Applus+ DatapointLabs

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Certificate # 1242.01
ISO/IEC 17025:2017

Nadcap
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Certificate # 17231205927
Non Metallic Materials Testing

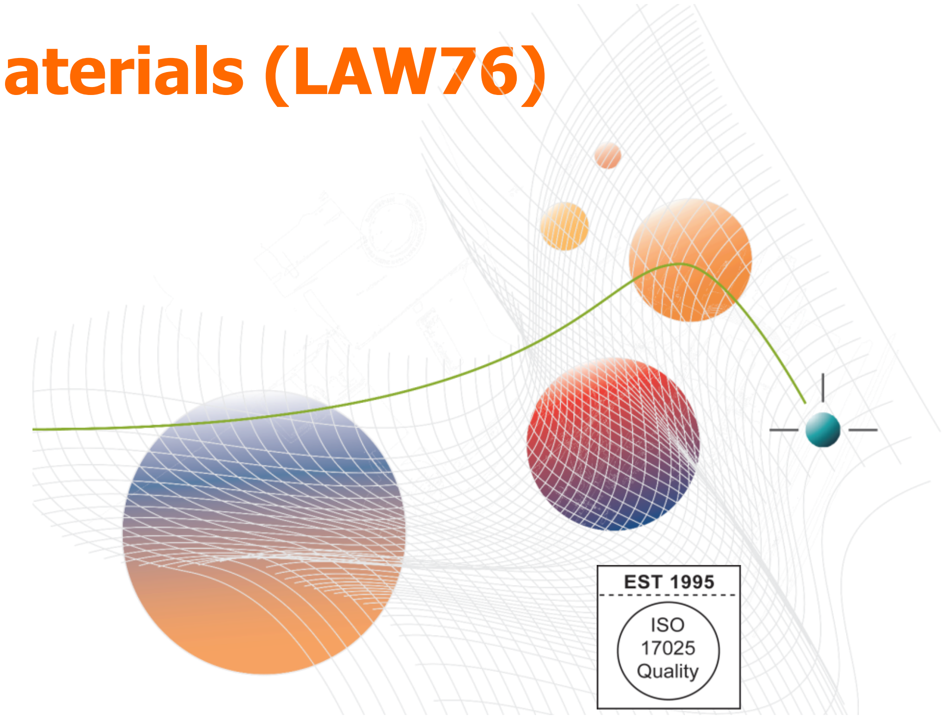
Beyond Standards: Material Testing and Processing for Successful Simulations of Polymeric Materials (LAW76)

Dr. Daniel Campos Murcia, *CAE Specialist*

TestCart

TestPaks

CAETestBench



EST 1995
ISO 17025 Quality

OpenRadioss™

LAW76_SAMP: Semi-Analytical Model for Polymers

1. DatapointLabs and Applus+ Group
2. Overview of LAW_76 SAMP
3. Testing for SAMP
4. Calibration of SAMP
5. Conclusions

Applus+ Group

Applus+ is a global leader in inspection, testing and certification. Driven by our passion for progress and technological development, we'll keep moving towards a more sustainable future alongside our customers; re-enforcing our mission and company motto: **Together beyond standards.**

26,000+
People in 2022

€2,058M
Revenue in 2023

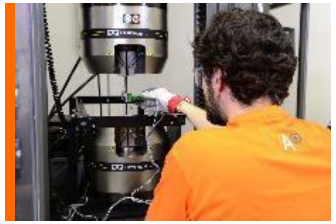
66
Countries in all continents

Accredited
By main international entities

Energy & Industry Division

€ 1,084.4M revenue

+16,000 personnel



Laboratories Division

€ 254.3M revenue

2,589 personnel

Automotive Division

€ 391.8M revenue

4,300 personnel

IDIADA Division

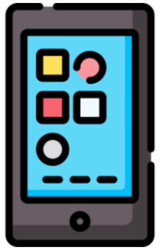
€ 331.5M revenue

3,158 personnel

Crash and impact simulation

Automotive

Aerospace



Goods & electronics

Industry

Food

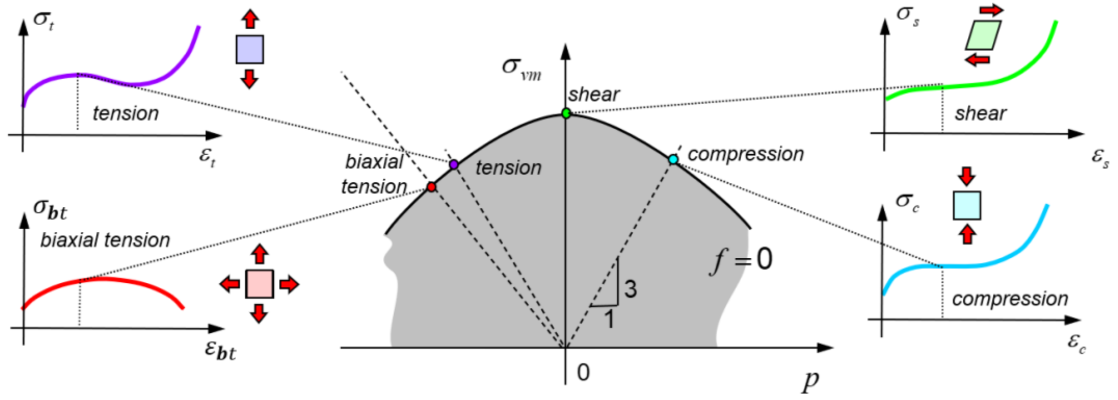
- More sectors interested in the reduction of prototyping cost and times
- Growing demand for crash and impact simulation applications
- New materials, higher complexity, new needs

LAW76_SAMP: Semi-Analytical Model for Polymers

- SAMP material law was developed at DaimlerChrysler, Sindelfingen, in collaboration with Paul Du Bois and Dynamore, Stuttgart
- It is based on a quadratic yield surface in the $\sigma_{VM} - \mathrm{p}$ space where the parameters A0, A1 and A2 are computed via curve definitions that could be directly converted from experimental data
- It includes strain-rate dependencies for tension, shear and compression inputs
- It also includes a damage model. In Radioss this damage can be introduced via ε_p^f (plastic strain at the start of damage) and ε_p^r (plastic strain at the element erosion), or via a damage function

