Full-Field Material Calibration Using LS-OPT®

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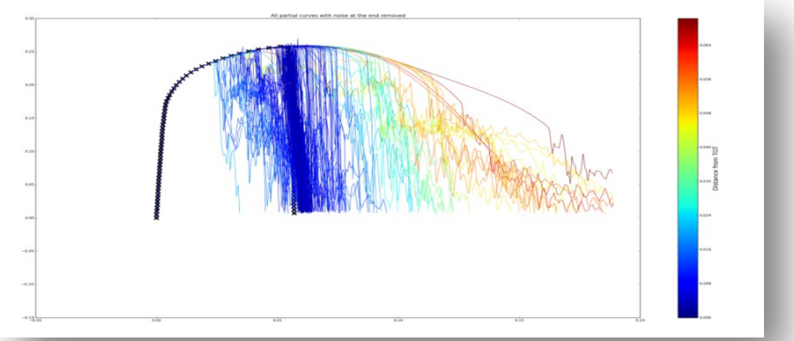
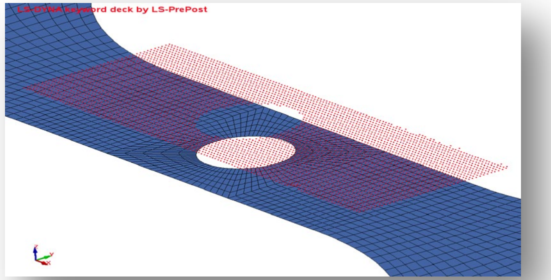
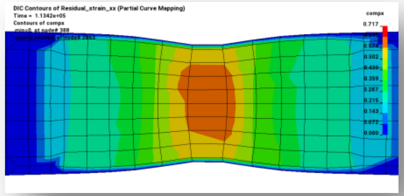
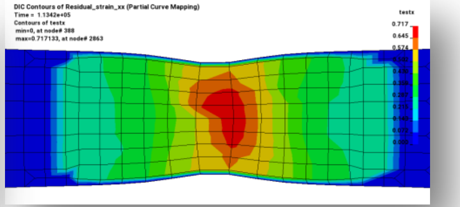








German LS-DYNA Forum

Bamberg, Germany

October 16, 2018

Parameter Identification: Overview

- New curve matching algorithm

  Dynamic Time Warping

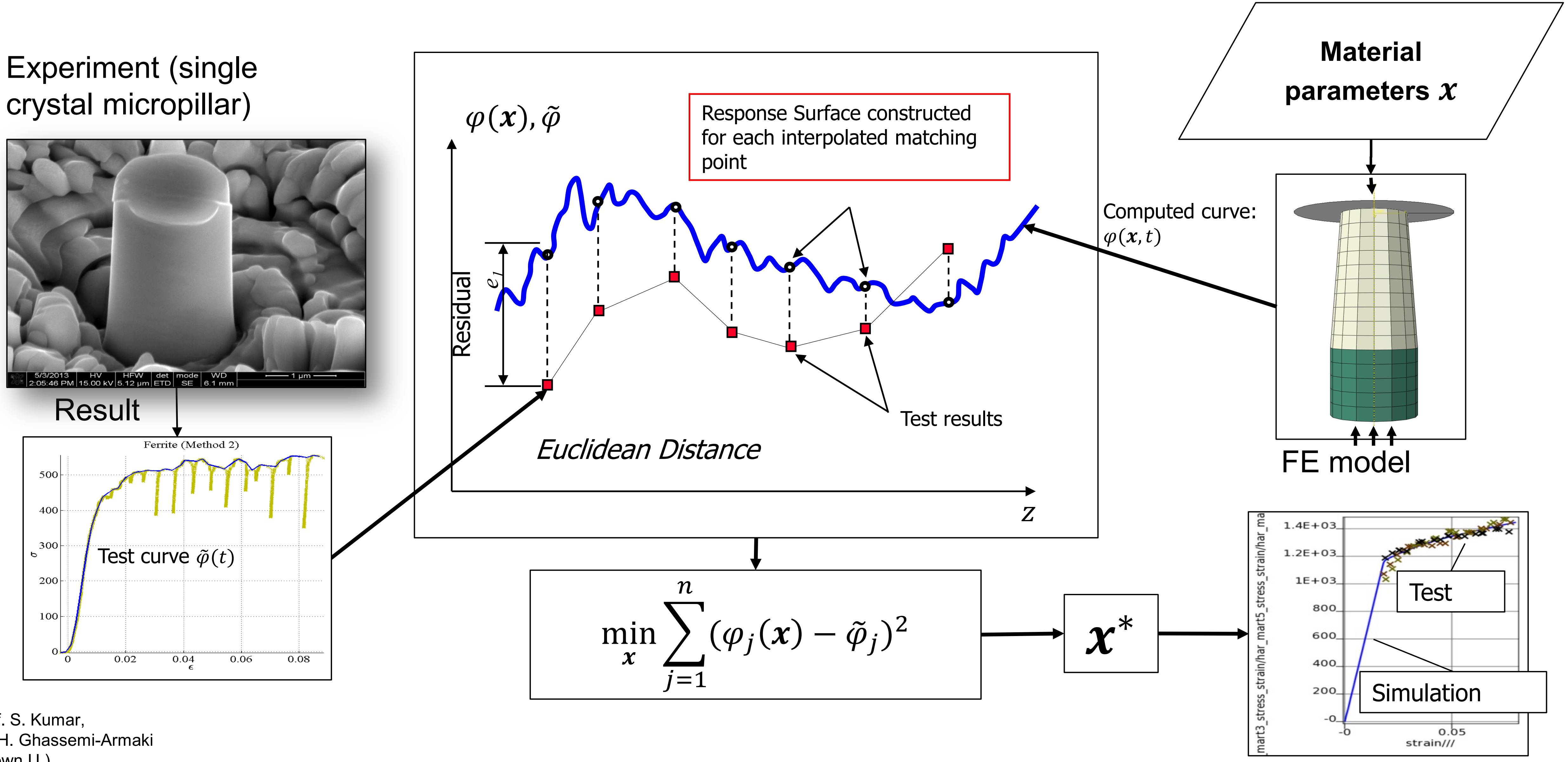
- Digital Image Correlation

  Nearest Neighbor Cluster: Reduce resources

- Post-processing

  Automated Contour History display (LS-PrePost) using Similarity Measure

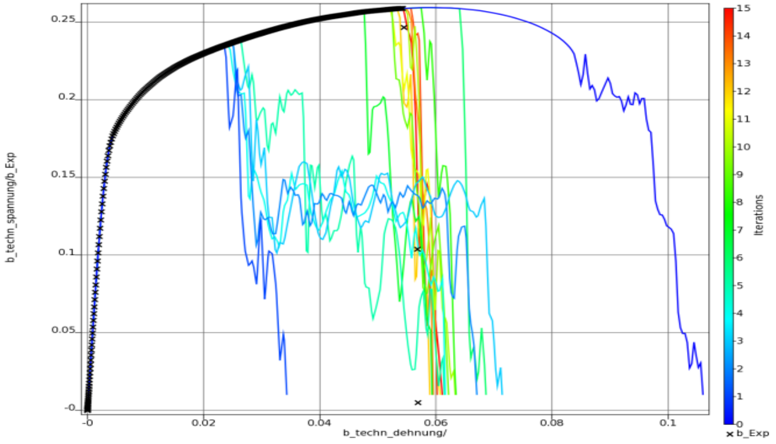
Material Calibration: Introduction

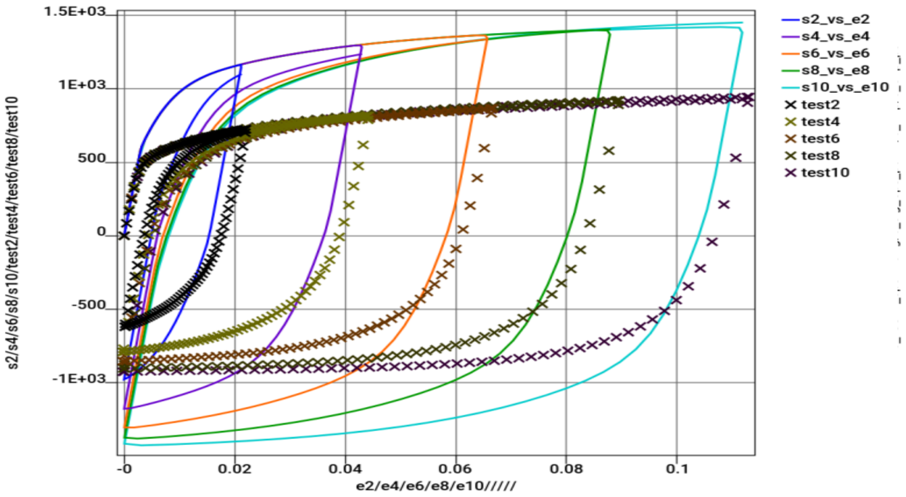


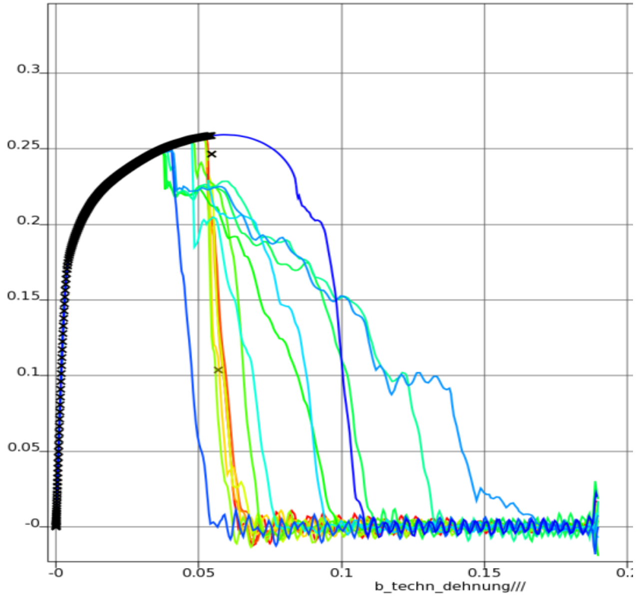
Prof. S. Kumar,
Dr. H. Ghassemi-Armaki
(Brown U.)
Prof. F. Pourboghrat (OSU)

