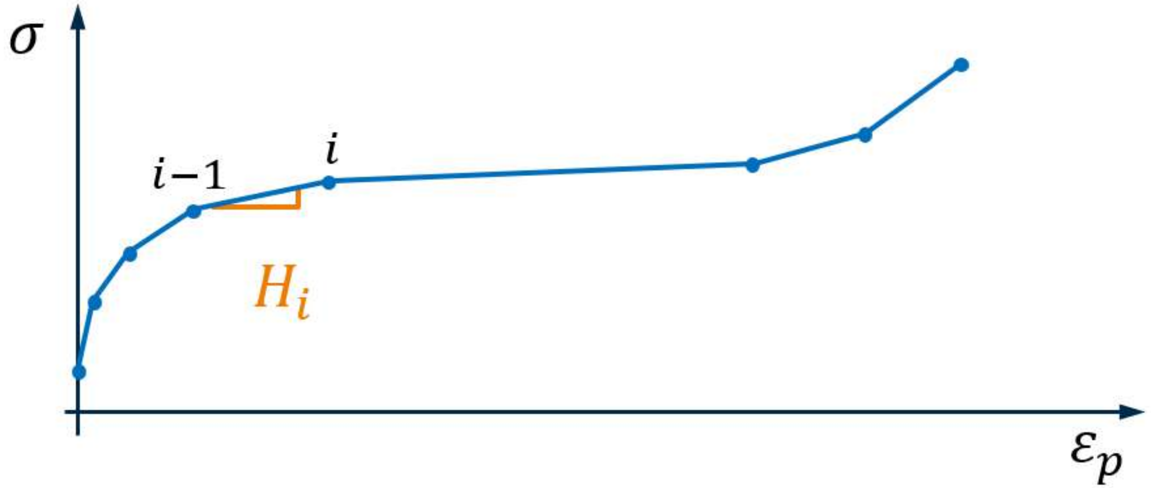
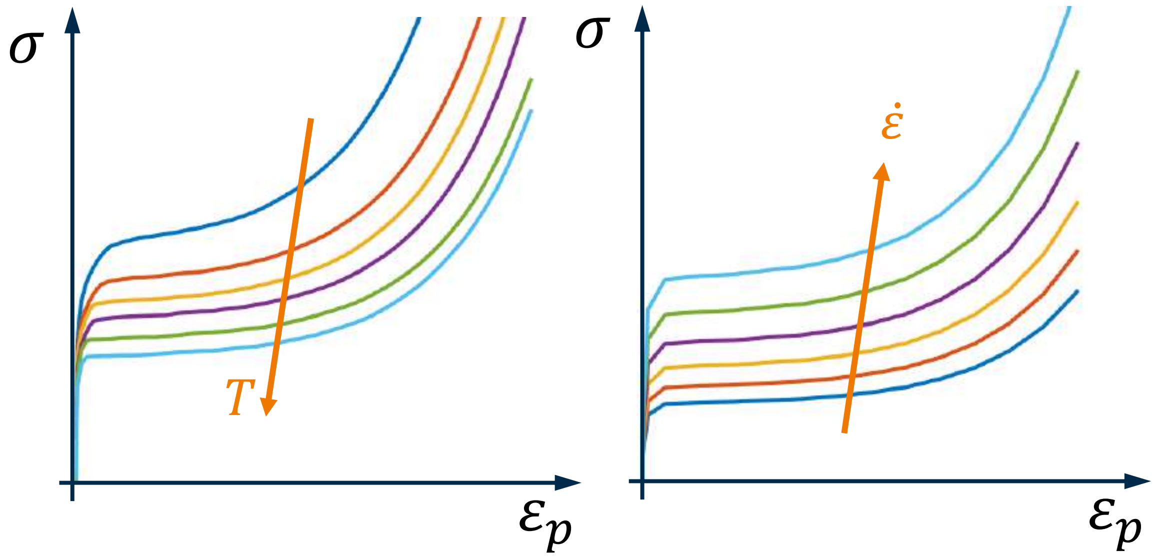
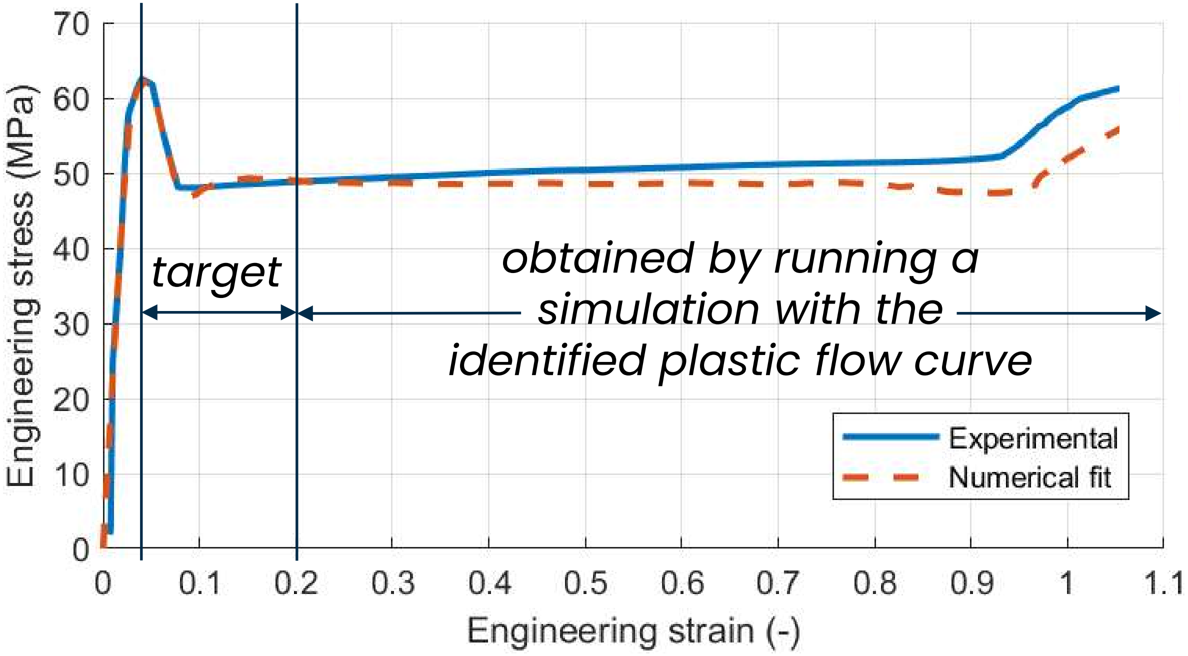
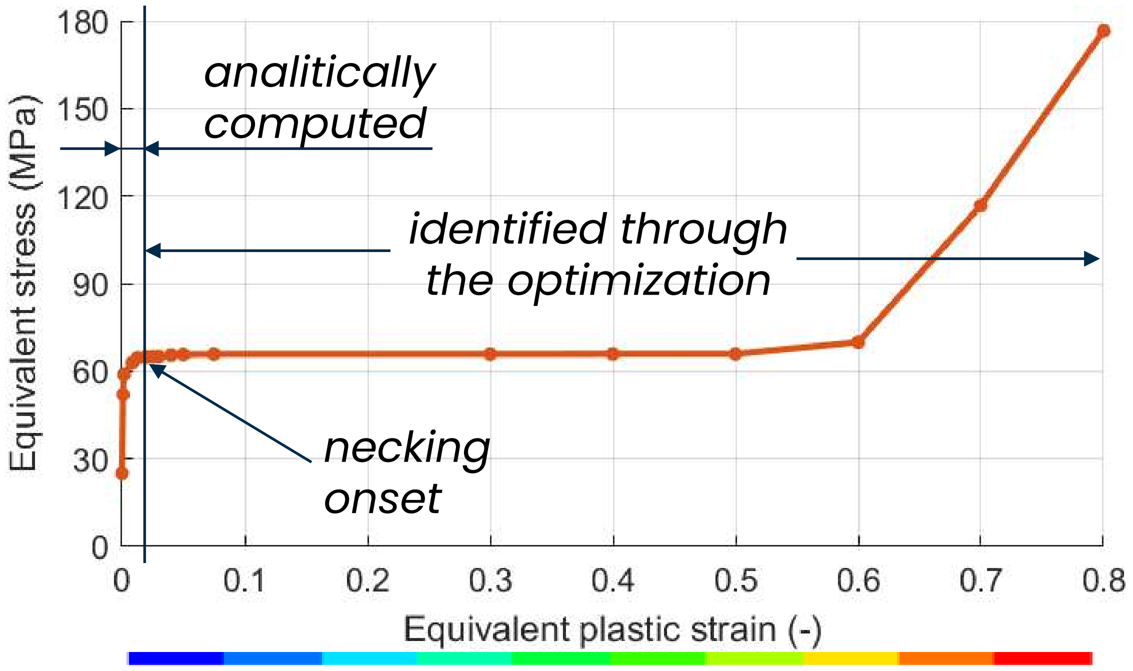
Machine learning algorithms can learn from all the attempts and therefore avoid to waste the information that could be obtained from them.