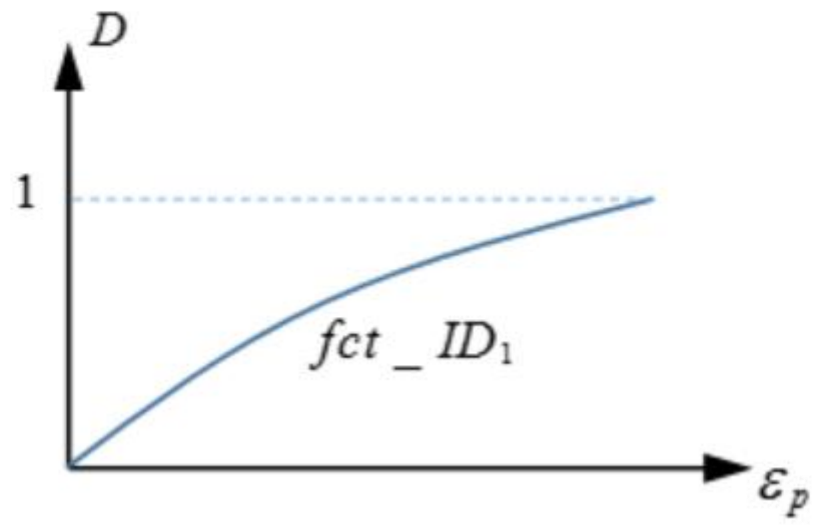
SAMP MODEL

$$f(p, \sigma_{vm}, \bar{\varepsilon}_p, \dot{\bar{\varepsilon}}_p) = \sigma_{vm}^2 - A_0 - A_1 p - A_2 p^2 \leq 0$$



From: Characterization and Material Card Generation for Thermoplastics, M. Hellbig, A. Erhart, A. Haufe. 16th International LS-Dyna User Conferene

DAMAGE MODEL



From Altair Radioss manual

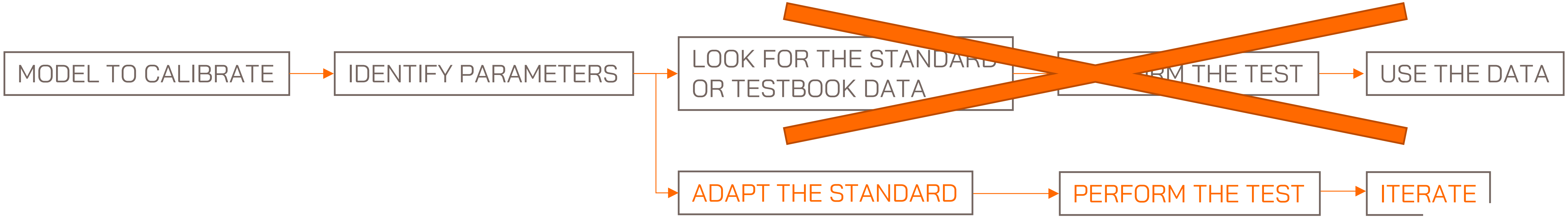
Limitations of LAW76_SAMP

- The equations assume a constant characteristic stress relation during the testing →Triaxiality has to be as close as possible to the theoretical value
- The use of arbitrary defined curves may result in severe convergence problems → Too much freedom is not always good
- Damage model contained in the Radioss implementation doesn't allow to use dependencies on strain-rate or triaxiality, usually not allowing to describe properly the damage and failure evolution under the different deformation modes.
- Execution speed is usually slow because of the slow convergence of the stress's integration, especially when a poorly defined yield surface is introduced
- It requires an iterative process to calibrate this model with constant inputs of new experimental data, especially when combined with more advanced damage models (i.e. Biquad)

LAW76_SAMP: Ready to use card

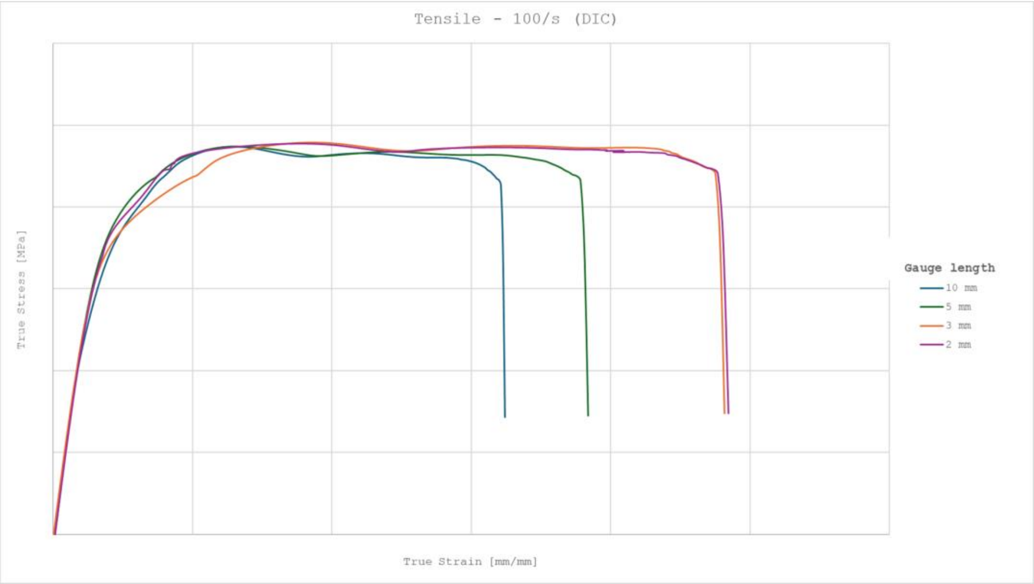
```
#RADIOSS STARTER
#---1----|----2----|----3----|----4----|----5----|----6----|----7----|----8----|----9----|---10----|
/UNIT/1
unit for mat
                  kg                  mm                  ms
#---1----|----2----|----3----|----4----|----5----|----6----|----7----|----8----|----9----|---10----|
/MAT/LAW76/1/1
LAW76_Material
#              RHO_I
                1E-6
#                  E                  nu
               100.0                  .3
#  TAB_IDt   TAB_IDc   TAB_IDs
      1000      1001      1003
#           Fscale_t            Fscale_c            Fscale_s                                    XFAC
               1.000               1.000               1.000                                   1.000
#               Nu_p  fct_IDpr           Fscale_pr   Fsmooth      Fcut
                 0.5         0                   0         1      1e30
#              EPS_f_p             EPS_r_p
                   0                   0
#funct_ID1                            Fscale_1
        0
#    IFORM     IQUAD     ICONV
         0         0         1
#---1----|----2----|----3----|----4----|----5----|----6----|----7----|----8----|----9----|---10----|
```

Testing process for advanced models



Why is it important to go beyond the standards?