Calibration: Computational challenges

Experimental and computational results can be difficult to compare







Noise

Failure model: GISSMO — element erosion a discrete process

Hysteresis

Material 125 — Loading/Unloading (5 cases)

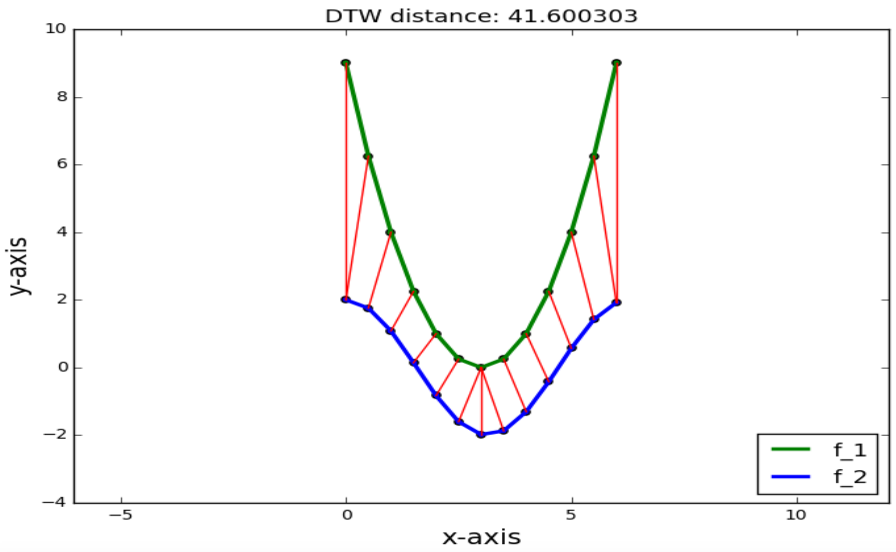
Partial Matching

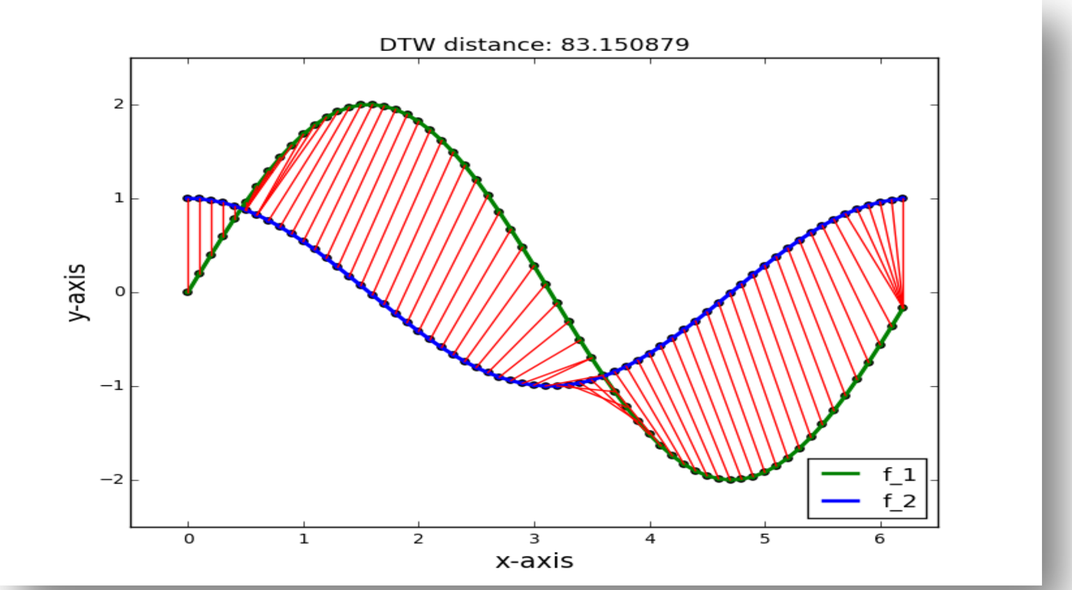
Failure model: GISSMO — post-failure oscillation of coupon

Addressing noise: Dynamic Time Warping

- DTW calculates the distance between two data sets, which may vary in time, via its corresponding warping path.
- This path is the result of the minimum accumulated distance which is necessary to traverse all points in the curves.
- The matching is end-to-end.
- While the Euclidean distance measure is a strict one-to-one mapping, DTW also allows one-to-many mappings.
- Mathematically, optimize the path:

$$DTW(P,Q) = \frac{1}{l} \min_{W} \left\{ \sum_{i=1}^{l} \delta(w_i) \right\}$$





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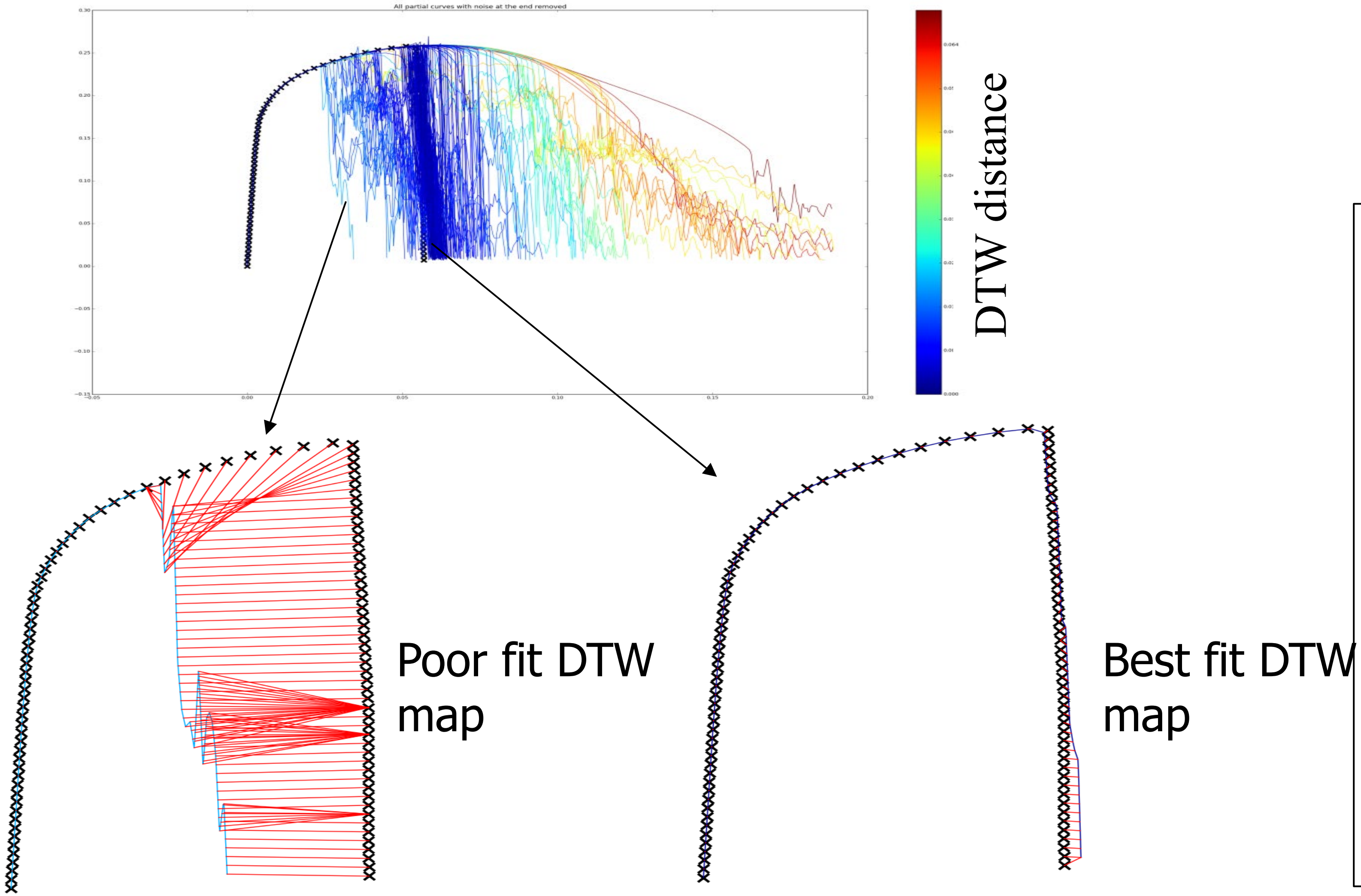
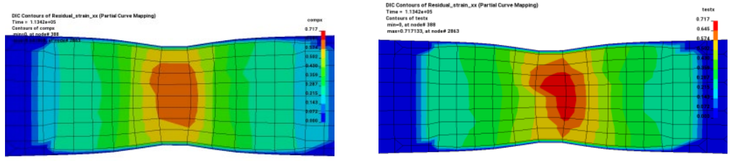
Dynamic Time Warping: DTW mapping