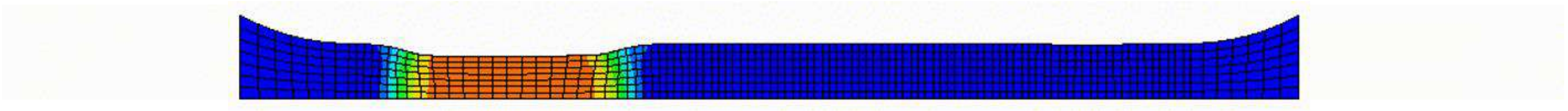




Calibration method: results





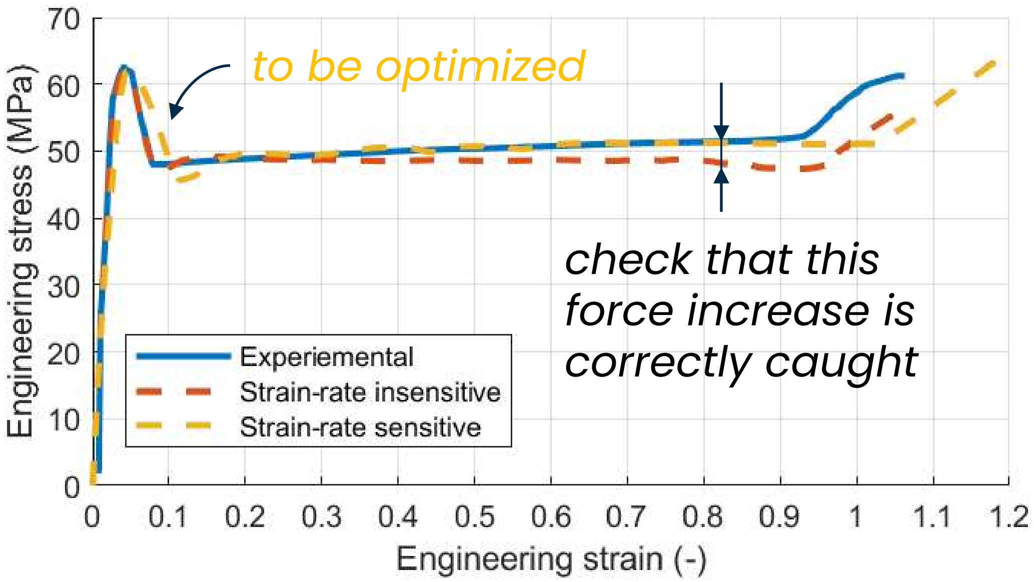


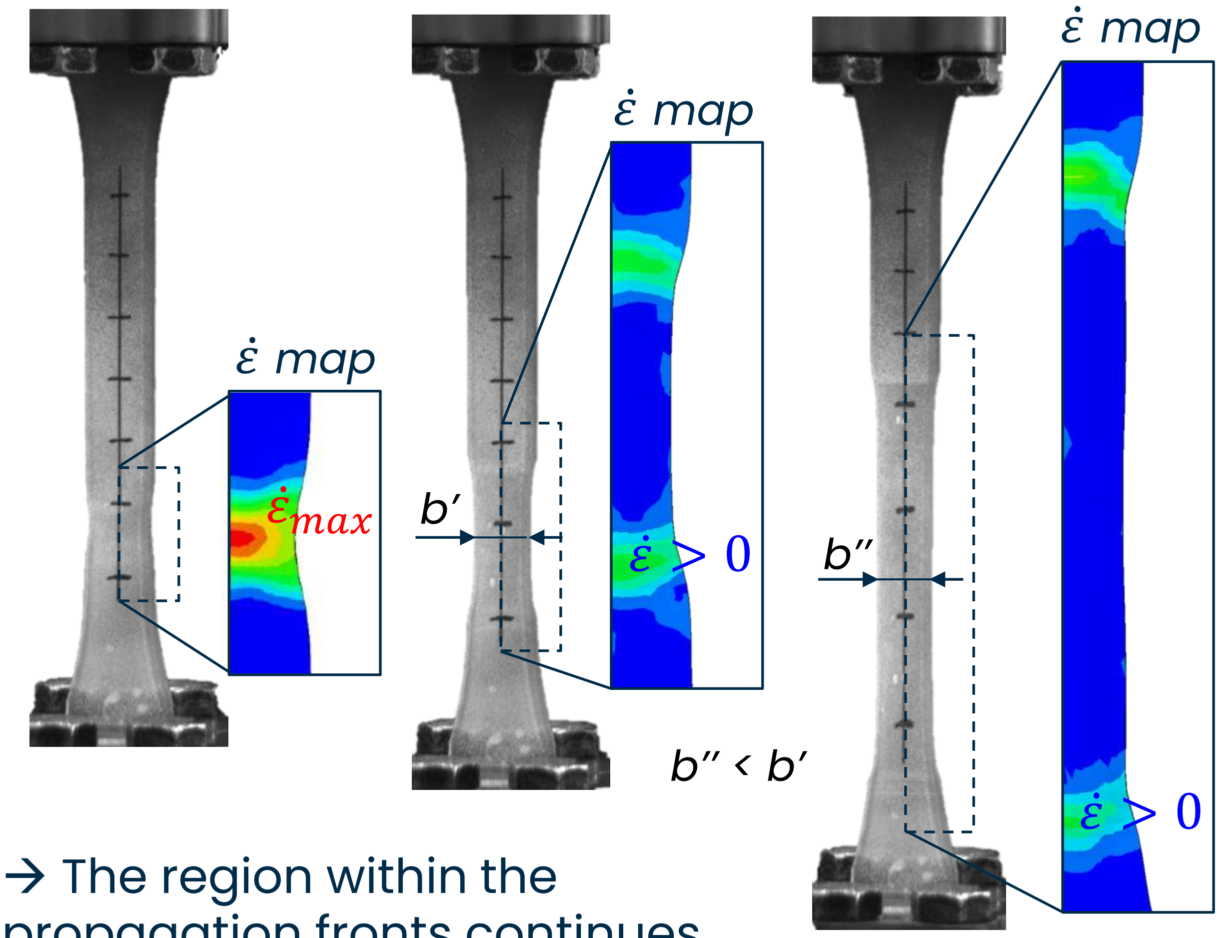
A strain-rate insensitive material model is not able to catch the slight hardening that experimentally occurs during necking propagation. However, it might still be used for calibrating the last hardening phase.

Strain-rate effect

The strain-rate on the **propagation front** is an order of magnitude higher than elsewhere, so here the material resistance is **higher**. This allows to further load the region where necking has already propagated.

