Webinar, 2023-06-22, 10:00 CET

Simulations of short fiber reinforced plastics – from injection molding to crash

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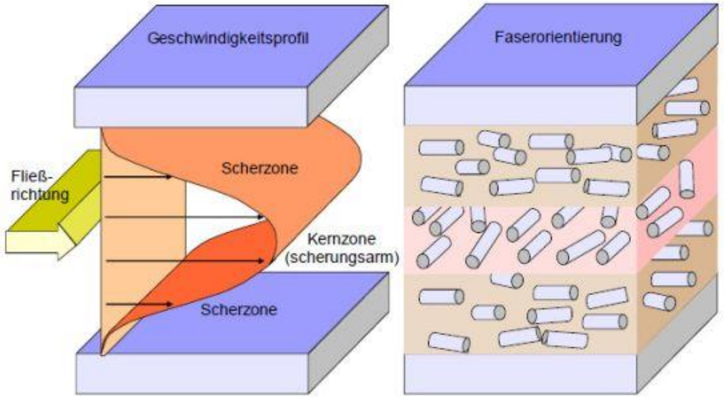
Agenda

- Introduction
  - SFRP and simulations
  - Process simulation paths
    - Example using Moldex3D
- Envyo
  - Fiber orientations
  - Homogenization
  - Mapping from Moldex3D to LS-DYNA
- Material models for SFRP
  - Calibration of material models
    - *MAT_215
    - *MAT_157
- Examples
  - Tensile test cut out from plate
  - Bracket with prestress
  - Bumper impact
- Final remarks
- Further information

Introduction

SFRP and simulations

- SFRP – short fiber reinforced plastics, or short fiber thermoplastics, are easy to process and that also makes it a cost-effective design solution.
- The mechanical properties of these materials depend heavily on the fiber orientation relative to the loading direction.
- Fiber orientations come from the manufacturing (often injection molding) and vary within the final components, leaving us with an inhomogeneous and anisotropic material.
- To completely capture the mechanical behavior, we need to model the complete process from manufacturing of the component to the applied loading.

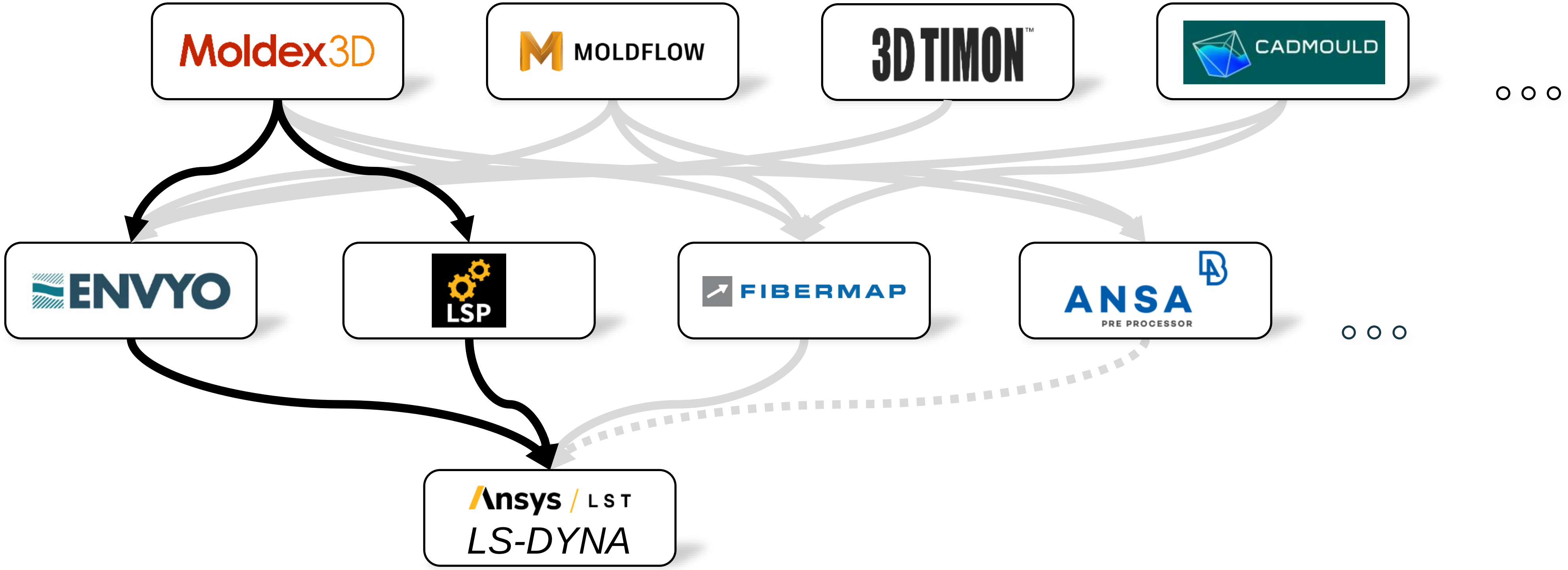


https://wiki.polymerservice-merseburg.de/index.php/Datei:Faserorientierung2.jpg

Introduction

Process simulation paths

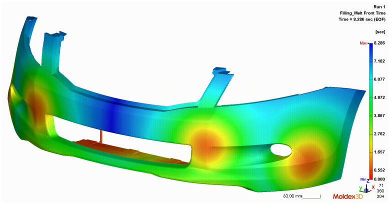
- Process simulation paths and focus of this webinar.

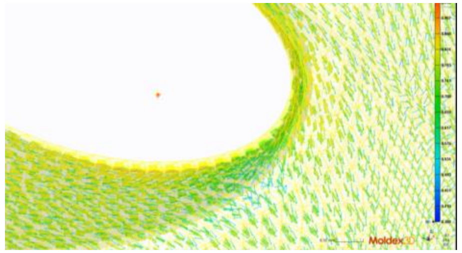


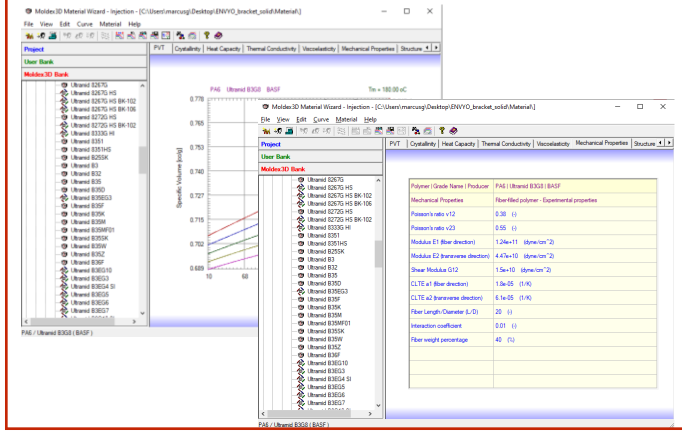
Process example using Moldex3D

Input

- Fiber orientation is predicted in the Moldex3D filling simulation
- Moldex3D Material database include fiber content and properties