Simulated GISSMO model: force-displacement curves for tensile test



Contour Mapping

- Multi-point histories: Apply to multiple points (full field): ε vs. force
- Use DTW *map* to construct test contours for comparison



simulation experiment

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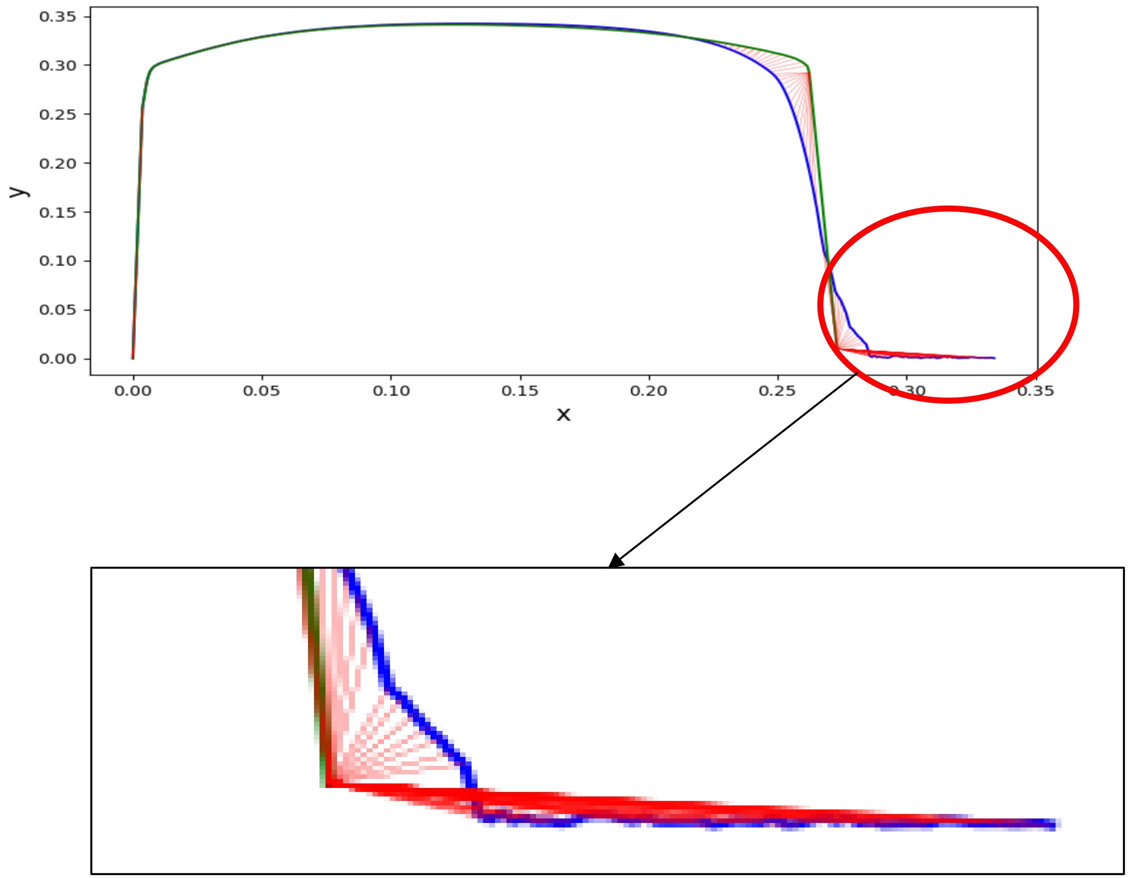
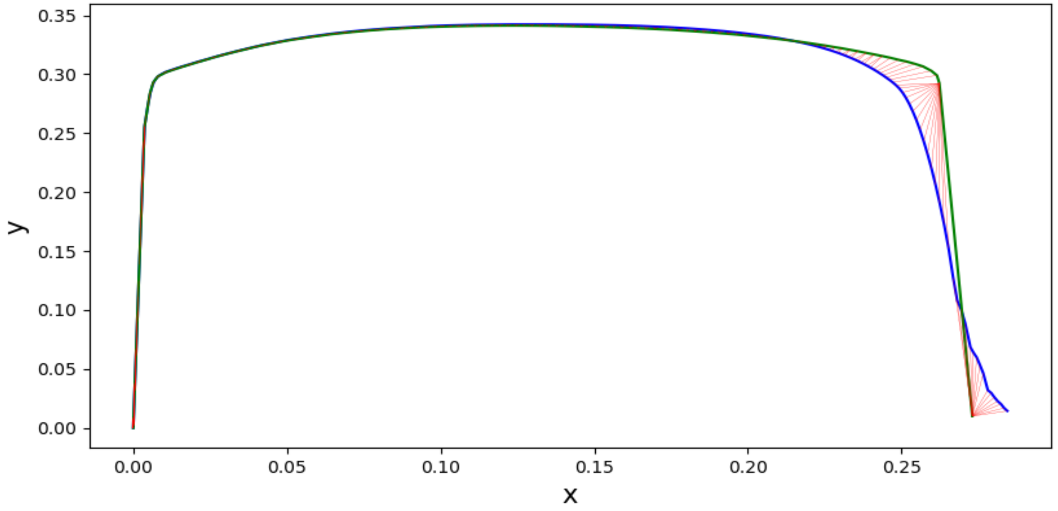
Dynamic Time Warping: Partial curves

Partial curve pairs can distort the DTW result



- In DTW, red connectors are summed
- Curve length difference artificially distorts mismatch
- Truncation required