- We need different strain-rates due to the application
- We loose accuracy using the measurement instruments described in the standard
- We need different geometries to capture the real triaxiality state
- We need different environmental conditions
- We need to modify the contacts, grips, fixtures due to the application



Planned test campaign for the calibration of SAMP+BIQUAD model

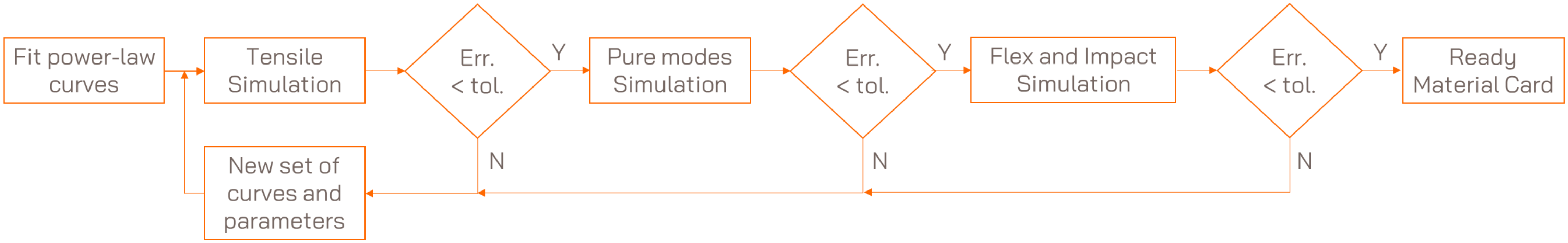
Test Type	Standard	Specimen shape	Crosshead speed	Gauge
Tensile 0.01/s	ASTM D638-22	ISO type 3 tensile bar	6 mm/min	DIC
Tensile 0.10/s	ASTM D638-22	ISO type 3 tensile bar	60 mm/min	DIC
Tensile 1.00/s	ASTM D638-22	ISO type 3 tensile bar	60 mm/min	DIC
Tensile 10.0/s	ASTM D638-22	ISO type 3 tensile bar	600 mm/min	DIC
Tensile 100/s	ASTM D638-22	ISO type 3 tensile bar	6000 mm/min	video
Compression 0.01/s	ASTM D6641/D6641M-23	Custom	1.3 mm/min	video
Shear 0.01/s	ASTM D5379M-19e1	In-plane shear	2 mm/min	DIC
Notched 0.01/s	ASTM D638-22	Notched R0.125in	2 mm/min	DIC
Flexural QS	ASTM D790-17	ASTM flex bar	1%/min	-
Impact 3.3 m/s	ASTM D3763-23	Plaque	3300 mm/s	-
Punch test	Non-standard	Plaque	34 mm/min	DIC

Extra tests performed for the calibration of SAMP+BIQUAD model

Test Type	Standard	Specimen shape	Crosshead speed	Gauge
Tensile 0.01/s X-Flow	ASTM D638-22	ISO type 3 tensile bar	6 mm/min	DIC
Small Notched 1.00/s	ASTM D638-22	Notched R0.125in	500 mm/min	video
Small Notched 100.0/s	ASTM D638-22	Notched R0.125in	5000 mm/min	video
Large Notched 0.01/s	ASTM D638-22	Notched R0.25in	2 mm/min	DIC
Large Notched 1.00/s	ASTM D638-22	Notched R0.25in	500 mm/min	video
Large Notched 100.0/s	ASTM D638-22	Notched R0.25in	5000 mm/min	Video
Shear 1.00 /s	ASTM D5379M-19e1	In-plane shear	1.5 mm/min	DIC
Shear 100.0/s	ASTM D5379M-19e1	In-plane shear	500 mm/min	DIC

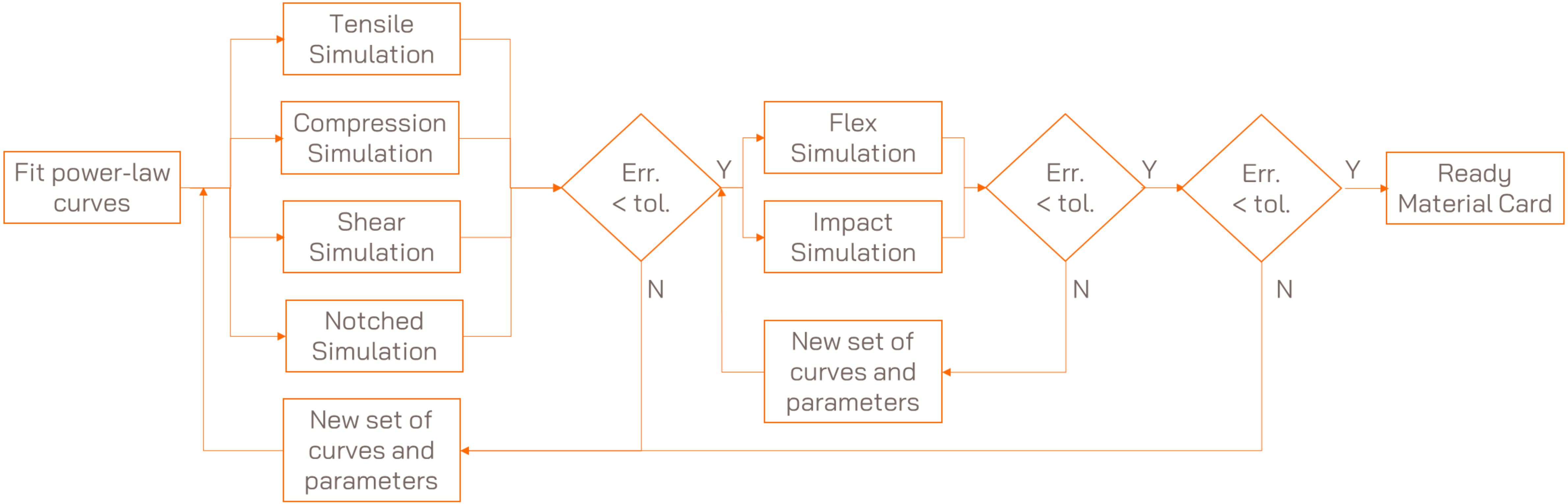
Semi-automated process for SAMP + BIQUAD (simplified diagram)