→ **Increasing force**

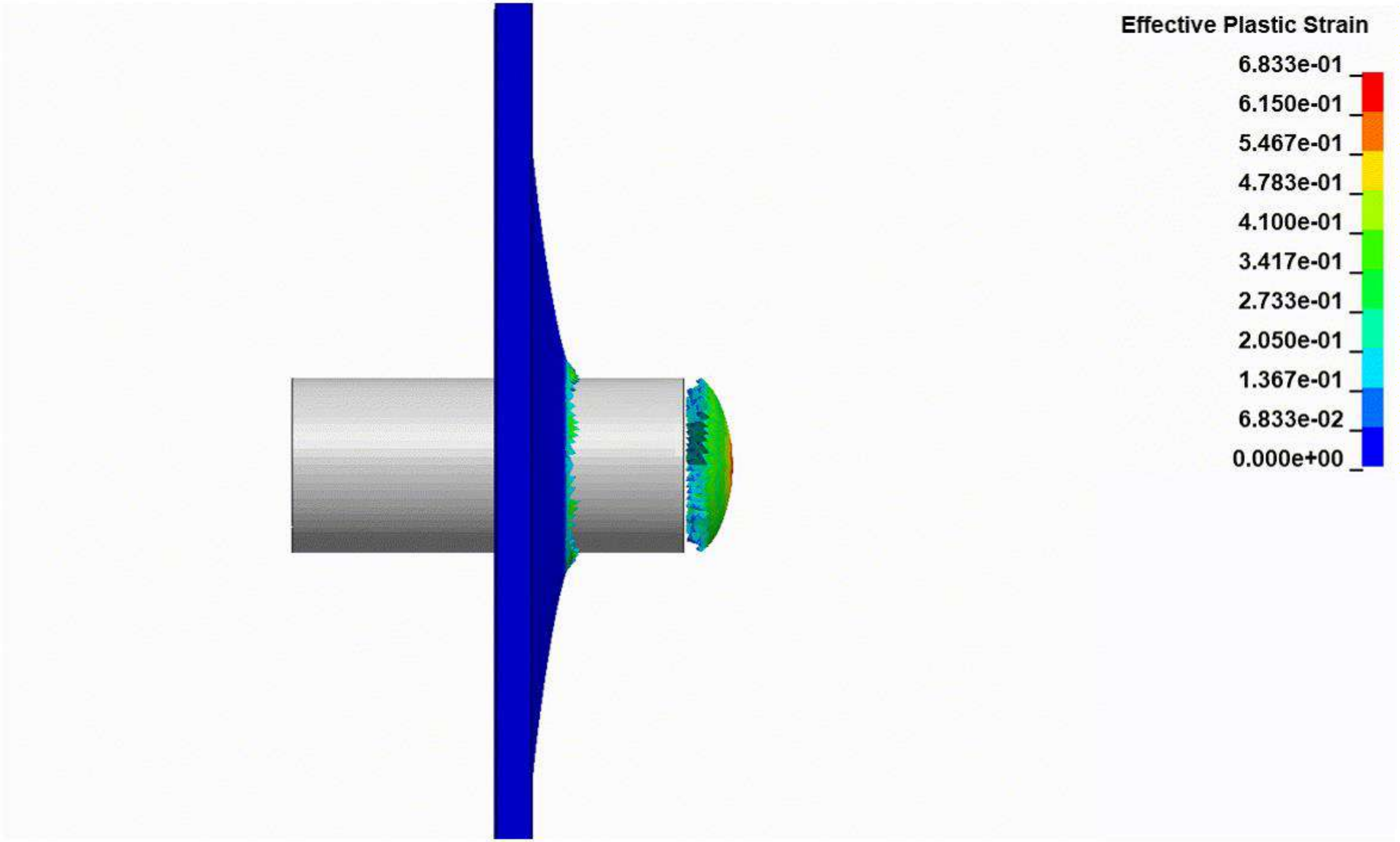




→ The region within the propagation fronts continues to be **deformed** uniformly.

Impact simulation

- *MAT_224 showed no issues in this preliminar FE model for impact simulations.
- The **fracture behavior** of polycarbonate is described through the simple equivalent plastic strain failure criterion, $\varepsilon_f = 0.85$ *.
- **Damage** can be added using GISSMO, the generalized incremental stress-state dependent damage model.



* Khan, A., Husain, A., & Ansari, R. (2017). Experimental and Numerical Investigation of Perforation of Thin Polycarbonate by Projectiles of Different Nose Shape. *Latin Am. J. Solids Struct*., 14(2), pp. 357–372.

Conclusions

- Using a **tabulated material model**, instead of a mathematical formulation, allows to represent more complex behaviors and to correctly impose the necking onset. Choosing a model where temperature and strain-rate affect the flow stress independently one with respect to the other limits the number of variables to be optimized.

- **Partitioning** the identification procedure allows to reduce the computational effort; this is particularly useful when dealing with long specimens.

- Imposing a constraint on the **specimen shape**, especially on the post-necking reduced section, is essential to increase the reliability of the calibrated plastic flow curve.

- Calibrating the behavior at **different strain-rates** is fundamental to catch the slight increase of the force during the propagation phase. It is possible that it could be identified without optimizing on the necking propagation phase, but just considering the post-necking behavior that precedes necking propagation.

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Thank you for your attention