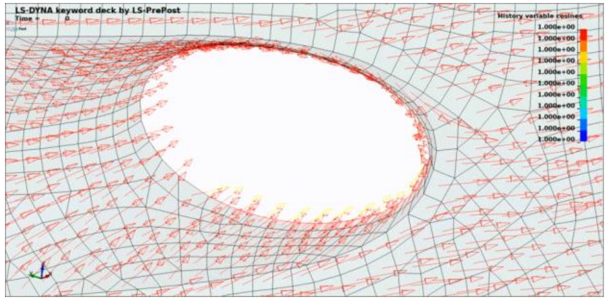
Flow analysis

Orientation information

\+

Material parameters

Moldex3D

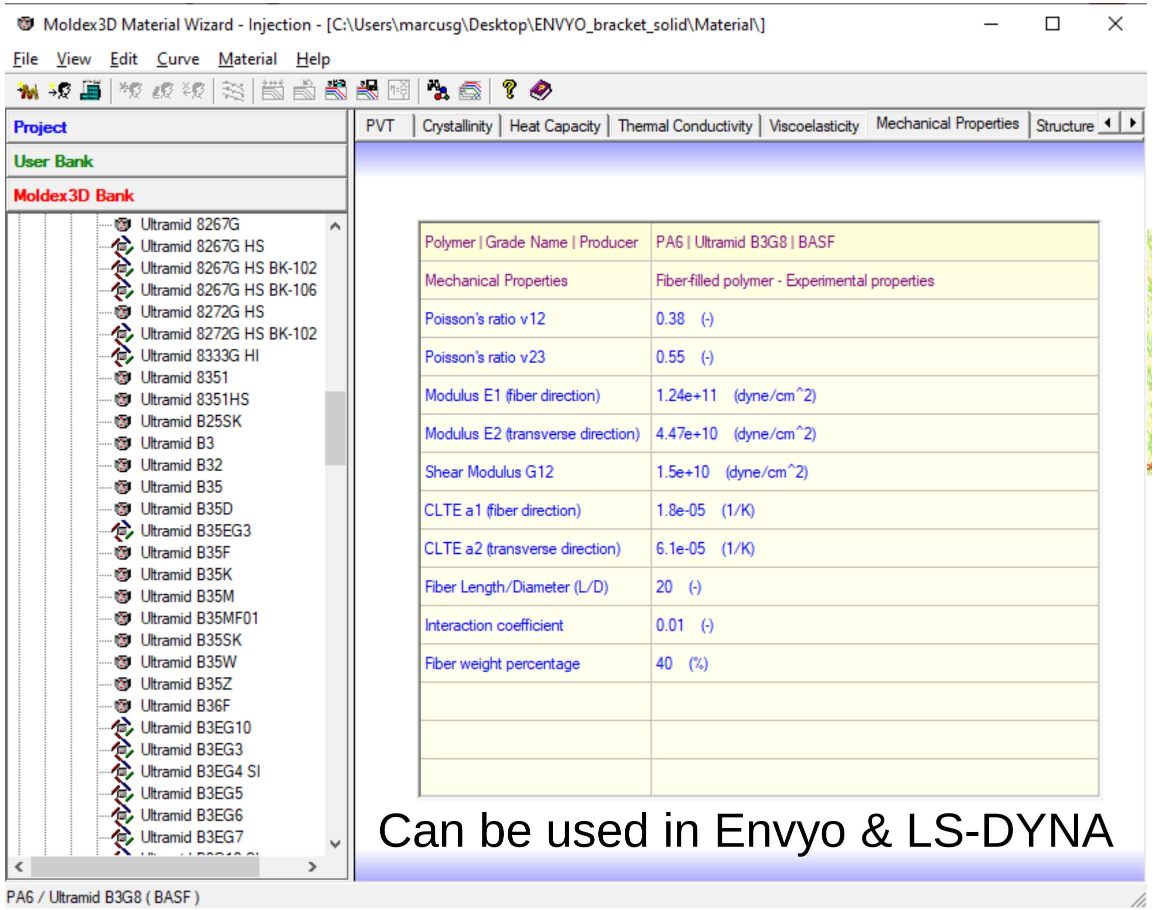


LS-DYNA model

Process example using Moldex3D

Input

- Fiber orientation is predicted in the Moldex3D filling simulation
- Moldex3D Material database include fiber content and properties



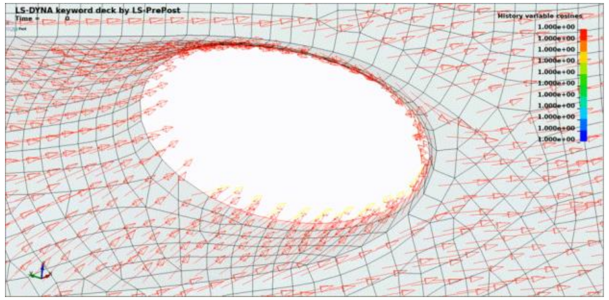
Can be used in Envyo & LS-DYNA

Flow analysis

Orientation information

+

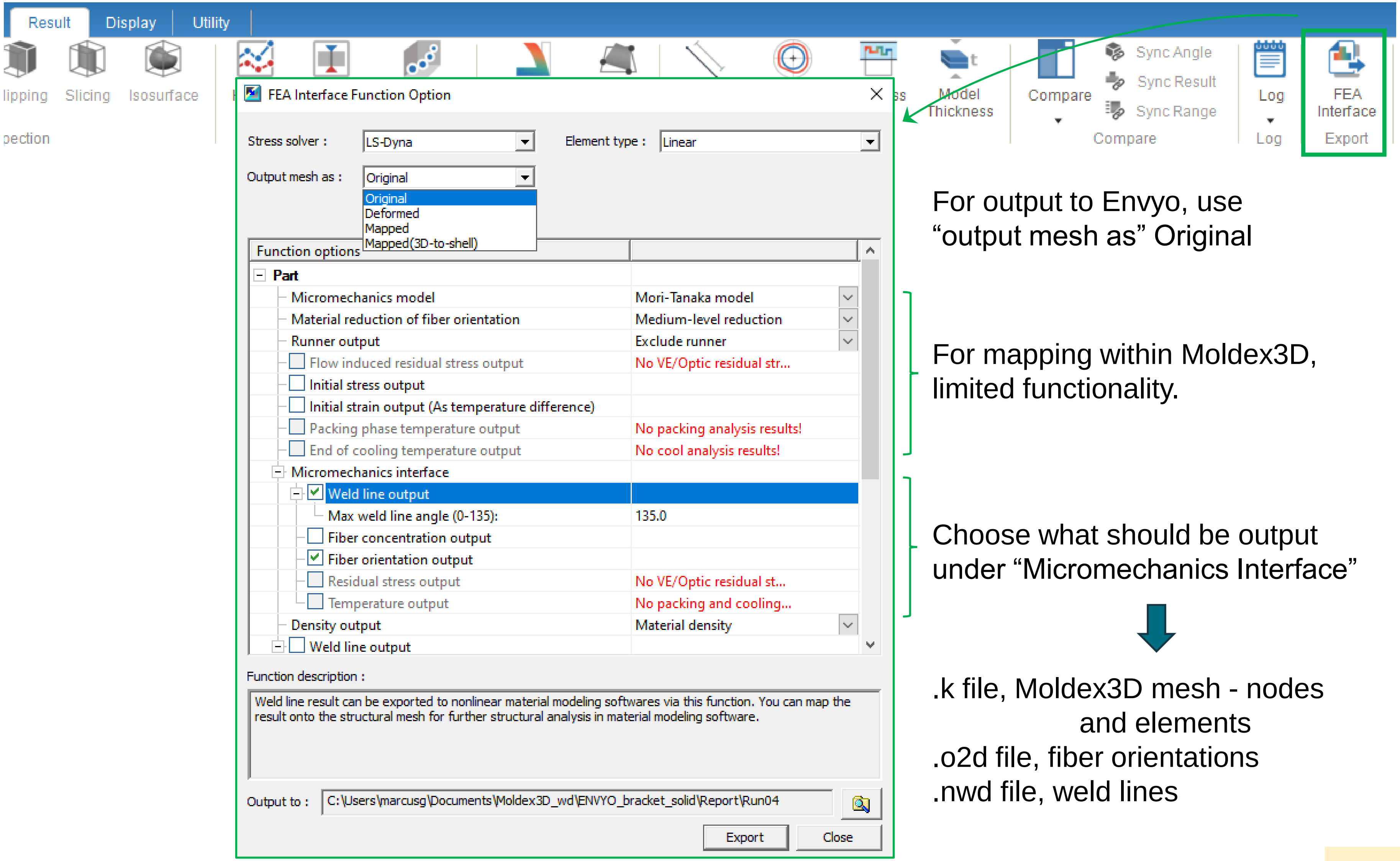
Material parameters



LS-DYNA model

Process example using Moldex3D

Output results for further analyses



For output to Envyo, use “output mesh as” Original

For mapping within Moldex3D, limited functionality.

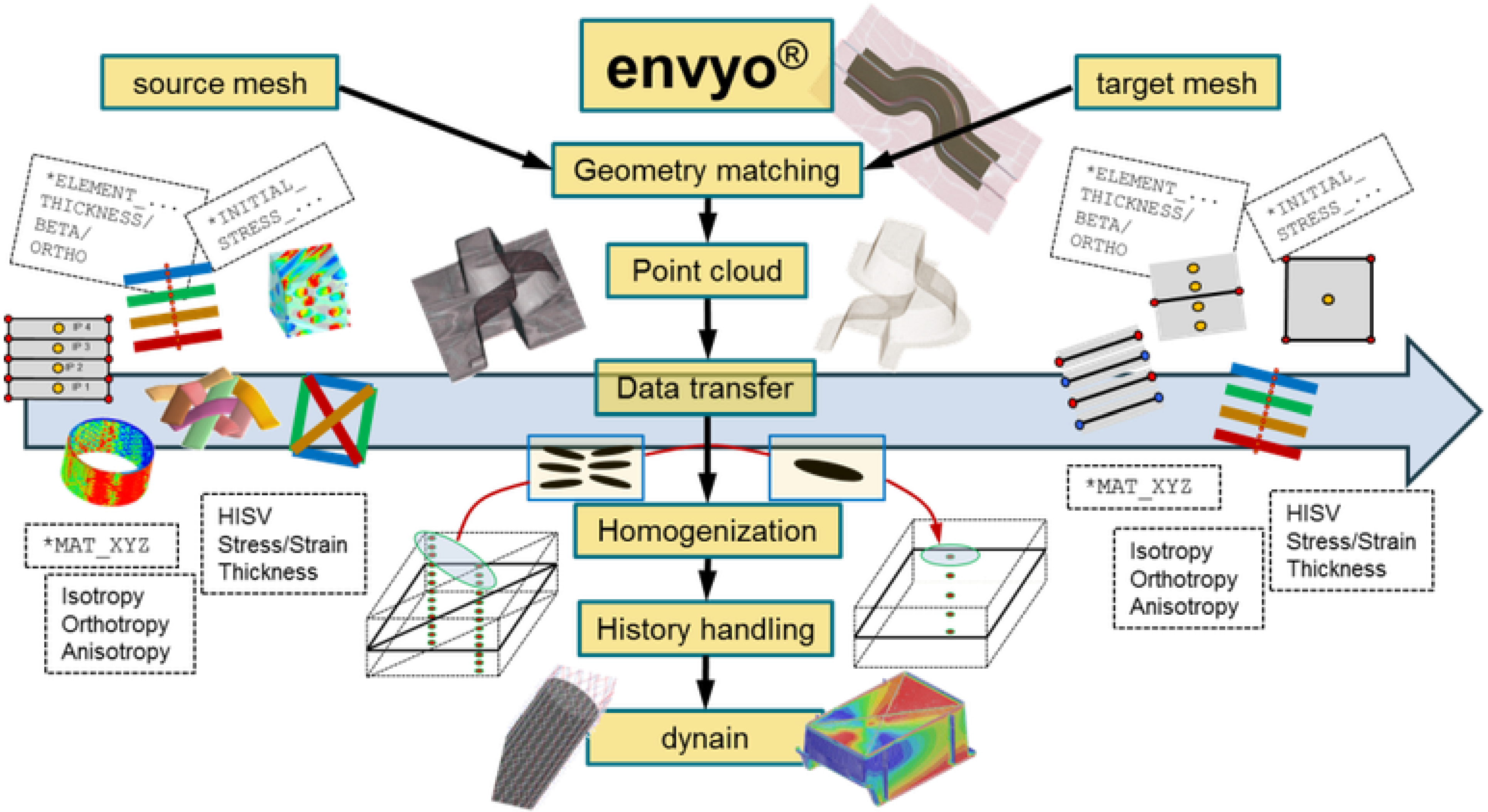
Choose what should be output under “Micromechanics Interface”