Cascade workflow



Semi-automated process for SAMP + BIQUAD (simplified diagram)

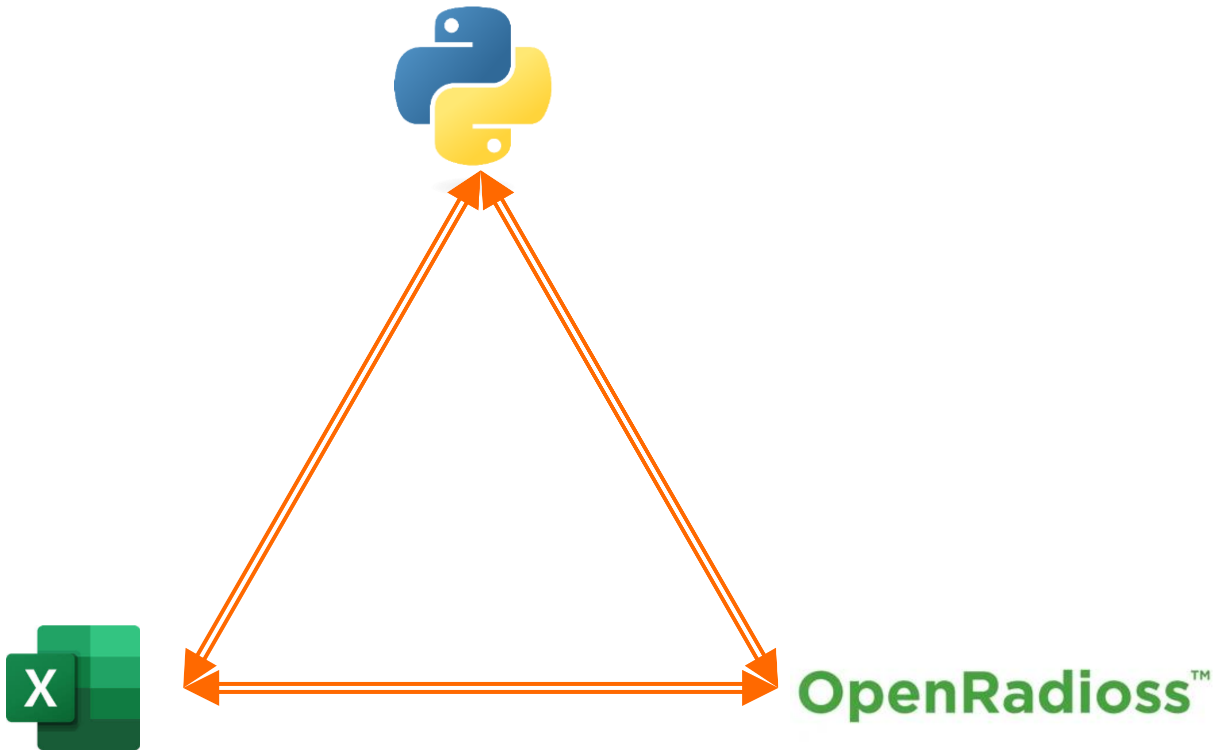
Parallel workflow



Semi-automated process for SAMP + BIQUAD (simplified diagram)

Optimization algorithm

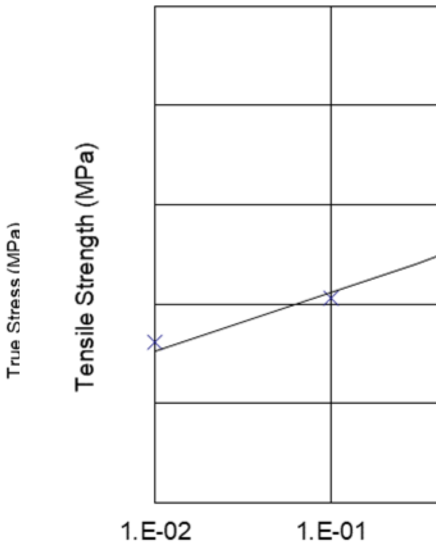
1. Selects a test model from a library
2. Imports material card to the selected test model
3. Executes simulation in OpenRadioss
4. Exports force-disp curves
5. Calculate eng. Stress-strain and/or other parameters
6. Calculate the error
   - Calculated through R2
   - Calculated through other indicators (max. stress, failure strain...)
7. Stores the error and compares with the previous iteration
8. Calculate the new parameters/curves
9. Creates the new material card and back to 1