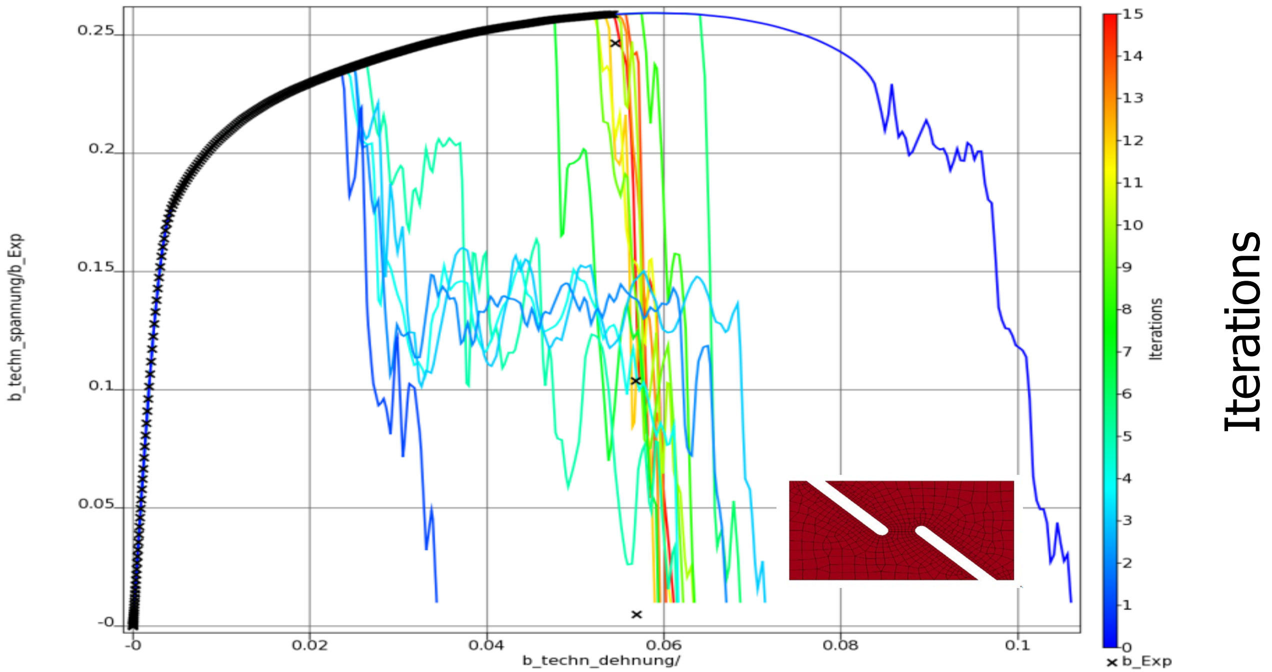


Example: GISSMO model

The GISSMO failure model requires special treatment for curve matching

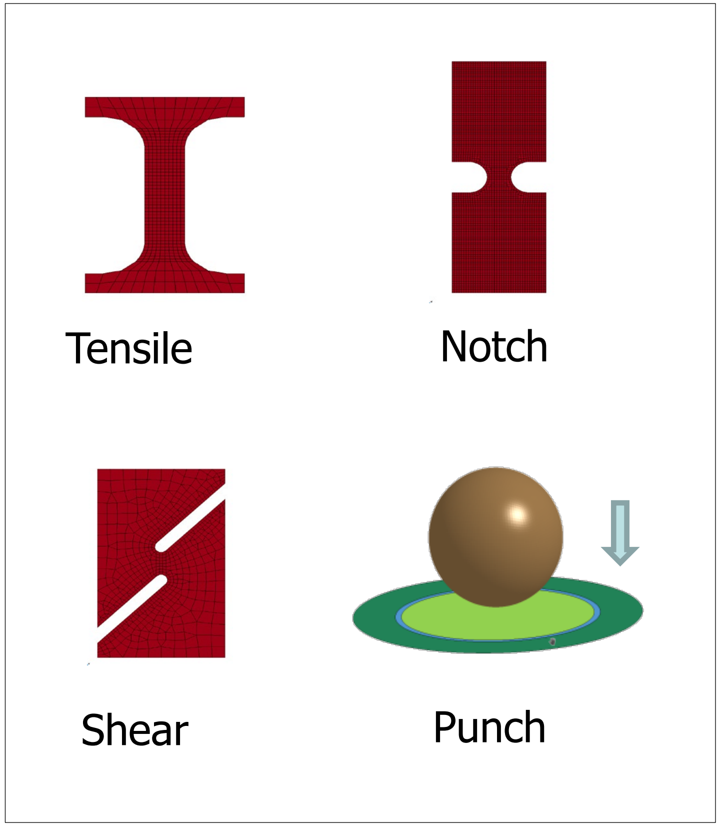
- Parameters: 7, Material Model: GISSMO
  - Uses discrete (element-by-element) erosion
- Curve Matching
  - Dynamic Time Warping (DTW)
  - Does not address partial curves ⇨ Truncate Force history at failure
- Optimization
  - SRSM (fast local optimizer)

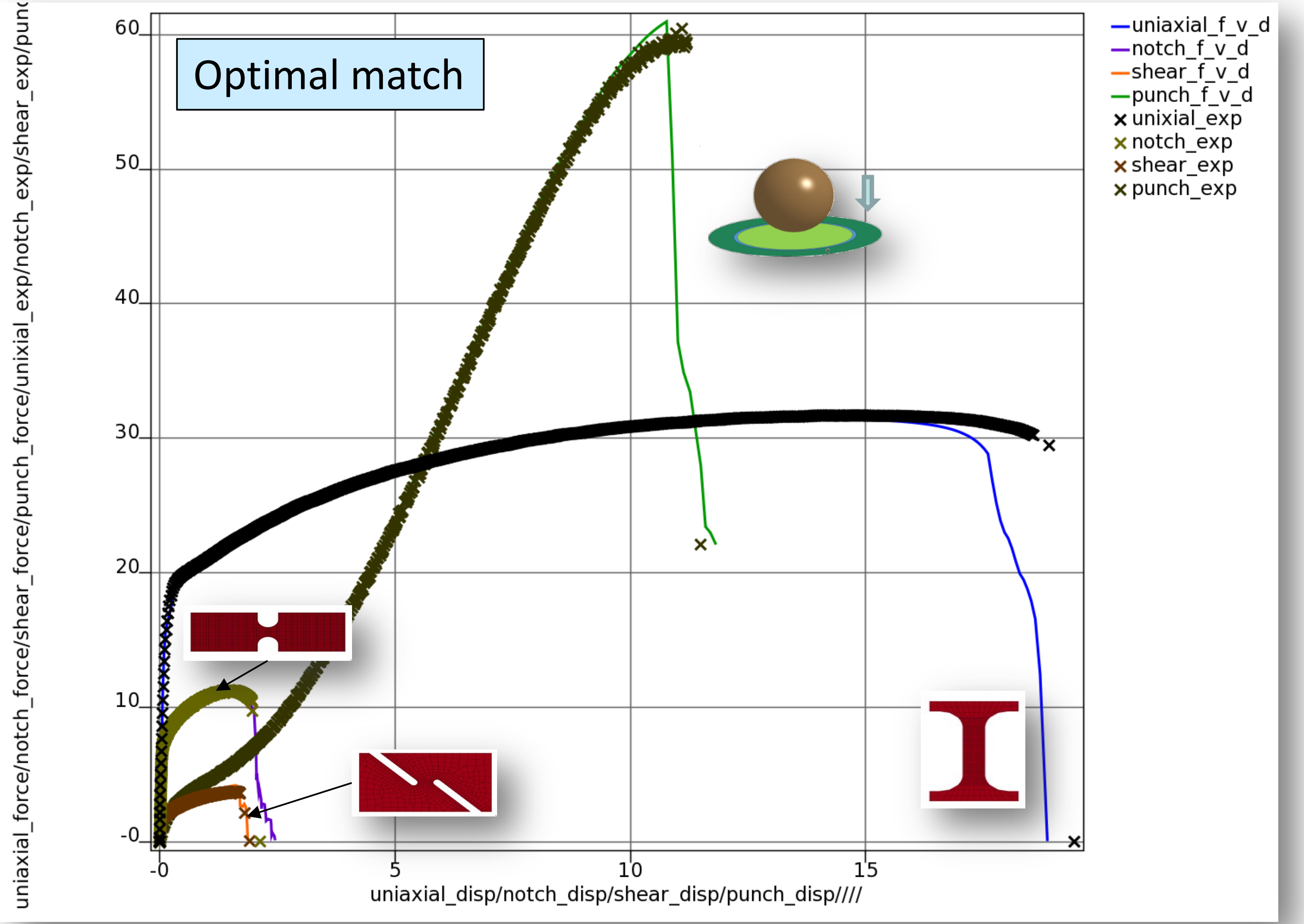
Shear: single case calibration history



Calibration: GISSMO model

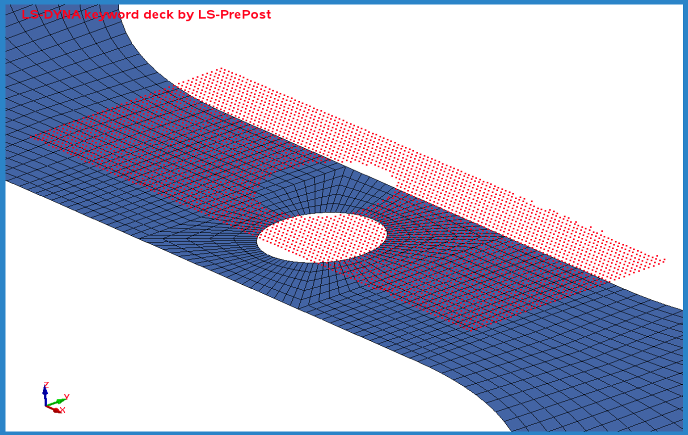
In industry, the calibration of the GISSMO model typically involves multiple cases





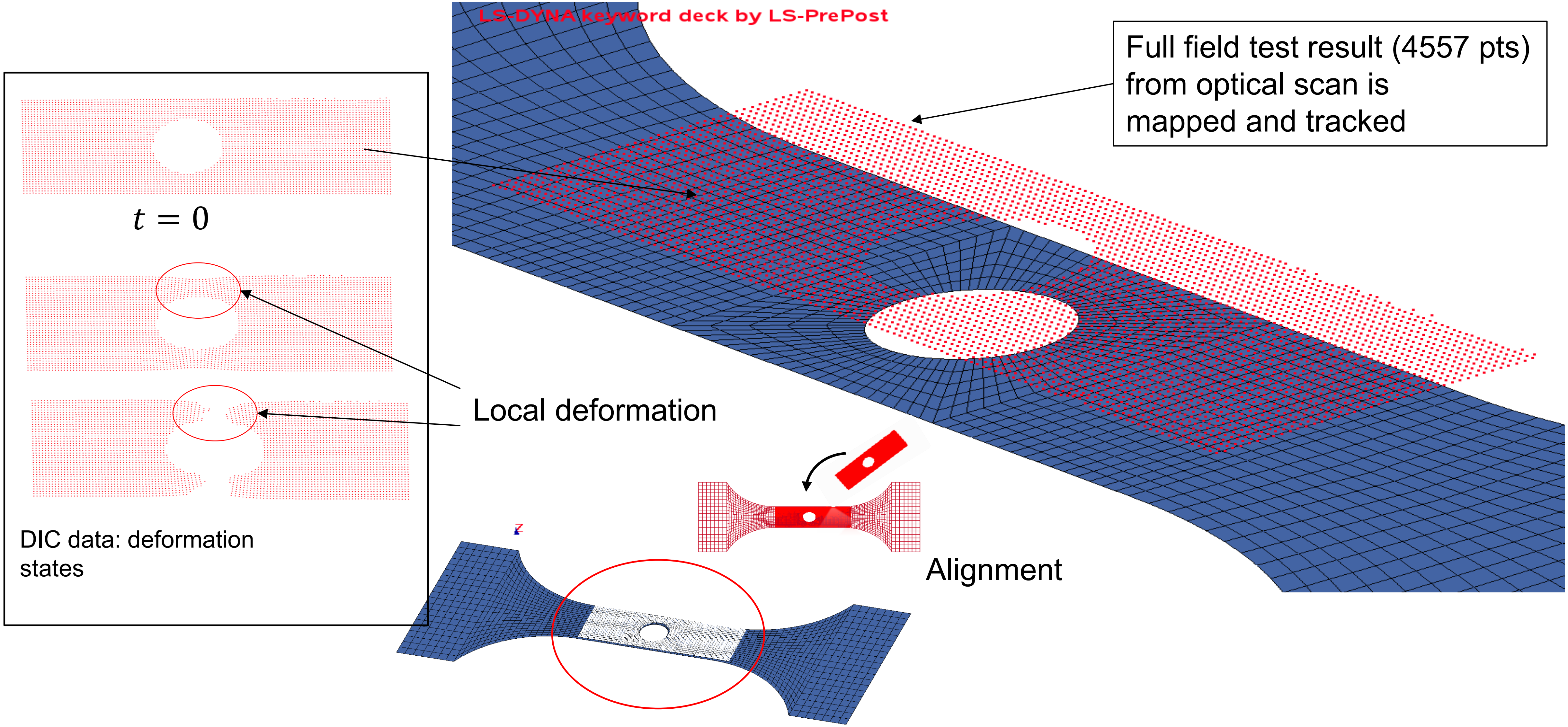
Courtesy: FCA

Digital Image Correlation



Digital Image Correlation (DIC)