.k file, Moldex3D mesh - nodes and elements
.o2d file, fiber orientations
.nwd file, weld lines

Envyo

- Envyo® is a mapping tool for multiple purposes, developed by DYNAmore GmbH, an Ansys company.
- Envyo can for instance map:
  - from different solvers
  - to other meshes including between different element types
  - from 2d axisymmetric simulation results to 3d models
  - from history variable values to other material models
  - from point clouds of experimental data
  - from images
  - …
- Mapping with Envyo can be used for many purposes, but mapping to an LS-DYNA input model is the most common application.

Envyo



envyo®
source mesh
target mesh
Geometry matching
Point cloud
Data transfer
Homogenization
History handling
dynain
*ELEMENT_...
THICKNESS/
BETA/
ORTHO
*INITIAL_
STRESS_...
*MAT_XYZ
Isotropy
Orthotropy
Anisotropy
HISV
Stress/Strain
Thickness

Envyo

Mapping injection molding results to LS-DYNA

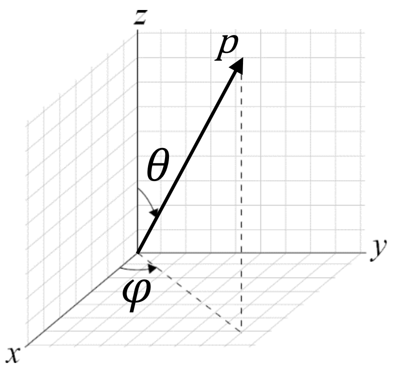
- When mapping from injection molding analyses, only mapping to shell and solid elements is available right now.
- A “weldline” can be put in a separate part with lower material properties. You also specify the width (radius) on the weldline. Currently no difference in what angle the fronts meet (flow line vs. weld line).

Envyo

Fiber orientations

- Each fiber has a definite direction described by

$$p = \begin{pmatrix} \sin\theta\cos\varphi \\ \sin\theta\sin\varphi \\ \cos\theta \end{pmatrix}, \quad -\frac{\pi}{2} \le \varphi \le \frac{\pi}{2}, \quad 0 \le \theta \le \pi$$



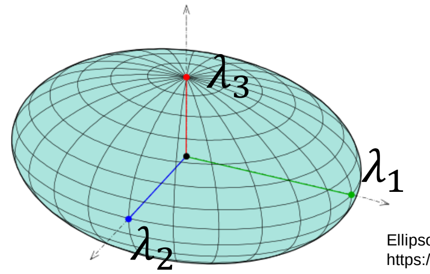
- The orientation tensor sums and averages the contributions from each fiber

$$a_{ij} = \frac{1}{n}\sum_{k=1}^{n} p_i^k p_j^k = \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix}$$

- The symmetric tensor has three orthogonal eigenvectors and corresponding eigenvalues λ_i that sum to 1

$$a_{ij} = a_{ji}$$

$$\lambda_1 + \lambda_2 + \lambda_3 = 1$$



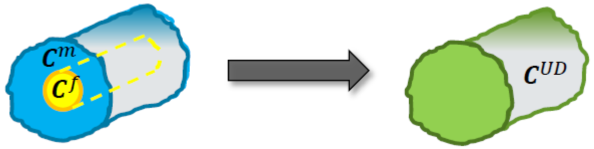
Ellipsoid adopted from Ag2gaeh - Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=45585493

- The eigenvector with the largest eigenvalue is often visualized along with the eigenvalue as the color fringe to show the fiber directions

Envyo

Homogenization

- Homogenization is the process of collecting the material properties of the constituents into one composite material.



- Not all properties are necessarily homogenized, some properties are given on the material card and need to be calibrated.
- Many homogenization methods exist, of which these are available in Envyo
  - Halpin-Tsai
  - Tandon-Weng
  - Voigt
  - Kukuri
  - Mori-Tanaka_1
  - Mori-Tanaka_2
  - Mori-Tanaka_3
- Mori-Tanaka_3 is the most widely used one, together with a linear closure approximation method and assumed spheroidal inclusion shape.

Material models for SFRP in LS-DYNA

*MAT_157 and *MAT_215

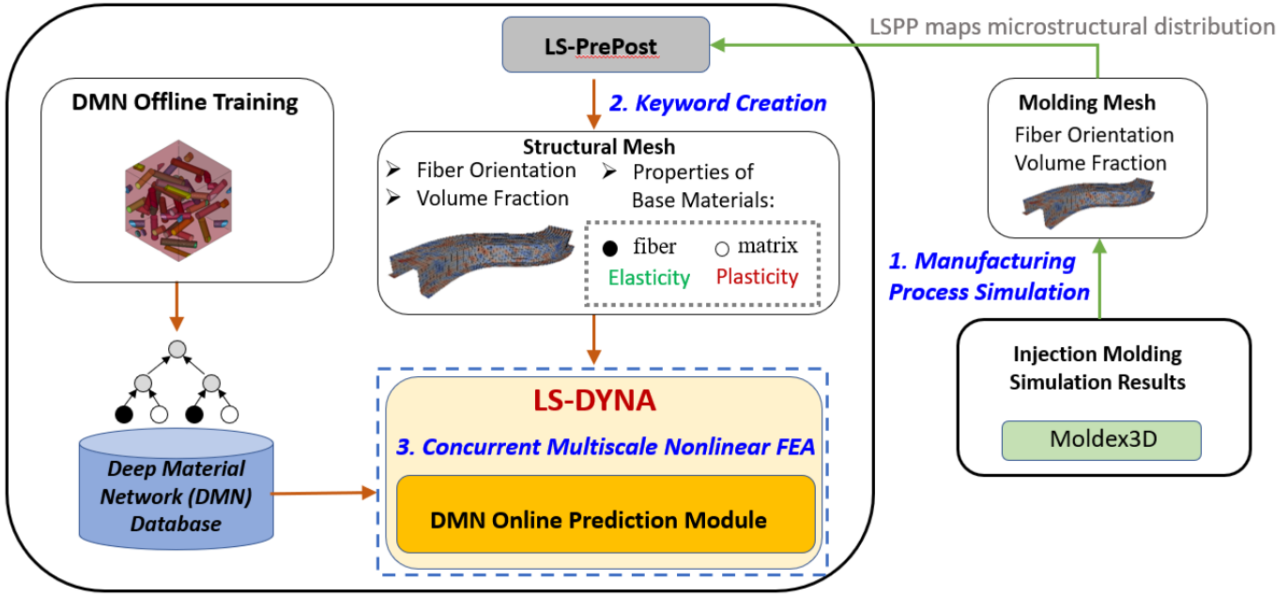
- *MAT_ANISOTROPIC_ELASTIC_PLASTIC (*MAT_157, explicit, implicit)
  - Anisotropic elastic adopted from *MAT_002
  - Anisotropic plastic adopted from *MAT_103_P (FGHLMN for solids, R-values for shells)
  - Strain rate dependency with table in LCSS
  - Brittle orthotropic failure available (phenomenological, Tsai-Wu or Tsai-Hill)
- *MAT_4A_MICROMEC (*MAT_215, explicit, implicit(R14.1/dev))
  - Michromechanical model with inelastic homogenization for describing the composite deformation
    - Mori-Tanaka Meanfield Theory
    - Ellipsoidal inclusions using Eshelby's solution
    - Orientation averaging
    - DIEM for matrix failure and maximum stress criterion for fiber failure
  - Matrix behavior is by an isotropic viscoplastic (on LCIDT) von Mises model
  - Fiber behavior is transversal isotropic elastic

Material model	mat_157, IHIS=1	mat_157, IHIS=3	mat_215
What is mapped?	• Material directions	• Material directions • Stiffness matrix (accounts for orientation degree)	• Length and orientation of ellipsoid

Material models for SFRP in LS-DYNA

*MAT_303

- Machine-learning based multiscale material model
  - User needs to provide
    - Fiber orientation tensor
    - Fiber volume fraction (optional)
    - Material properties for each constituent
  - LSPP can be used for data transfer from Moldex3D
  - Model is trained “offline” utilizing the LS-DYNA RVE Analysis tool
  - Available since R14, explicit
    - Eight-node hexahedral elements, four-node tetrahedrons
    - Type 25 four node shell elements



Wei, Wu, Lyu, Hu, Rouet, Zhang, Ho, Oura, Nishi, Naito, Shen: *Multiscale Simulation of Short-Fiber-Reinforced Composites: From Computational Homogenization to Mechanistic Machine Learning in LS-DYNA,* 13th European LS-DYNA Conference 2021, Ulm.