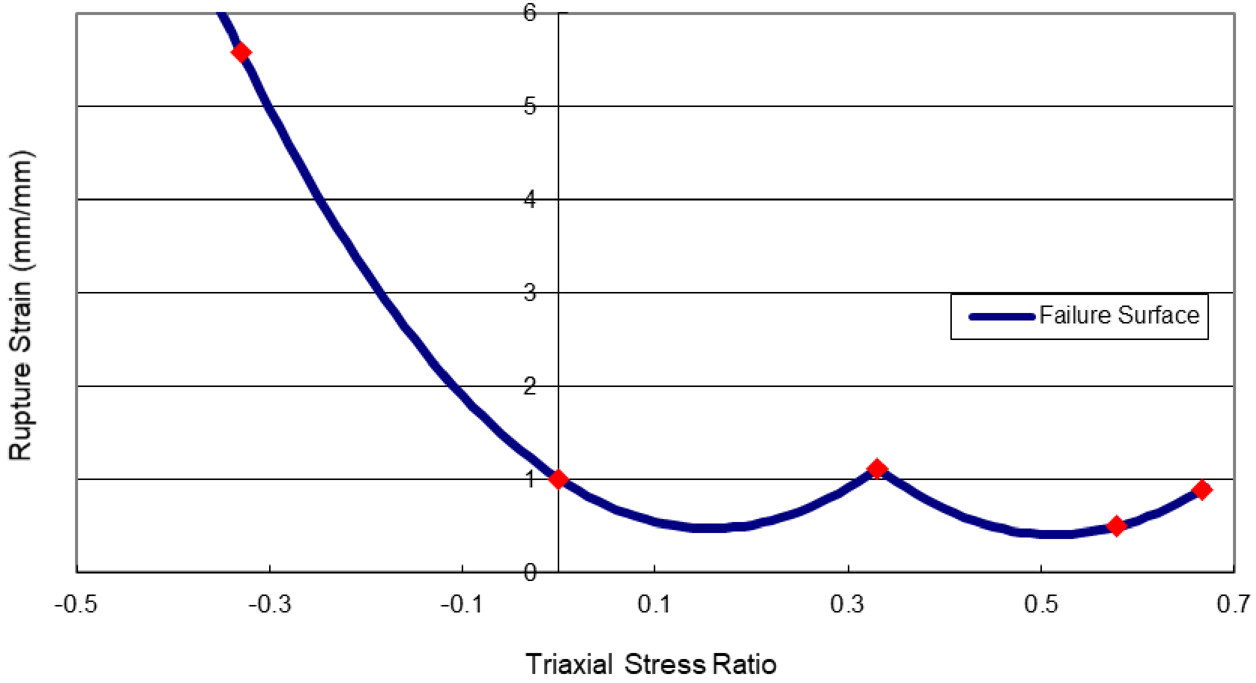


Test data preparation

1. **Fitting power law models**
2. **Extrapolating strain-rates**
3. **Fitting Biquad law**