Align and *map* optical data to the Finite Element model



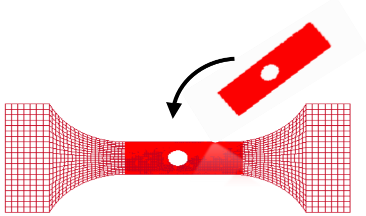
Digital Image Correlation: LS-OPT technologies (1)

- ***Alignment*** *in 3D of test to FE model.* Least Squares solution:

$$\boxed{\min_{\boldsymbol{T},\hat{s}} \|\hat{s}\boldsymbol{X}_1\boldsymbol{T} - \boldsymbol{X}_2\|}$$

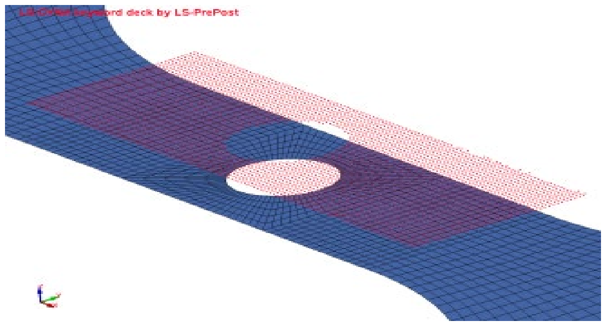
$\boldsymbol{X}_1$:Test pts (subset), $\boldsymbol{X}_2$: FE model pts, $\boldsymbol{T}$: transform, $\hat{s}$: Isotropic scaling. Typically 3 or 4 points

  - *Alternative*: LS-PrePost® to translate, rotate and scale test points.



Align Test points

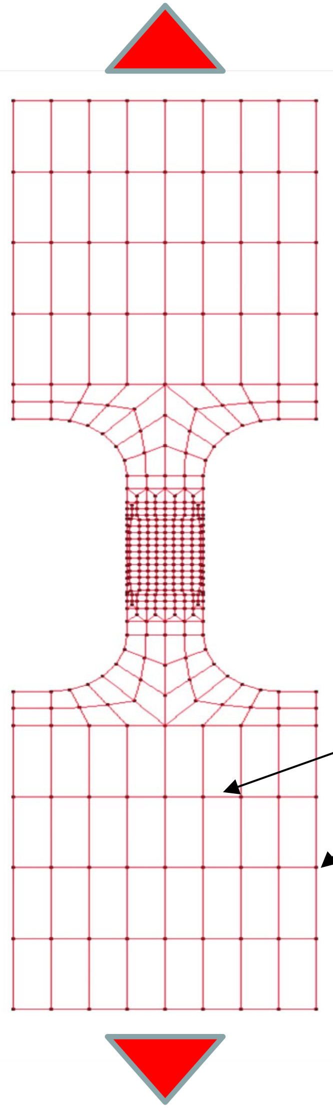
- ***Map:*** *Test → FE mesh:*
  - Exact Nearest Neighbor (bin tree) search and element interpolation ($10^7 \rightarrow 10^7$ pts). (Practice: ~ 10^6)



- ***Optimization:*** *Minimize Similarity Measure:*

$$\boxed{\min_{x} \sum_{p=1}^{points} DTW(P,Q)_p}$$

Validation of a Synthetic Problem

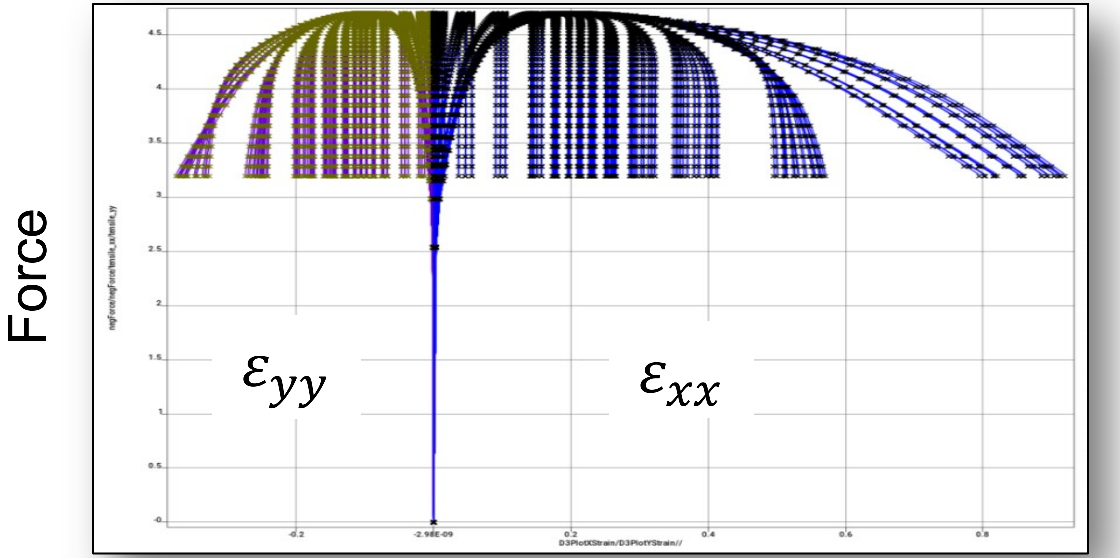


Test pts & nodes coincide

Material 24 with *Hockett-Sherby* flow curve extrapolation

$$f(\varepsilon_p) = A - Be^{-c\varepsilon_{pl}^{n}}$$

- **c and n are variables**



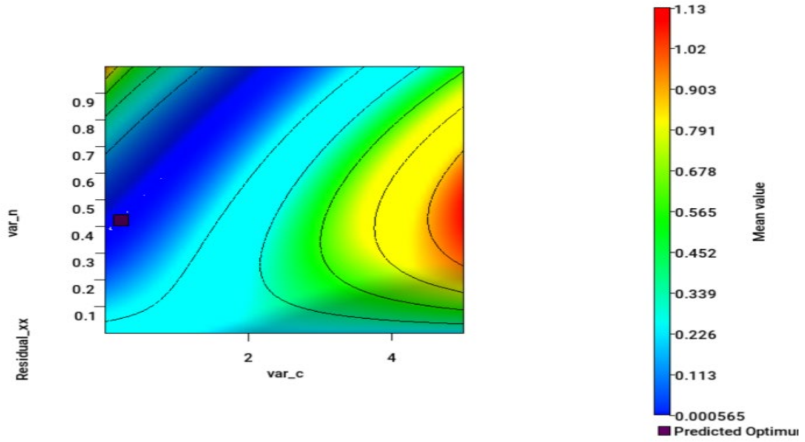
Full-field deformation

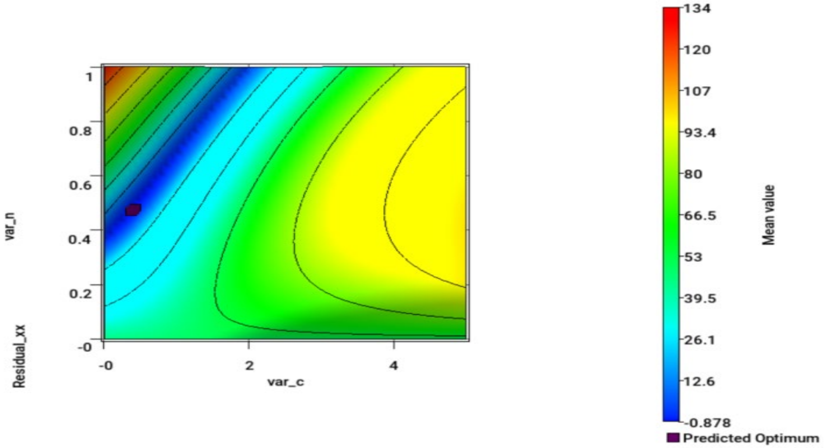
	c^*	n^*
Start	4.0	0.9
PCM	0.502	0.501
DF	0.500	0.500
DTW	0.497	0.499
Exact	0.500	0.500