Mapping to *MAT_157, IHIS=1

MAT_157 = MAT_ANISOTROPIC_ELASTIC_PLASTIC

```
*MAT_ANISOTROPIC_ELASTIC_PLASTIC
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$#     MID        RO      SIGY      LCSS       QR1       CR1       QR2       CR2
         1
$#     C11       C12       C13       C14       C15       C16       C22       C23

$#     C24       C25       C26       C33       C34       C35       C36       C44

$#     C45       C46       C55       C56       C66    R00||F    R45||G    R90||H

$#  S11||L    S22||M    S33||N       S12      AOPT        VP                MACF
                                               0.0
$#      XP        YP        ZP        A1        A2        A3               EXTRA

$#      V1        V2        V3        D1        D2        D3      BETA      IHIS
                                                                               1
*INITIAL_STRESS_SOLID
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$# EID/SID      NINT     NHISV     LARGE    IVEFLG    IALEGP    NTHINT    NTHHSV
         1         1         6         1
$#         SIGXX               SIGYY               SIGZZ               SIGXY               SIGYZ

$#         SIGZX                 EPS               HISV1               HISV2               HISV3
                                                      q1                  q2                  q3
$#         HISV4               HISV5               HISV6               HISV7               HISV8
              q4                  q5                  q6
```

Green text = input if element type is shell

Material directions given on this form can only be visualized in LS-PrePost after an initialization in LS-DYNA.

Input to Envyo:

- SourceFile=XYZ_1.k (from Moldex3D)
- TargetFile=XYZ_2.k (target mesh)
- MappingResult=XYZ_3.key (result file)
- OrientationFile=XYZ_4.o2d (from Moldex3D)
- WeldlineFile=XYZ_5.nwd (from Moldex3D)

- ETYP=1
- MapStress=Yes (does not map residual stresses)
- MapWeldline=Yes
- WeldlinePID=10
- WeldlineRADIUS=1.0
- MapMainDir=No

- ALGORITHM=ClosestPoint
- SORT=BUCKET
- REPEAT=YES
- INN=4
- TargetMaterialModel=157
- IHIS=1

The q_{ij} terms are the first and third rows of a rotation matrix for the rotation from a co-rotational element's system and the *a-b-c* material directions. The c_{ij} terms are the upper triangular terms of the symmetric stiffness matrix, c_{11}, c_{12}, c_{13}, c_{14}, c_{15}, c_{16}, c_{22}, c_{23}, c_{24}, c_{25}, c_{26}, c_{33}, c_{34}, c_{35}, c_{36}, c_{44}, c_{45}, c_{46}, c_{55}, c_{56}, and c_{66}.

Mapping to *MAT_157, IHIS=3

MAT_157 = MAT_ANISOTROPIC_ELASTIC_PLASTIC

```
*MAT_ANISOTROPIC_ELASTIC_PLASTIC
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$#     MID        RO      SIGY      LCSS       QR1       CR1       QR2       CR2
         1
$#     C11       C12       C13       C14       C15       C16       C22       C23

$#     C24       C25       C26       C33       C34       C35       C36       C44

$#     C45       C46       C55       C56       C66         F         G         H

$#       L         M         M                AOPT        VP                MACF
                                               0.0
$#      XP        YP        ZP        A1        A2        A3               EXTRA

$#      V1        V2        V3        D1        D2        D3      BETA      IHIS
                                                                               3
*INITIAL_STRESS_SOLID
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$# EID/SID      NINT     NHISV     LARGE    IVEFLG    IALEGP    NTHINT    NTHHSV
         1         1        27         1
$#          SIGXX               SIGYY               SIGZZ               SIGXY               SIGYZ

$#          SIGZX                 EPS               HISV1               HISV2               HISV3
                                                       q1                  q2                  q3
$#          HISV4               HISV5               HISV6               HISV7               HISV8
               q4                  q5                  q6                 c11                 c12
$#          HISV9              HISV10              HISV11              HISV12              HISV13
              c13                 c14                 c15                 c16                 c22
$#         HISV14              HISV15              HISV16              HISV17              HISV18
              c23                 c24                 c25                 c26                 c33
$#         HISV19              HISV20              HISV21              HISV22              HISV23
              c34                 c35                 c36                 c44                 c45
$#         HISV24              HISV25              HISV26              HISV27              HISV28
              c46                 c55                 c56                 c66
```

Input to Envyo:

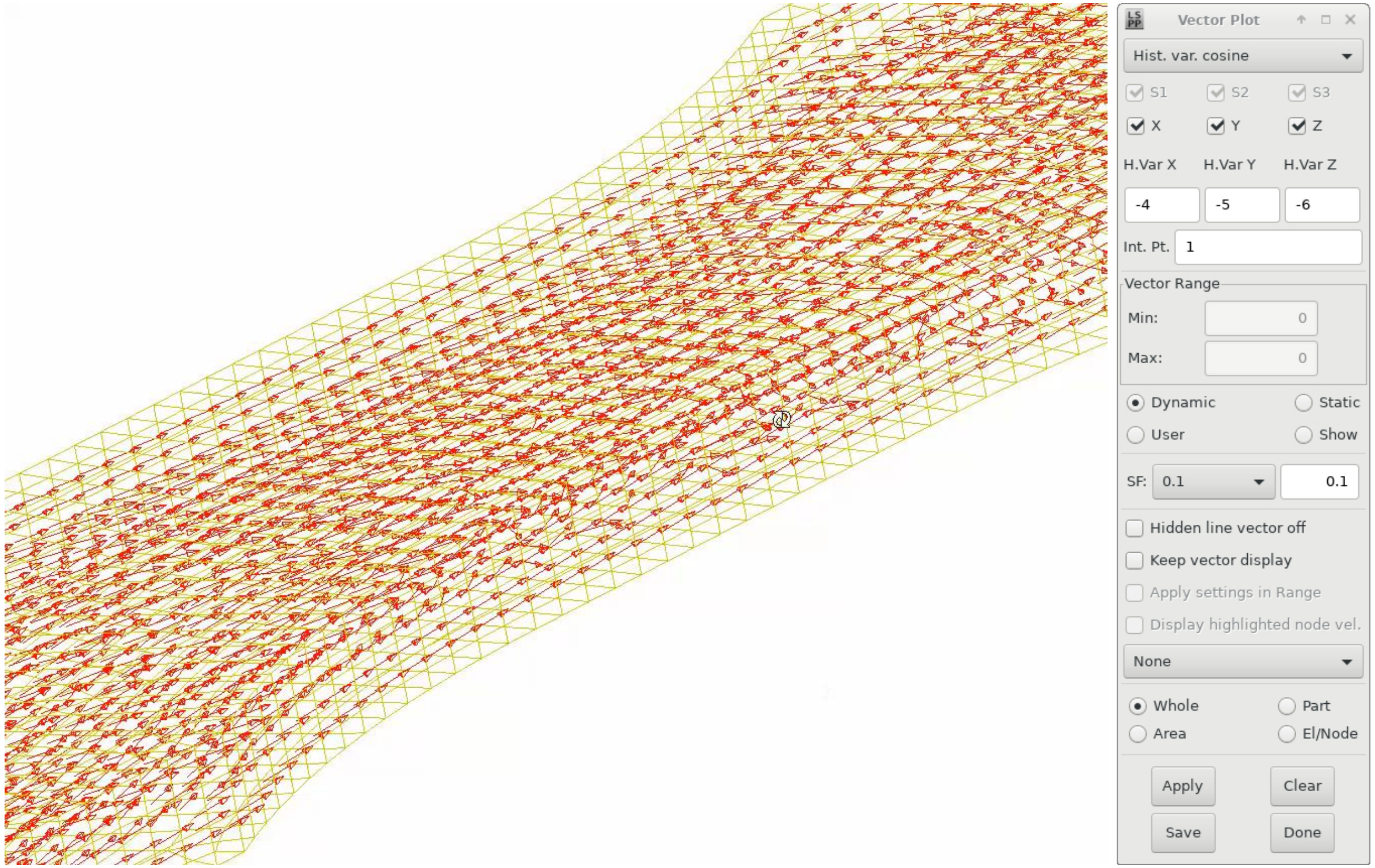
- …
- IHIS=3

- HomogenizationMethod=method
- ClosureApproximation=method
- E11F="Fiber Young's modulus in main direction"
- E22F="Fiber Young's modulus in thickness direction"
- RHOF="Fiber density"
- PRBAF="Fiber in-plane Poisson's ratio"
- PRCBF="Fiber out-of-plane Poisson's ratio"
- G12F="Fiber shear modulus"
- EM="Matrix Young's modulus"
- RHOM="Matrix density"
- PRM="Matrix Poisson's ratio"
- AspectRatio="Fiber aspect ratio (length/thickness)"
- FiberVolumeFraction="Fiber volume fraction in percent"
- InclusionShape="Shape of the inclusions."
  - Spheroidal
  - Spherical
  - Needle
  - Disc