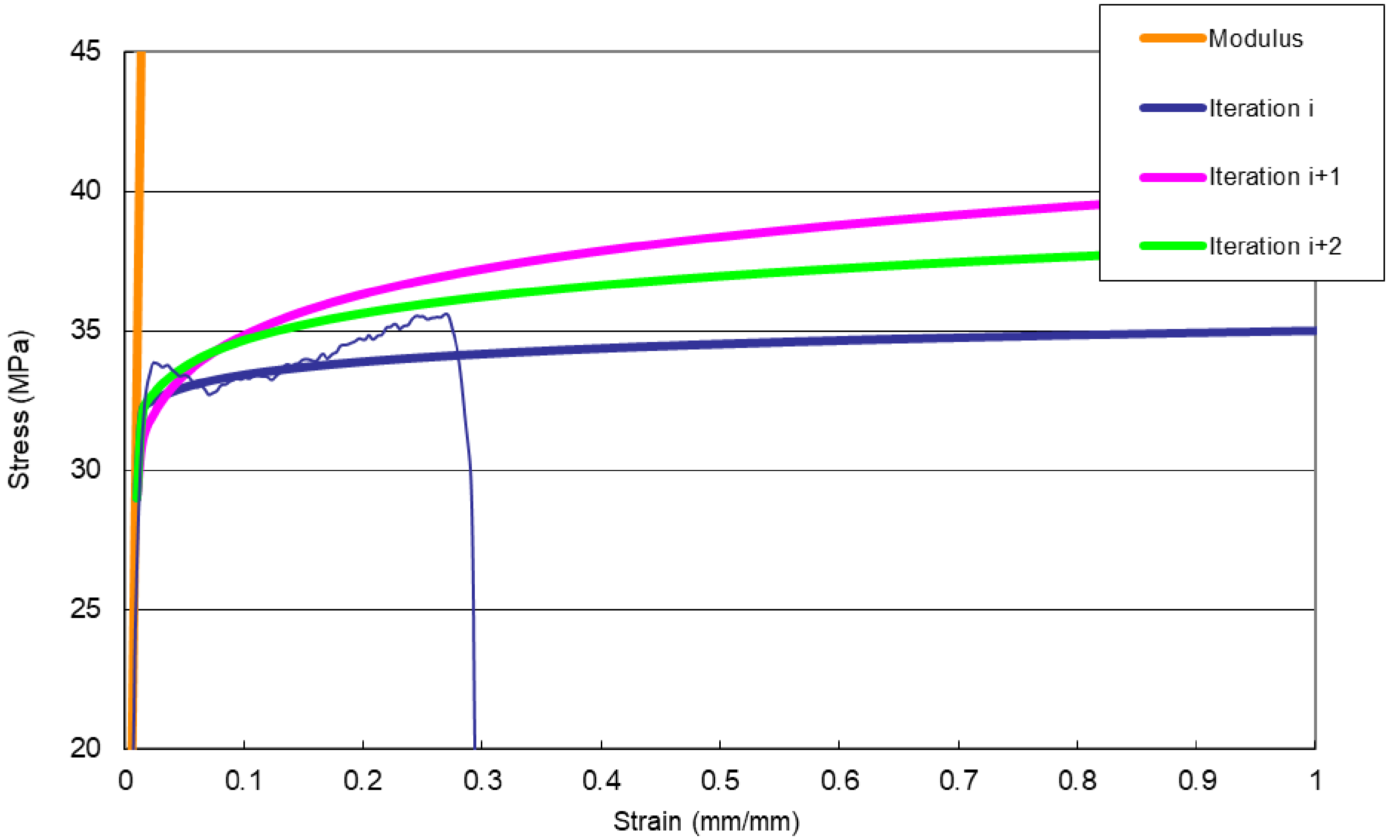
$$\sigma = m \cdot \varepsilon^{n}$$





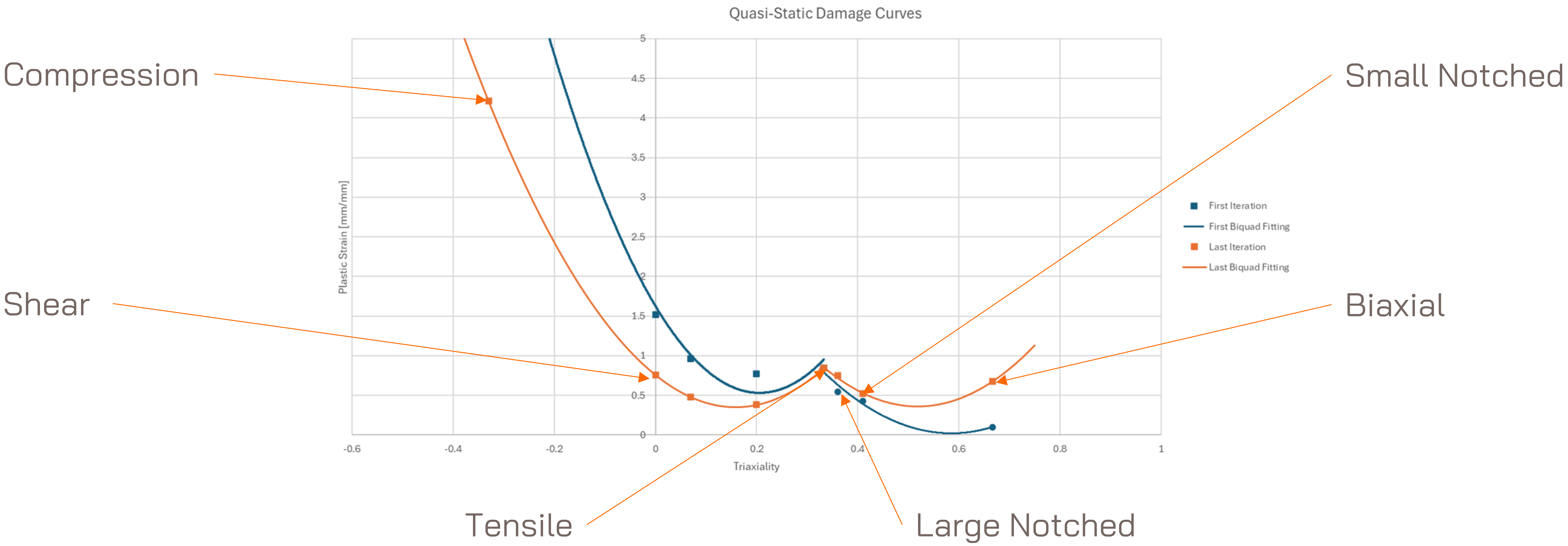
Intermediate solutions of the optimization process