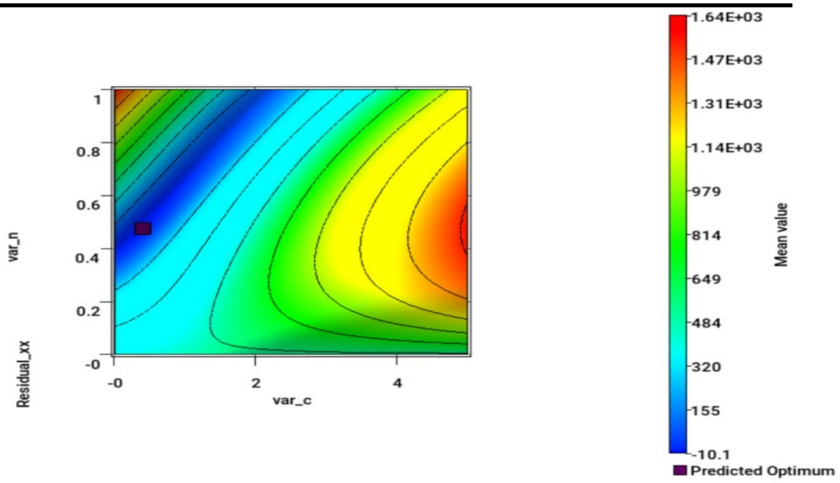
Distance vs. parameters

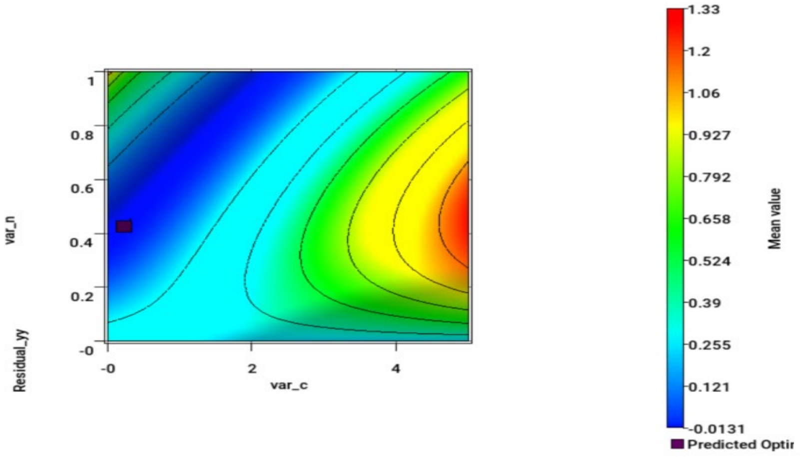
Different similarity measures compared

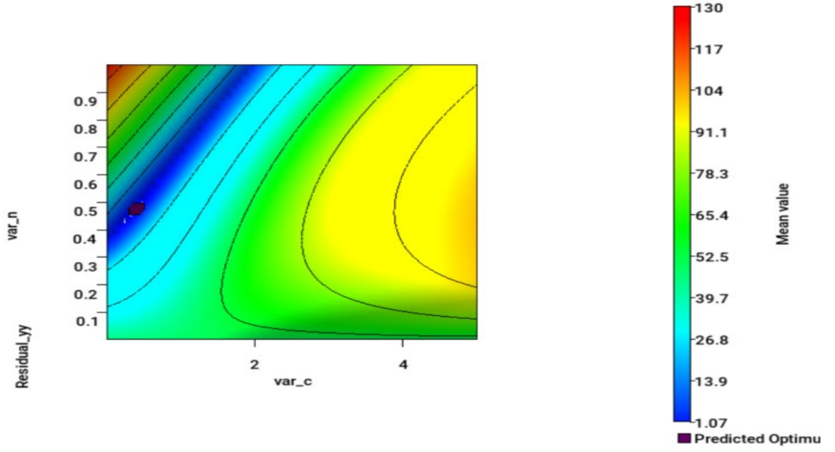
Partial Curve Mapping	Discrete Fréchet	Dynamic Time Warping