The q_{ij} terms are the first and third rows of a rotation matrix for the rotation from a co-rotational element's system and the *a*-*b*-*c* material directions. The c_{ij} terms are the upper triangular terms of the symmetric stiffness matrix, c_{11}, c_{12}, c_{13}, c_{14}, c_{15}, c_{16}, c_{22}, c_{23}, c_{24}, c_{25}, c_{26}, c_{33}, c_{34}, c_{35}, c_{36}, c_{44}, c_{45}, c_{46}, c_{55}, c_{56}, and c_{66}.

Visualizing fiber directions in LS-PrePost

1. Run an analysis (a single time step is enough).
2. Open the d3plot and navigate through "Post" to the "Vector-Plot“ functionality.
3. Select "Hist. Var. cosine" - and insert -4 for H.Var X, -5 for H.Var Y and -6 for H.Var Z, that's where the first vector of the principal axis of the material coordinate system is stored in the d3plot. For shells, insert -1 for H.Var X, -2 for H.Var Y.

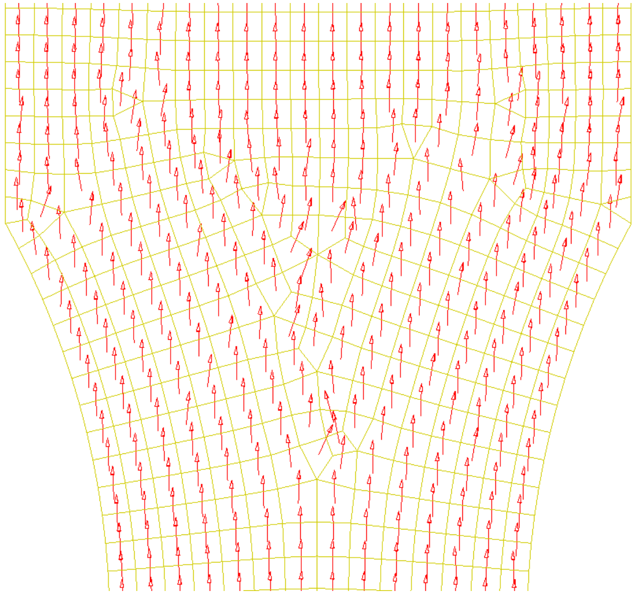


Invariant node numbering

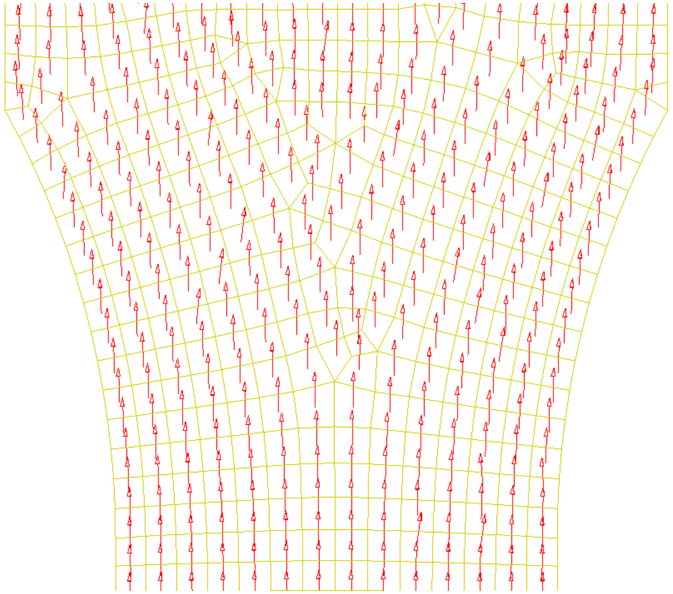
INN flag on *CONTROL_ACCURACY

- Calculation of local element coordinate system is calculated differently depending on the value of the INN flag on *CONTROL_ACCURACY.
- Example, Envyo is set to INN=1

INN=4



INN=1



- Envyo currently supports all positive inputs of INN.

Mapping to *MAT_215

MAT_215 = MAT_4A_MICROMEC

```
*MAT_ANISOTROPIC_ELASTIC_PLASTIC
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$#      MID     MMOPT      BUPD                                FAILM     FAILF    NUMINT
          1
$#     AOPT      MACF        XP        YP        ZP        A1        A2        A3

$#       V1        V2        V3        D1        D2        D3      BETA

$#      FVF                  FL        FD                 A11       A22
    13.3916                 20.        1.
$#      ROF        EL        ET       GLT      PRTL      PRTT
    2.54E-9    72000.    72000.    29500.      0.22      0.22
$#       XT                                                      SLIMXT    NCYRED

$#      ROM         E        PR
     0.9E-9     1430.       0.4
$#    SIGYT     ETANT                                EPS0         C

$#    LCIDT                                          LCDI       UPF
     123123
*INITIAL_STRESS_SOLID
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$# EID/SID      NINT     NHISV     LARGE    IVEFLG    IALEGP    NTHINT    NTHHSV
          1         1        16         1
$#           SIGXX               SIGYY               SIGZZ               SIGXY               SIGYZ

$#           SIGZX                 EPS               HISV1               HISV2               HISV3

$#           HISV4               HISV5               HISV6               HISV7               HISV8

$#           HISV9              HISV10              HISV11              HISV12              HISV13
               a11                 a22              q1/q11              q2/q12               -/q13
$#          HISV14              HISV15              HISV16              HISV17              HISV18
             -/q31               -/q32               -/q33
```

Green text = input if element type is shell

Input to Envyo:

- …
- TargetMaterialModel=215

*MAT_215 history variables

Extravar.	DESCRIPTION
1	effs - equivalent plastic strain rate of matrix
2	eta - triaxiality of matrix … $\eta = -\frac{p}{q}$
3	xi - lode parameter of matrix … $\xi = -\frac{27\bullet J_3}{2\bullet q}$
4	dM - Damage initiation d of matrix (Ductile Criteria)
5	DM - Damage evolution D of matrix
6	RFF - Fiber reserve factor
7	DF- Fiber damage variable
8	Currently unused

Extravar.	DESCRIPTION
9	A11 - fiber orientation first principal value
10	A22 - fiber orientation second principal value
11	q1/q11
12	q2/q12
13	-/q13
14	-/q31
15	-/q32
16	-/q33
17	FVF- Fiber-Volume-Fraction
18	FL- Fiber length

Material directions given on this form can only be visualized in LS-PrePost after an initialization in LS-DYNA.