Fitting power law models

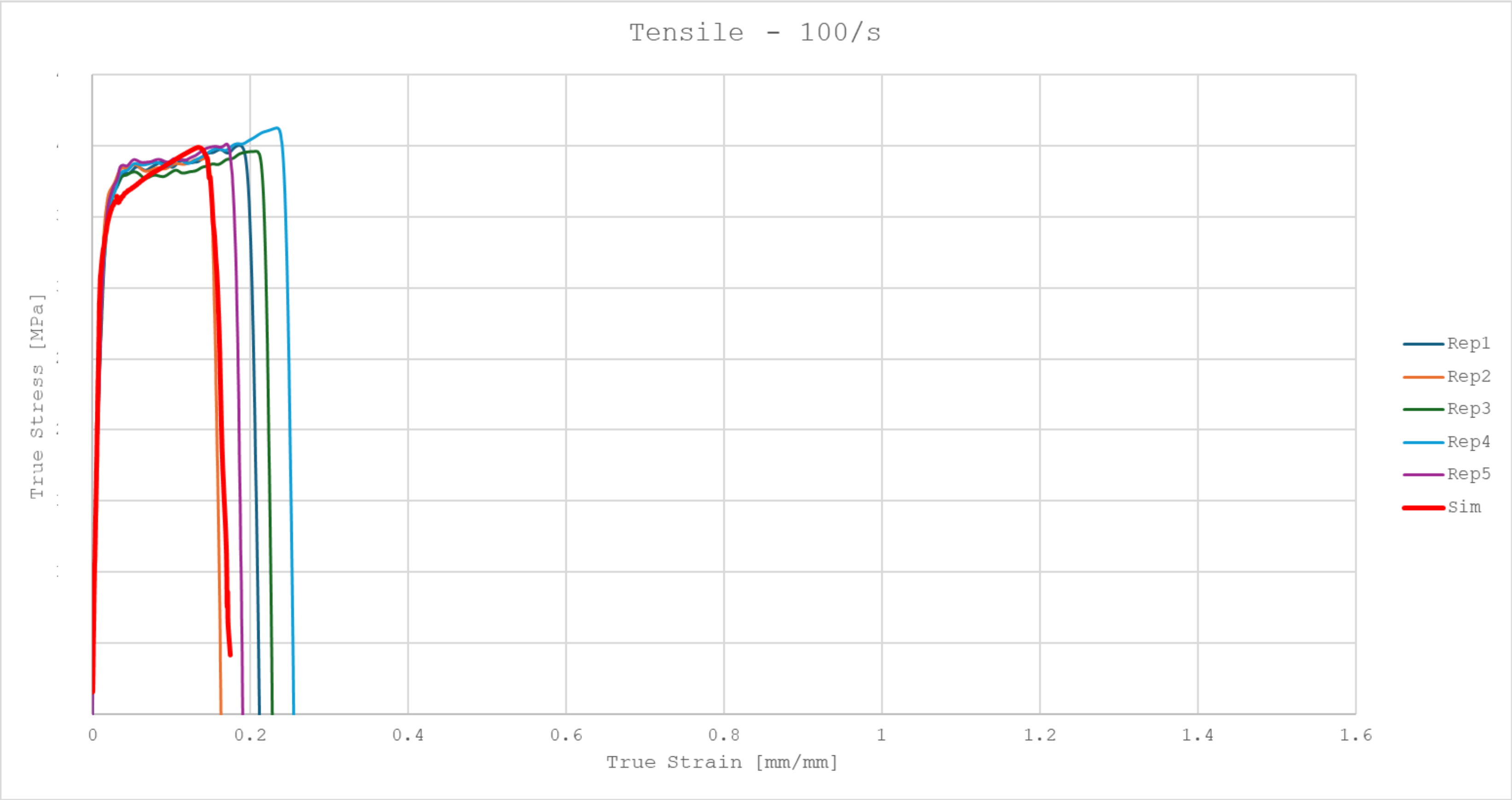


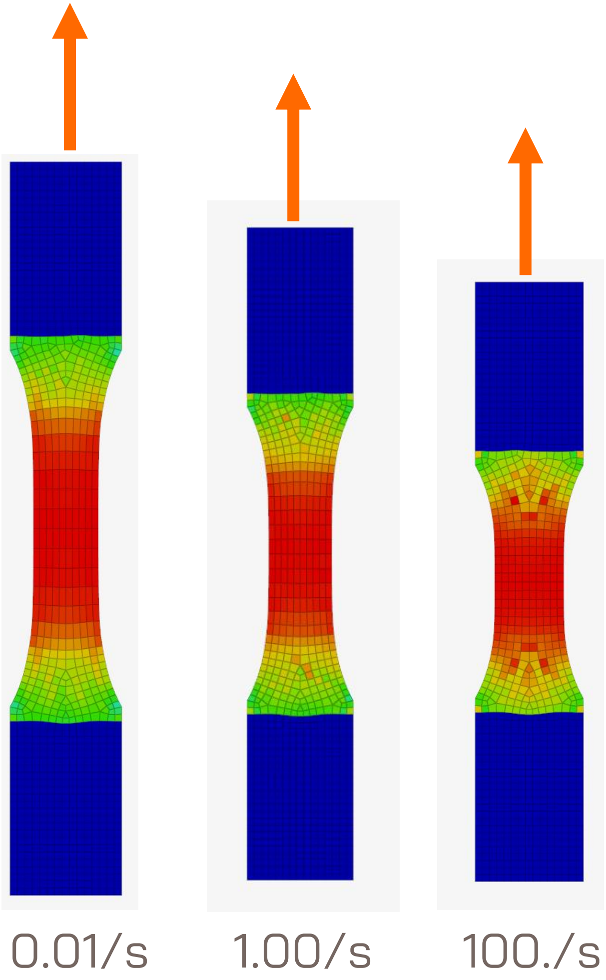
Intermediate solutions of the optimization process