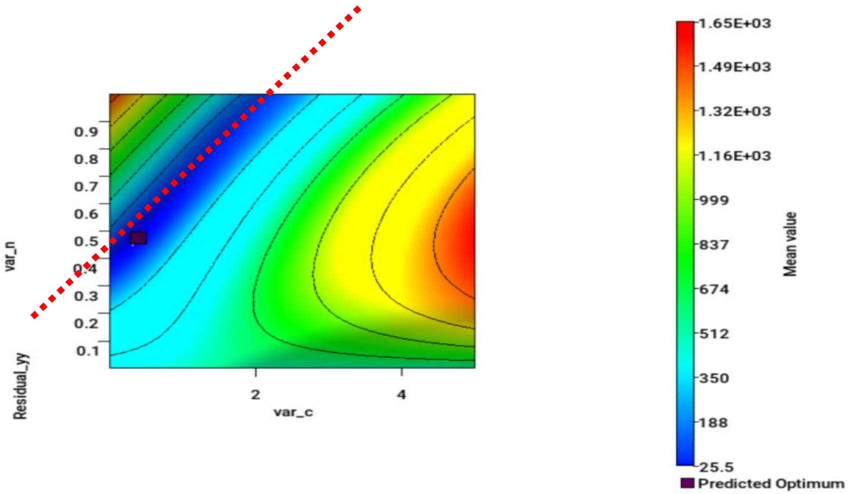






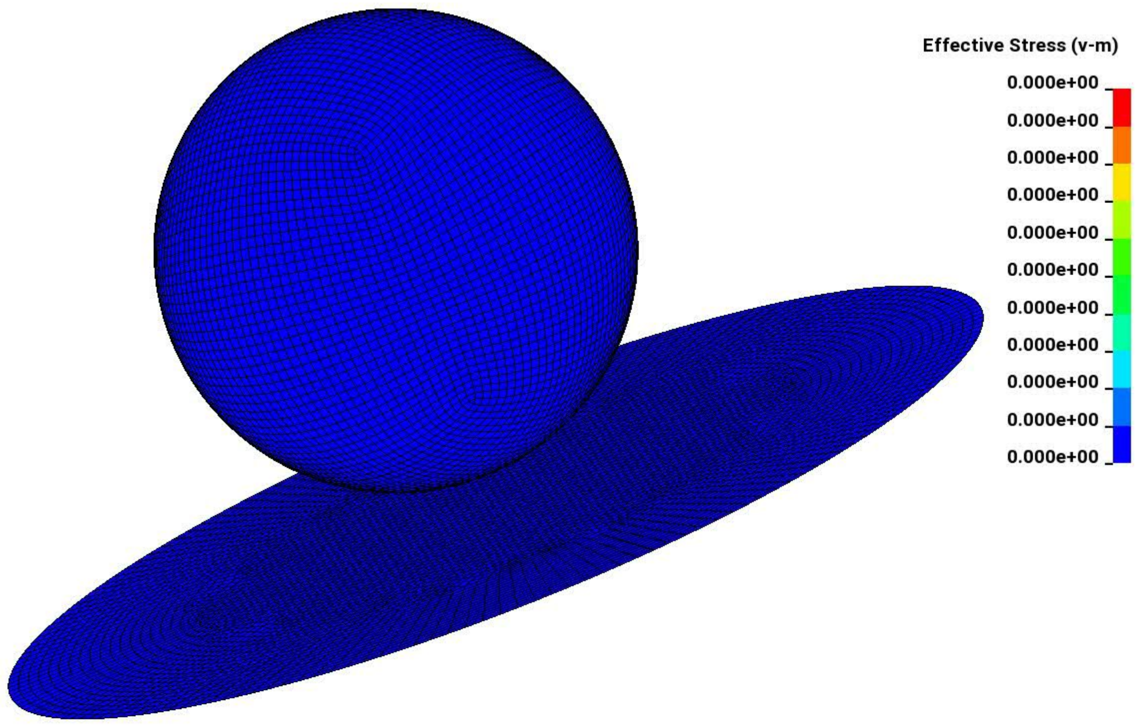


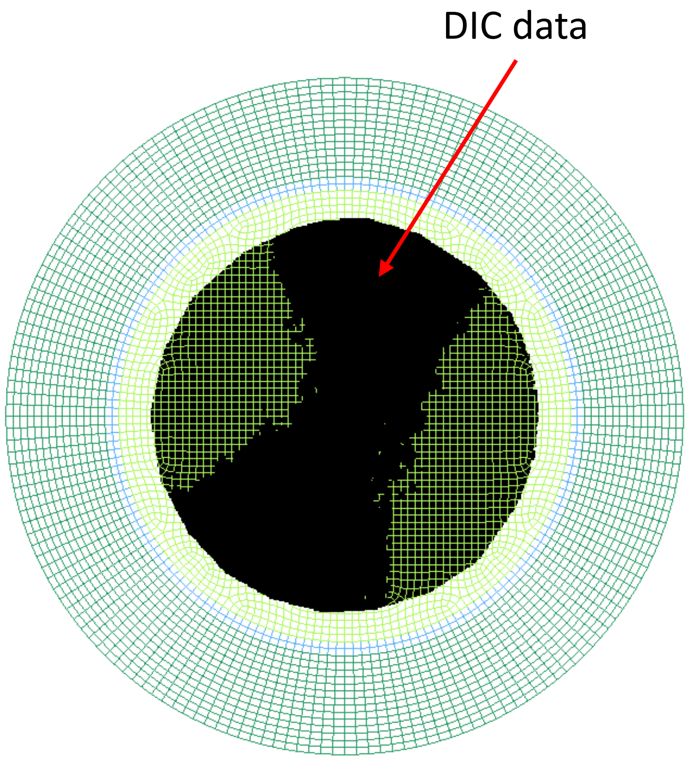




Example 1: DIC Validation: Punch example

Calibrate GISSMO material properties using strains/transverse displacement

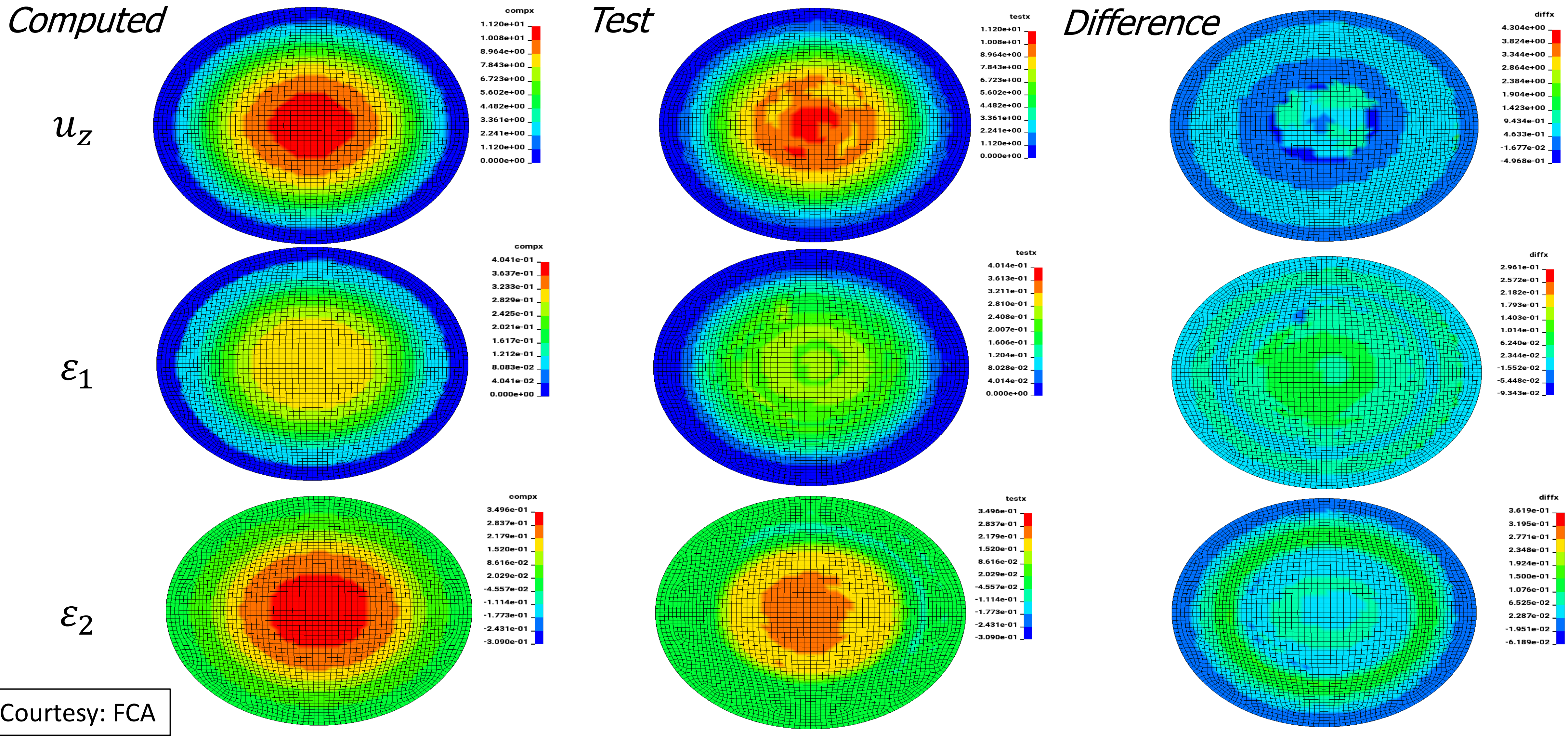




Courtesy: FCA

Example 1: DIC Validation: Punch example

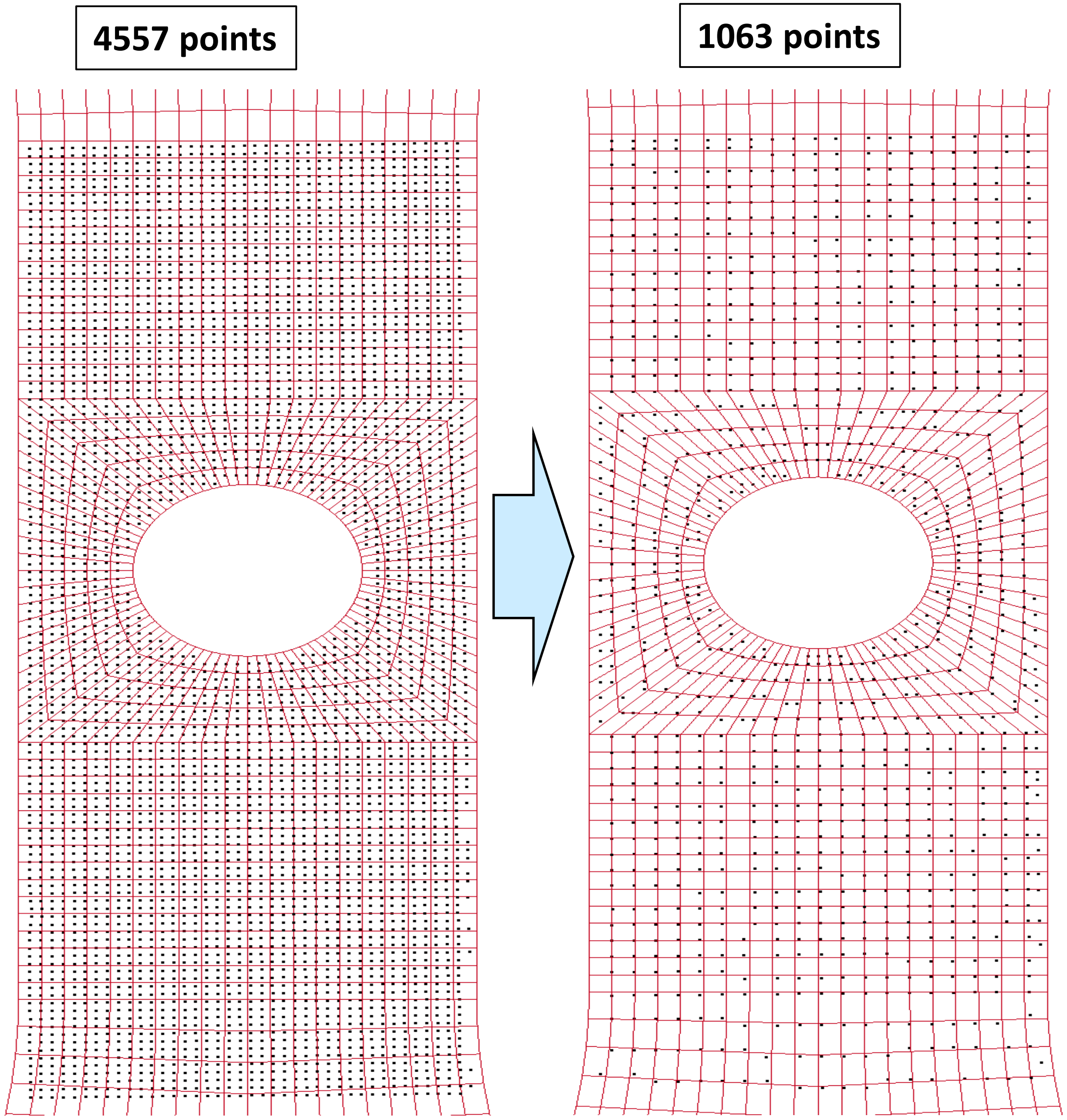
The calibration was done using a Force-Displacement similarity match (GISSMO)



Courtesy: FCA

Digital Image Correlation: *Nearest Neighbor Cluster*

- **Accuracy and cost**
- **Nearest Neighbor Clustering**
  - Pre-processing feature
  - Reduce resources for large point set ($\sim 10^6$)
    - Storage space
    - CPU time: mapping is done at each time step (vanishing nodes/points)
  - Nodal 1-to-1 map
  - Can also apply a proximity tolerance for removing outlier points
- **Algorithm ($\boldsymbol{t = 0}$)**
  - Nearest node to each point → *reduced node set*.
  - Prune *reduced node set* → *nearest points*
  - 1-to-1 map