Mapping to *MAT_303

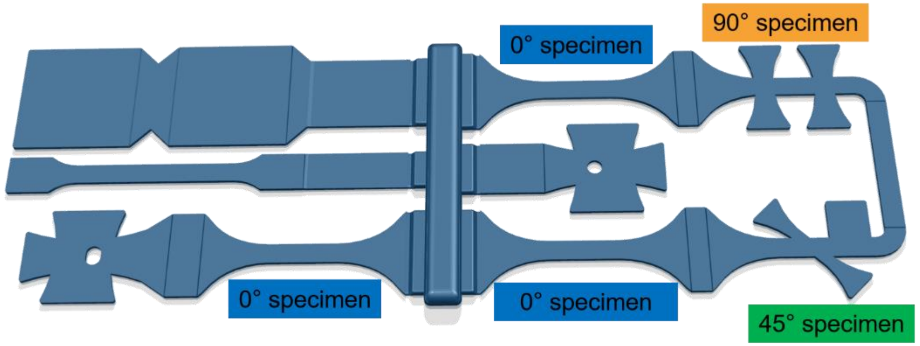
MAT_303 = MAT_DMN_COMPOSITE_FRC

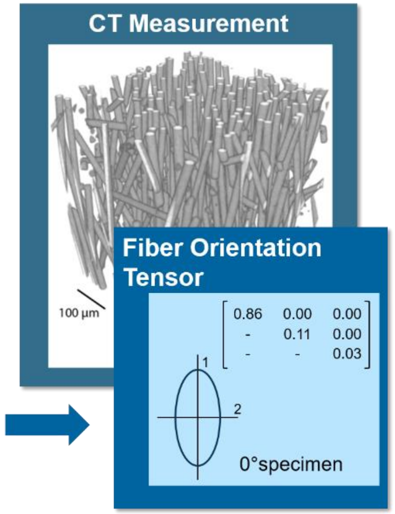
```
*MAT_DMN_COMPOSITE_FRC
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$#     MID
         1
$#     FVF        RO        RF        RM        FL        FD
   13.3916              2.54E-9    0.9E-9       20.        1.
$#     F_E      F_PR       ISO
     72000      0.22         0
$#     M_E      M_PR      M_SY      M_H1      M_H2      M_H3       ITC
     1430.       0.4                                                  0
$#   LCIDT     LCIDC
    123123
*INITIAL_STRESS_SOLID
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$# EID/SID      NINT     NHISV     LARGE    IVEFLG    IALEGP    NTHINT    NTHHSV
         1         1         6         1
$#        SIGXX           SIGYY           SIGZZ           SIGXY           SIGYZ

$#        SIGZX             EPS           HISV1           HISV2           HISV3
                                            Axx             Ayy             Axy
$#        HISV4           HISV5           HISV6           HISV7           HISV8
            Ayz             Axz             fvf
```

- Additional input lines may be given:
  - ISO: Flag for anisotropy of the fiber phase:
    - EQ.0: Isotropic fiber material property
    - EQ.1: Transversely isotropic fiber material property
  - ITC: Option for the elastoplastic material law for the matrix phase.
    - EQ.0: No tension-compression asymmetry in material properties
    - EQ.1: Use tension-compression asymmetric material properties

Material testing and calibration

- By Borealis Polyolefine GmbH, Austria.
- “The Borealis GF-tool”
  - Specimens with high fiber alignment in 0, 45 and 90° angle relative loading direction.
- CT scanning to determine detailed orientation distribution.
- GD301FE was characterized.

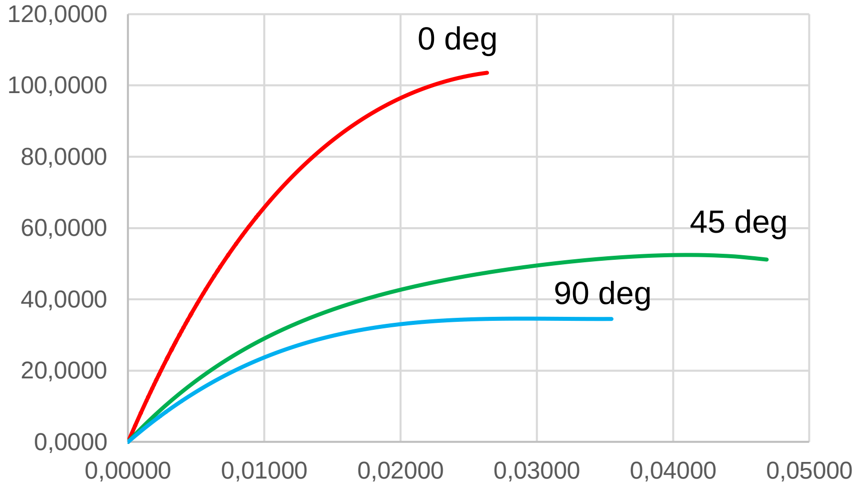




Calibrations of material models

Test data GD301FE

- Quasistatic response:



- CT scans of tensile tests report an average orientation degree used in the calibrations:
  - 0 deg: a11=0.86 a22=0.105
  - 45 deg: a11=0.822 a22=0.148
  - 90 deg: a11=0.778 a22=0.201
- Test data for higher strain rates data is also available, but we have not used it in this presentation.

Calibration of *MAT_215

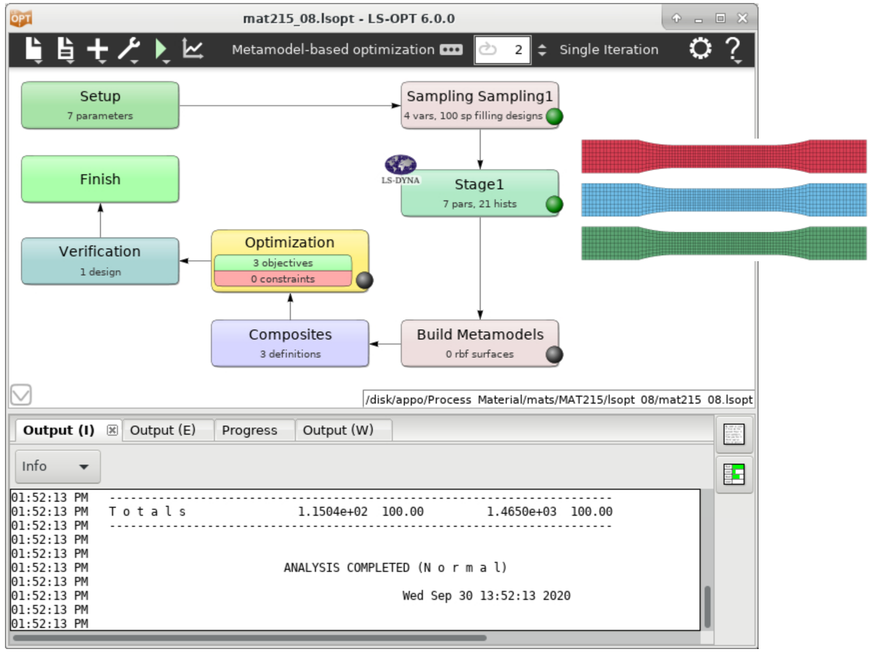
Setup

- Input fiber properties.
- Parameterize the model to optimize the matrix properties. Only the hardening curve was optimized.

```
*MAT_4A_MICROMEC_TITLE
GD301FE 0 deg
$#     mid     mmopt      bupd    unused    unused     failm     failf    numint
         1       1.0      0.01                           0.0         0       1.0
$#    aopt      macf        xp        yp        zp        a1        a2        a3
       2.0         1       0.0       0.0       0.0       1.0       0.0       0.0
$#      v1        v2        v3        d1        d2        d3      beta
       0.0       0.0       0.0       0.0       0.0       0.0       0.0
$#     fvf    unused        fl        fd    unused       a11       a22
      -0.3                32.0       1.0                0.86     0.105
$#     rof        el        et       glt      prtl      prtt
2.54000E-9   72000.0   72000.0   29500.0      0.22      0.22
$#      xt    unused    unused    unused    unused    unused    slimxt    ncyred
       0.0                                                         0.0      10.0
$#     rom         e        pr
9.0000E-10&em              0.4
$#   sigyt     etant    unused    unused      eps0         c
&sigym    &etanm                               0.0       0.0
$#   lcidt    unused    unused    unused      lcdi       upf
    123123                                       0       0.0
```