Biquad law models



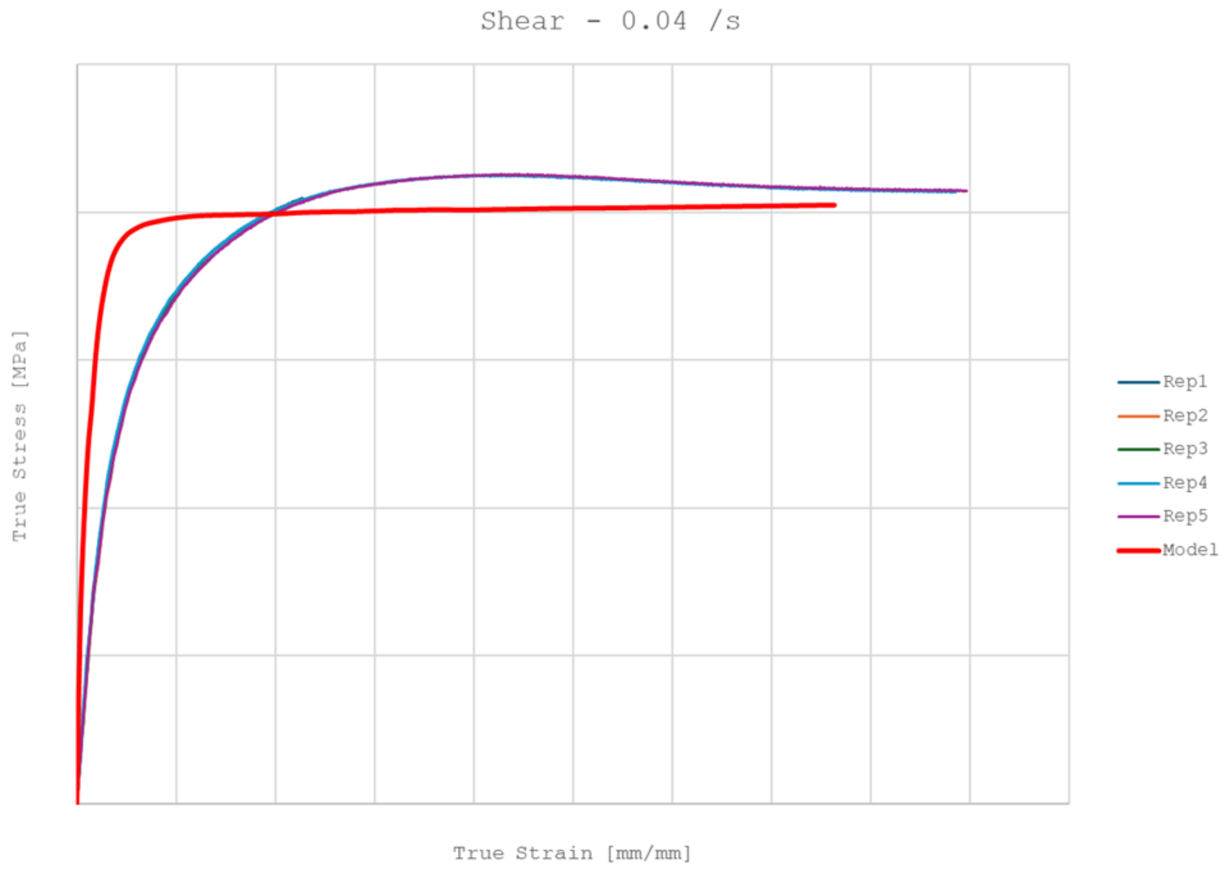
Tensile tests

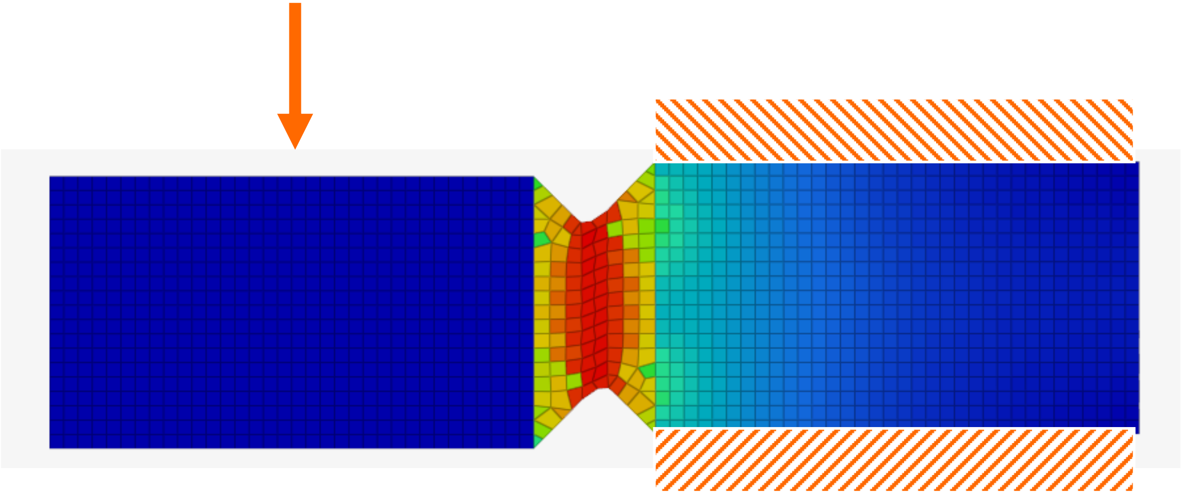




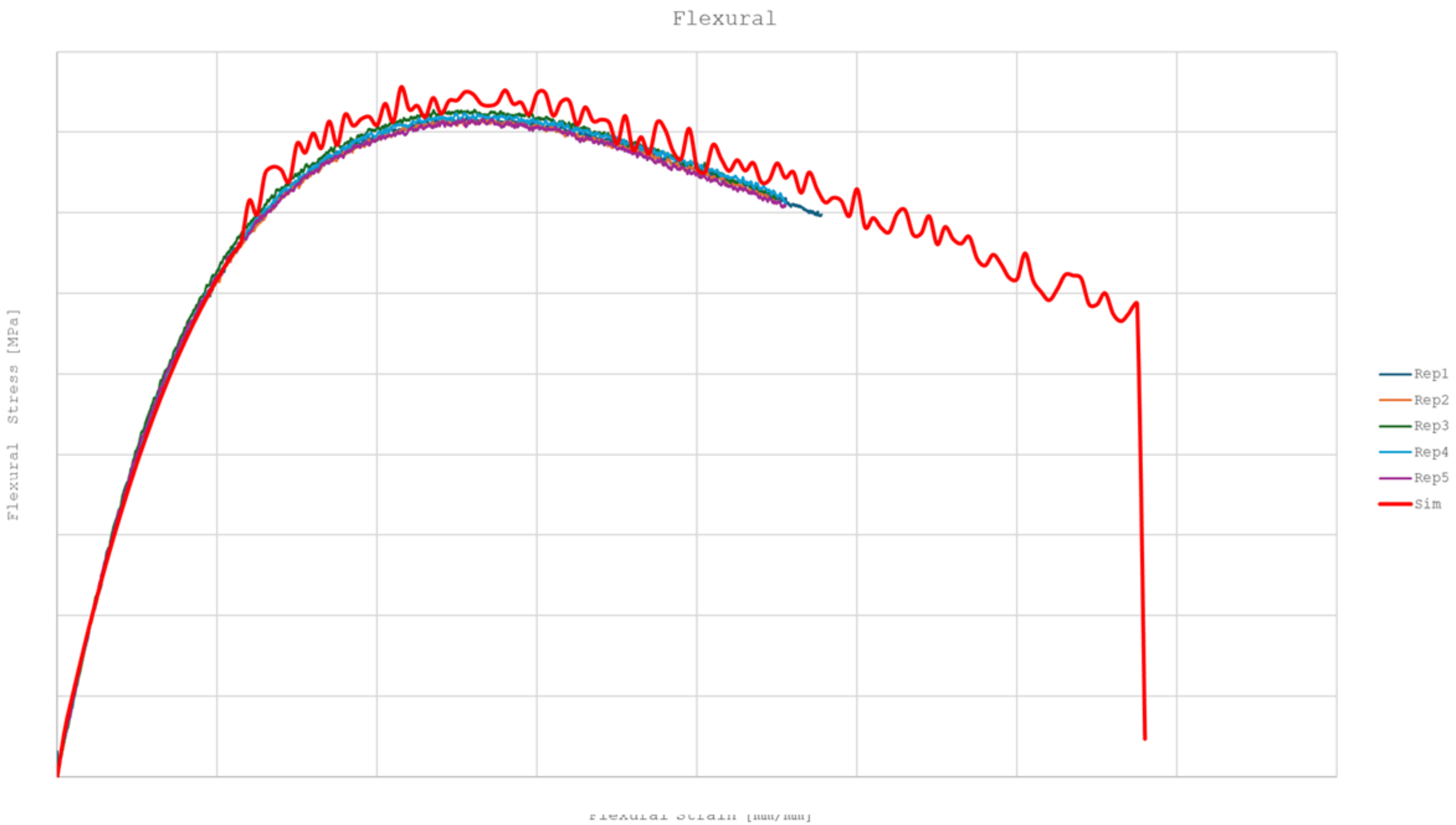
Different damage models for each strain-rate

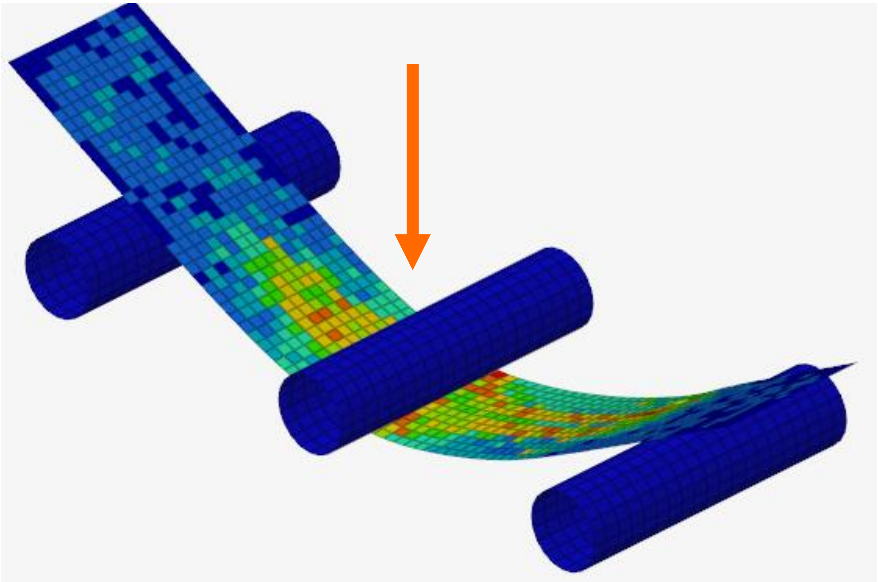
Shear Calibration





Flexural





- SAMP model provides exceptional accuracy in predicting the behavior of unfilled polymers under various loading conditions
- Requires extensive knowledge in calibration
- Flexibility in parameterization can lead to convergence errors and instabilities if not carefully managed
- Lacks a damage model that incorporates strain-rate and triaxiality state dependencies simultaneously
- SAMP is part of our extensive catalog of over 200 Testpaks, all developed over 27 years of collaboration with our clients and industry experts

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