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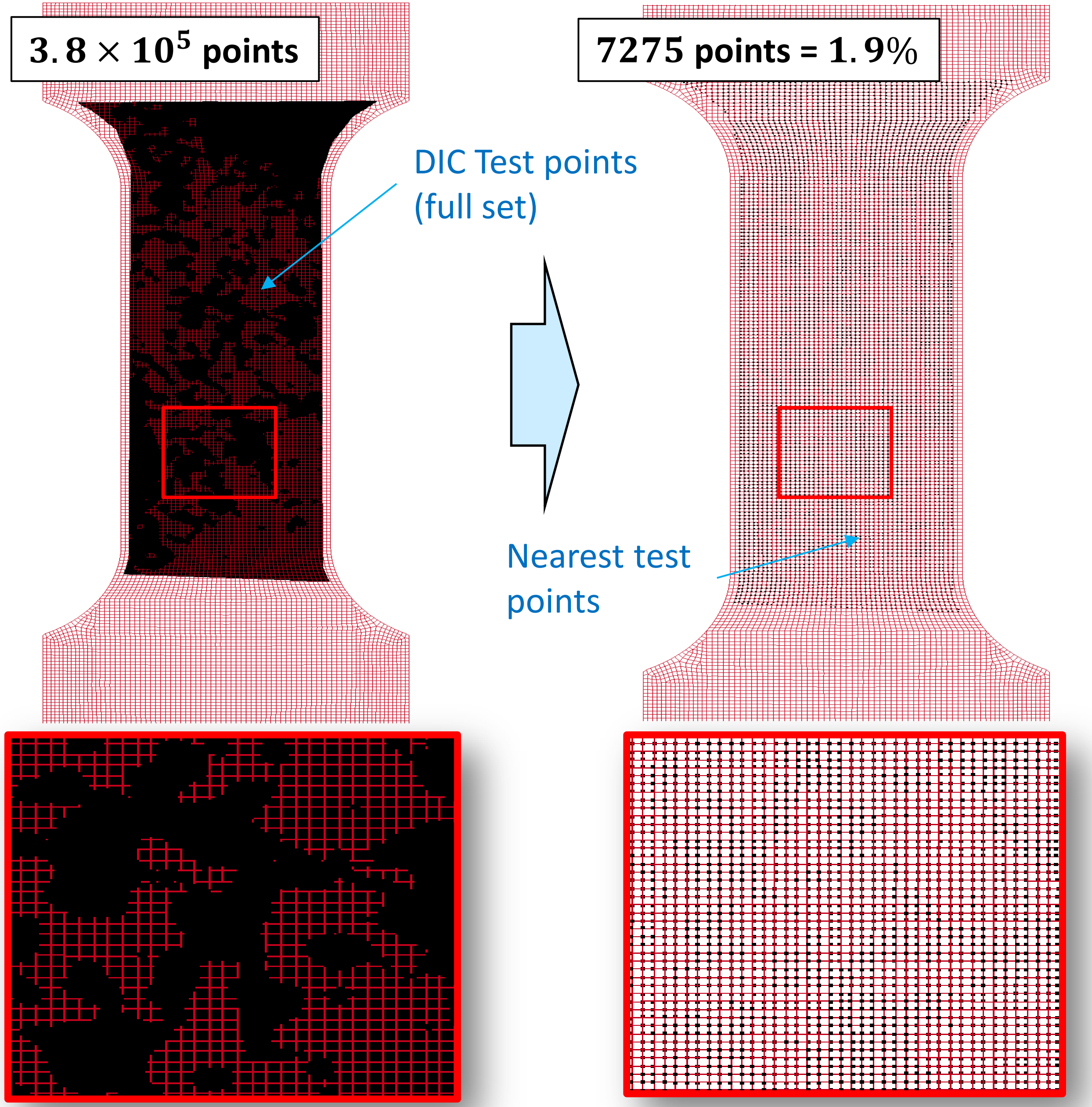
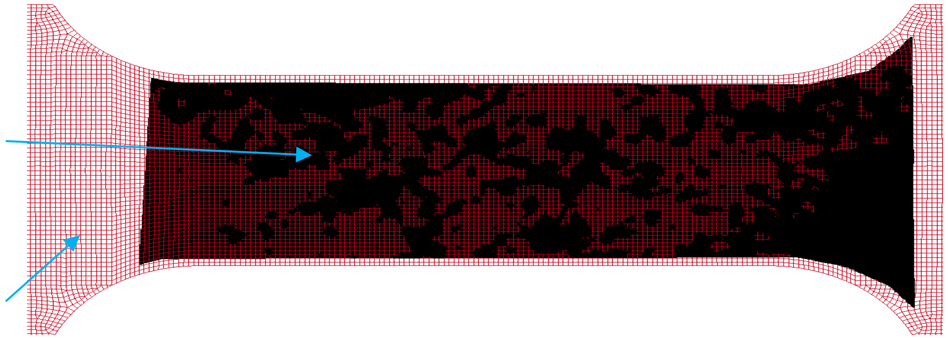


Example 2: Tensile test

The contour comparison uses *Dynamic Time Warping:* 3.8×10^5 DIC points

DIC Test points

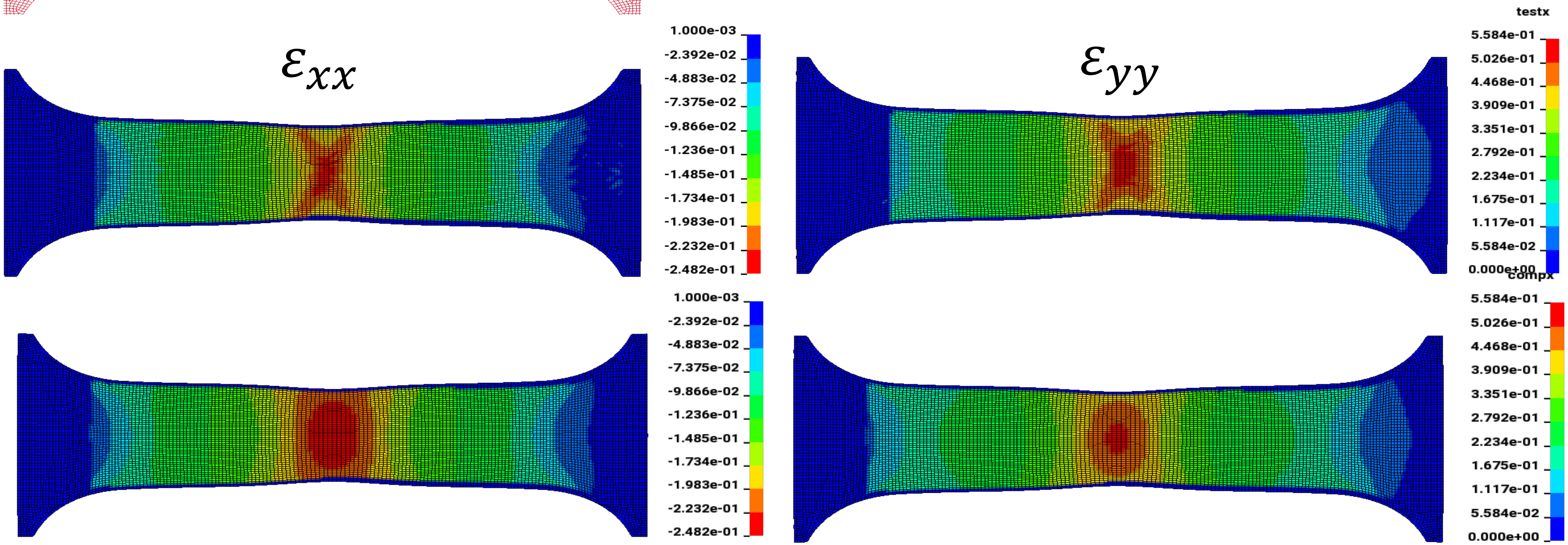
FE model



- Reduces 380,000 DIC points to 7275 points with nodal neighbors
- Reduces extraction time from 2 hours → 6 minutes

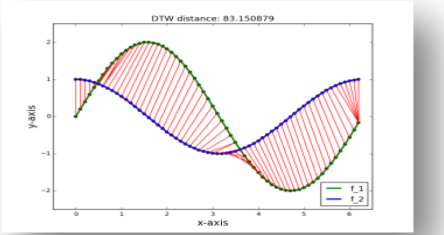
DIC

Computed



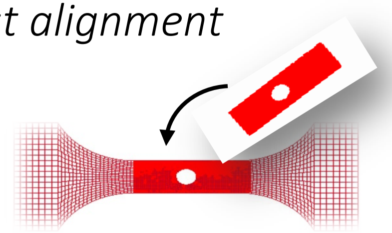
LS-OPT *DIC* calibration feature summary (v6.0)

- DIC Interfaces:
  - gom/ARAMIS
    - v6 CSV
    - v7 XML
  - Fixed Format (LS-PrePost)
  - Free Format (LS-OPT/GenEx parser)
- LS-DYNA interface
  - Multi-point histories (d3plot)
  - Entities
    - Nodal
    - Shell
    - Solid
  - *Exact nearest neighbor point* mapping (~10^7 pts). Test pt → FE pt
- Curve similarity methods
  - Euclidean, Fréchet, *DTW*, PCM

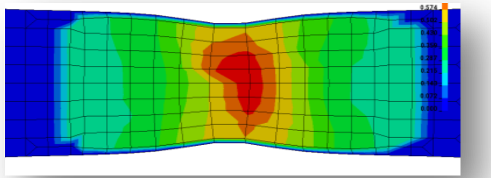


DTW

- Filtering
  - Online filtering (SAE, Ave)
- GUI
  - Test pre-view
  - *Test alignment*



  - *Strain fringe plot* (LS-PrePost)
    - Simulation
    - Experiment
    - Error



Outlook

- General feature: Improved pre-viewing/pre-processing of experimental data.

  Interactive filtering and truncation of test results
- Partial DTW-based curve mapping

  DTW-LCS method
- Further speedup

  Multiple similarity responses typically have the same mapping