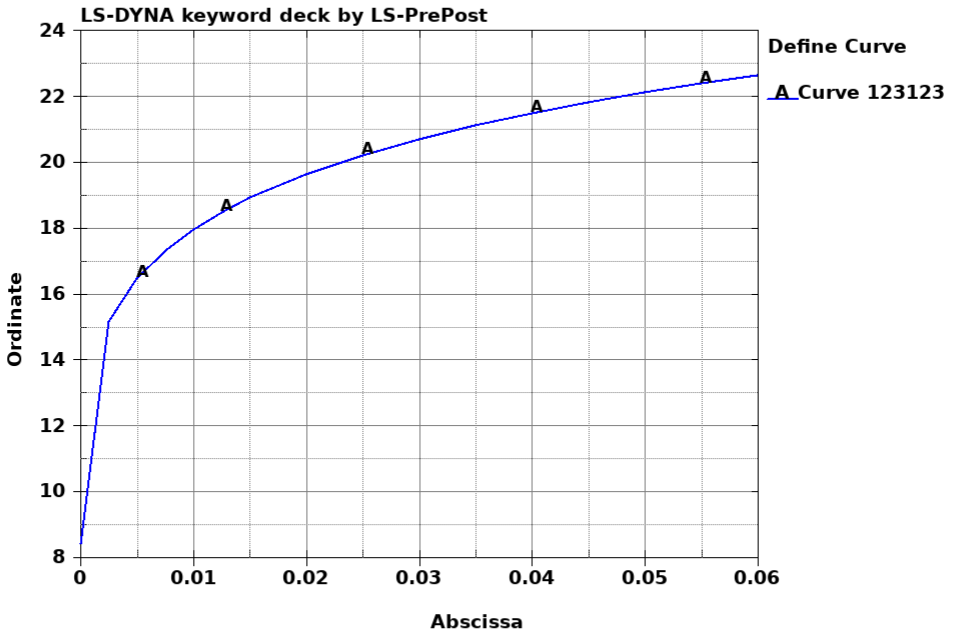
$$\sigma = A - Be^{-C\varepsilon_p^H}$$

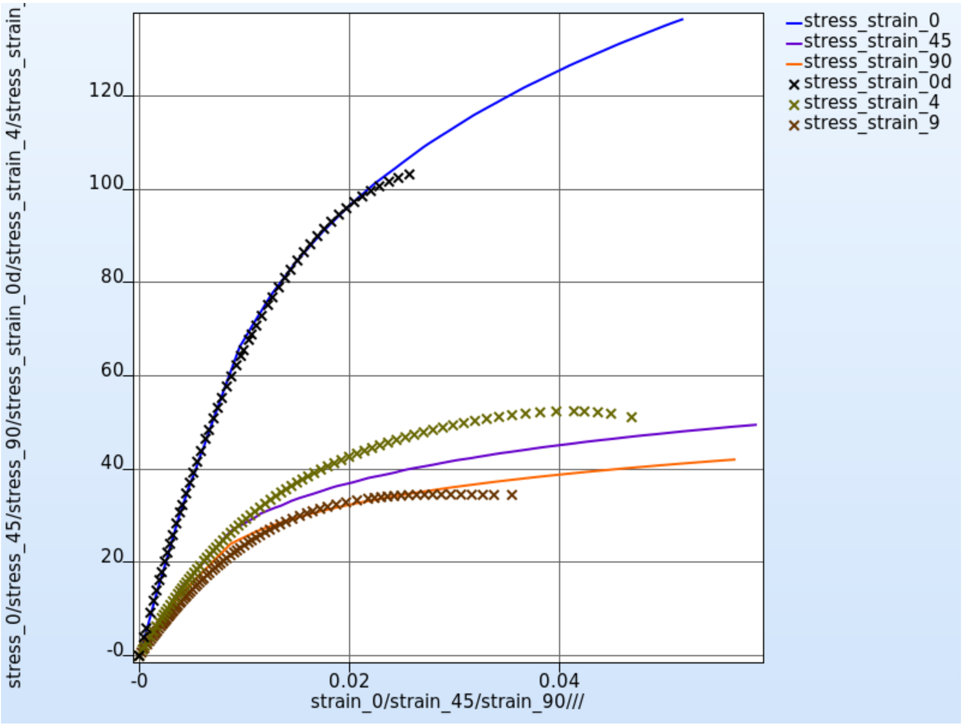
- Simulate the three tensile specimens (with shells) and optimize using curve matching composites in LS-OPT.



Calibration of *MAT_215

Results

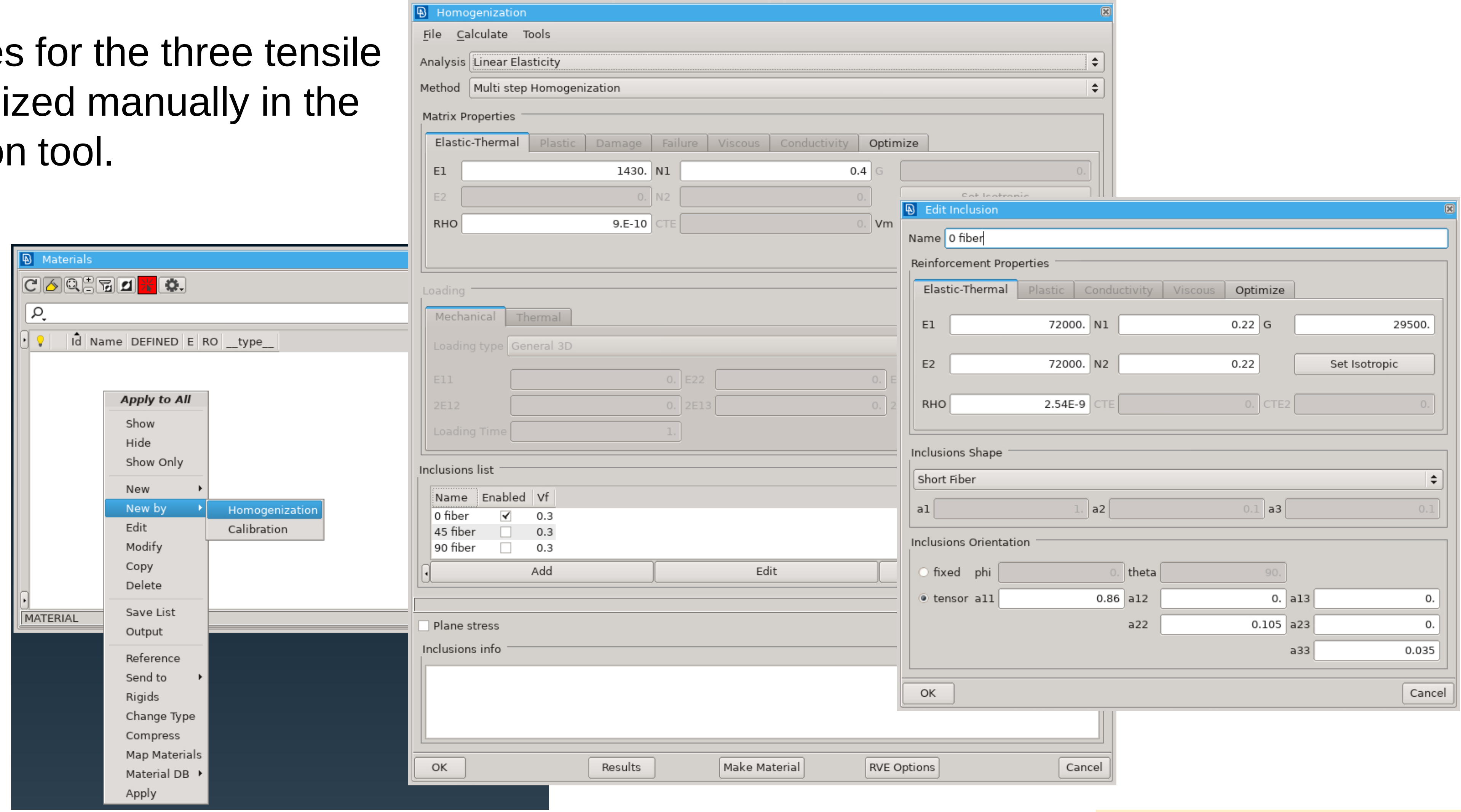




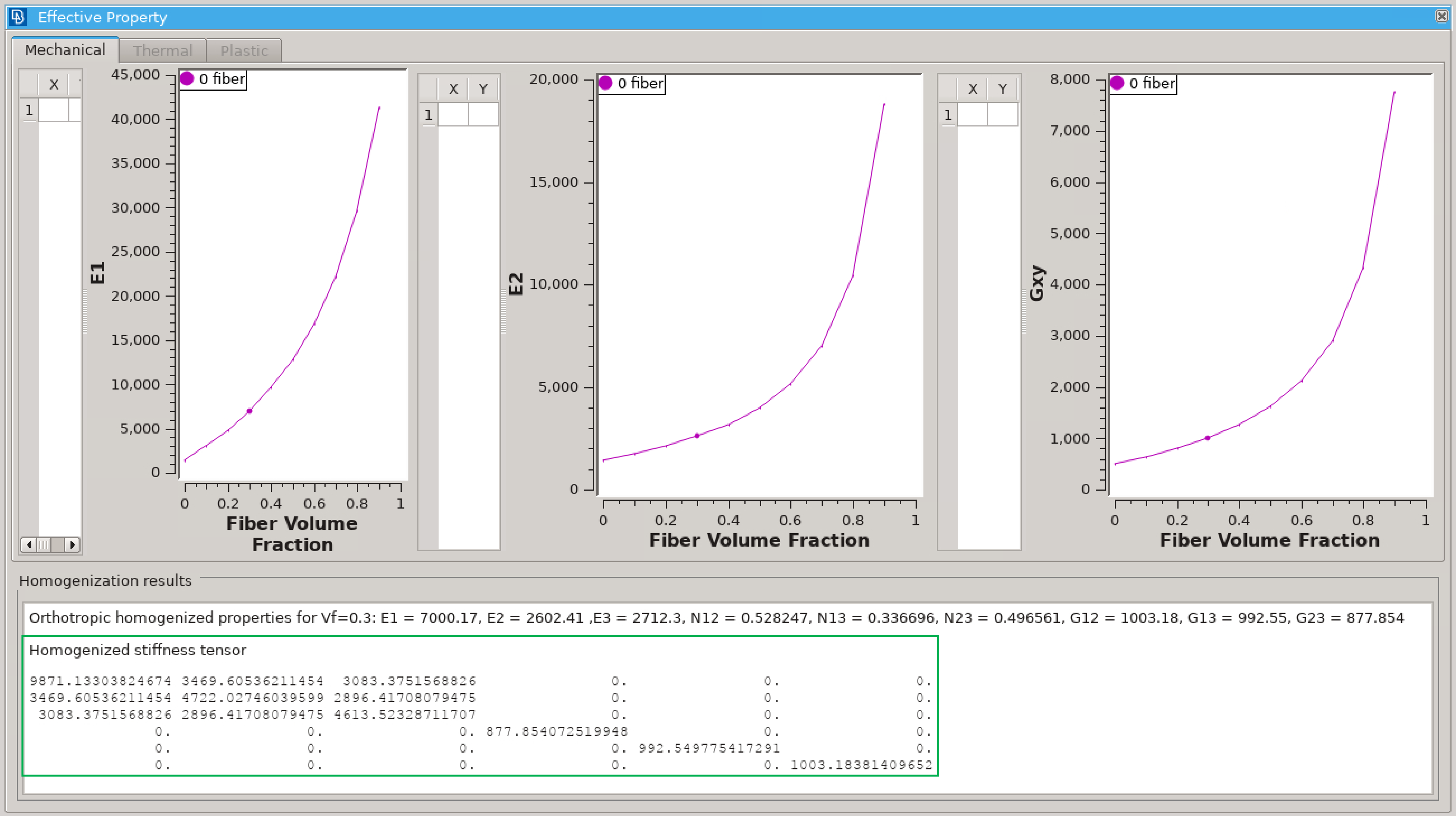
- Possible reasons for deviation:
  - Constant fiber orientation through tensile specimen assumed.
  - The assumed equation for the hardening is insufficient.
  - Limitations of shell description.

Calibration of *MAT_157

- The elastic properties for the three tensile tests were homogenized manually in the Ansa homogenization tool.



Calibration of *MAT_157



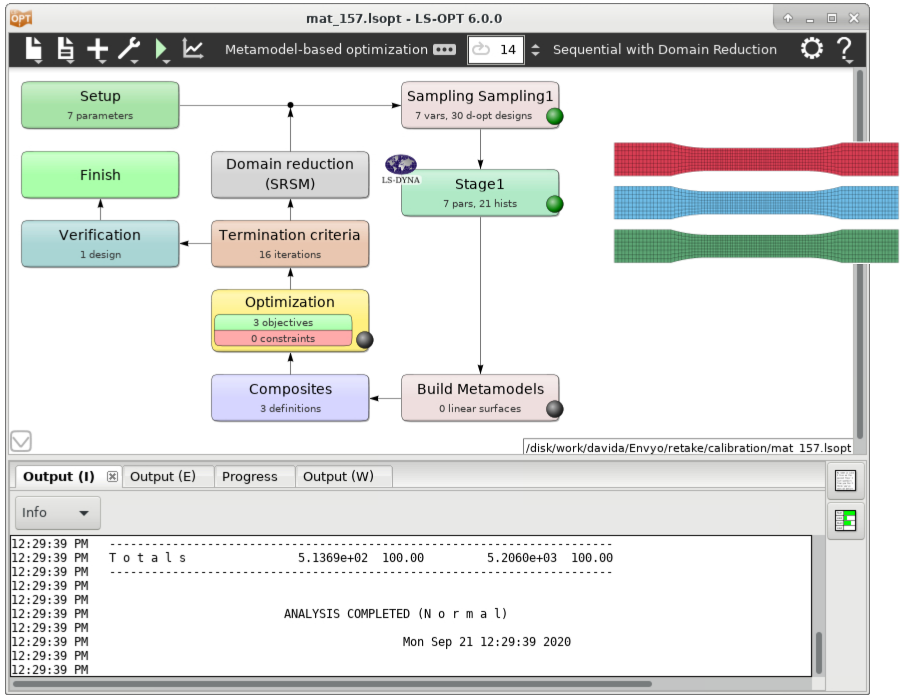
Calibration of *MAT_157

Setup

- Homogenize the elastic and mass properties of the matrix and fibers to get a composite stiffness matrix and density.
- Parameterize the model to optimize the hardening and the R-values.

```
*MAT_ANISOTROPIC_ELASTIC_PLASTIC_TITLE
GD301FE 0 deg
$#     mid        ro      sigy      lcss       qr1       cr1       qr2       cr2
         1 1.120E-09      20.0    123123
$#     c11       c12       c13       c14       c15       c16       c22       c23
9871.133043469.605363083.37516        0.        0.    0.4722.027462896.41708
$#     c24       c25       c26       c33       c34       c35       c36       c44
        0.        0.    0.4613.52329        0.        0.    0.877.854073
$#     c45       c46       c55       c56       c66   r00||F    r45||G    r90||H
        0.    0.992.549775       0.1003.18381&R0        &R45      &R90
$#  s11||L    s22||M    s33||N       s12      aopt        vp                macf
                                                 2
$#      xp        yp        zp        a1        a2        a3
                                       1.
$#      v1        v2        v3        d1        d2        d3      beta      ihis
                                                                              0
```

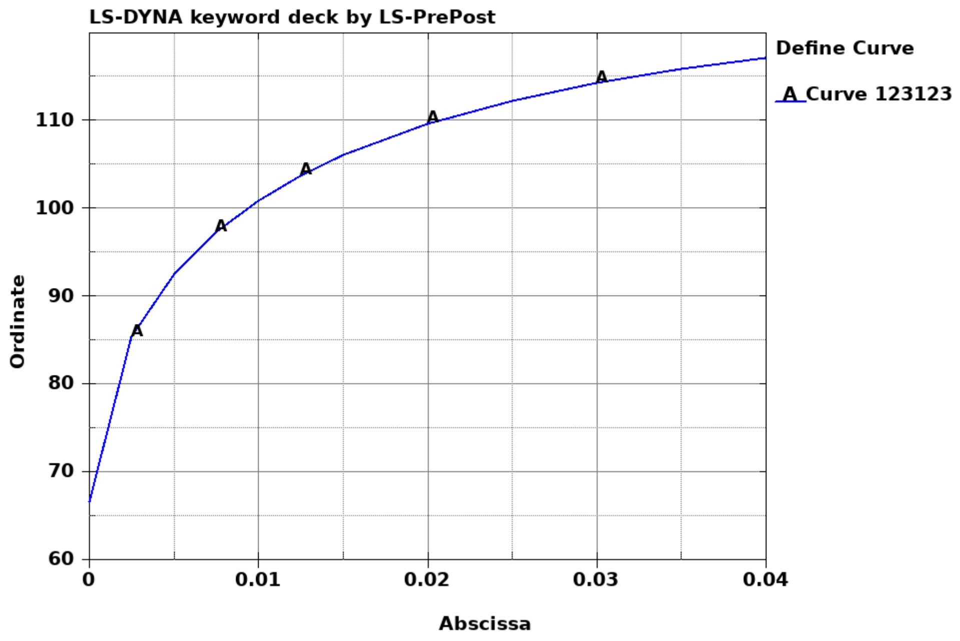
$$\sigma = A - Be^{-C\varepsilon_p^H}$$

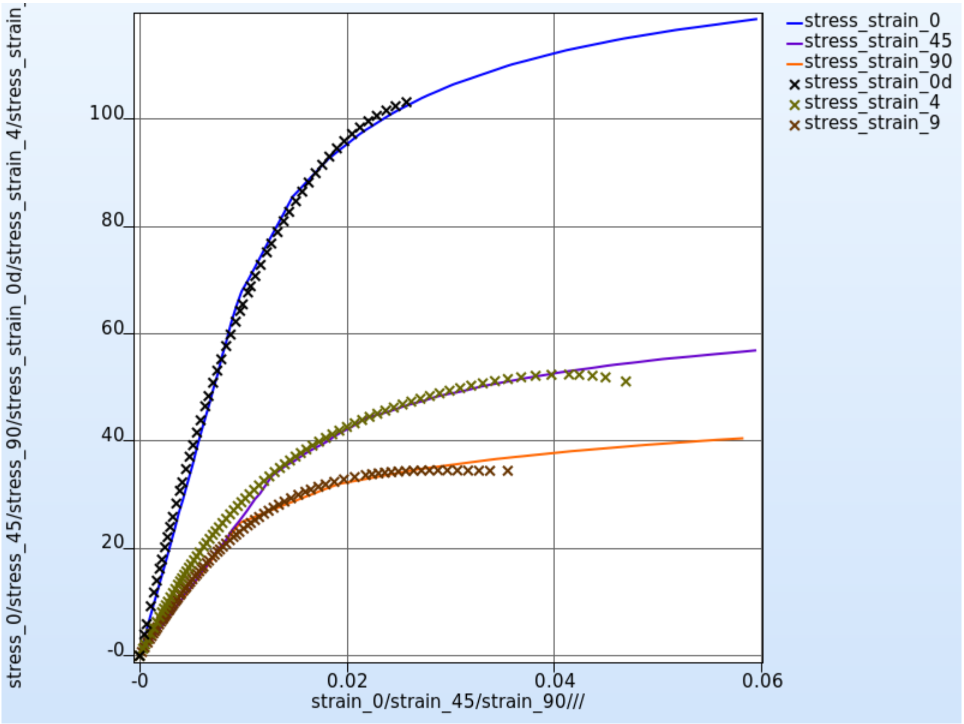


- Simulate the three tensile specimens (with shells) and optimize using curve matching composites in LS-OPT.

Calibration of *MAT_157

Results



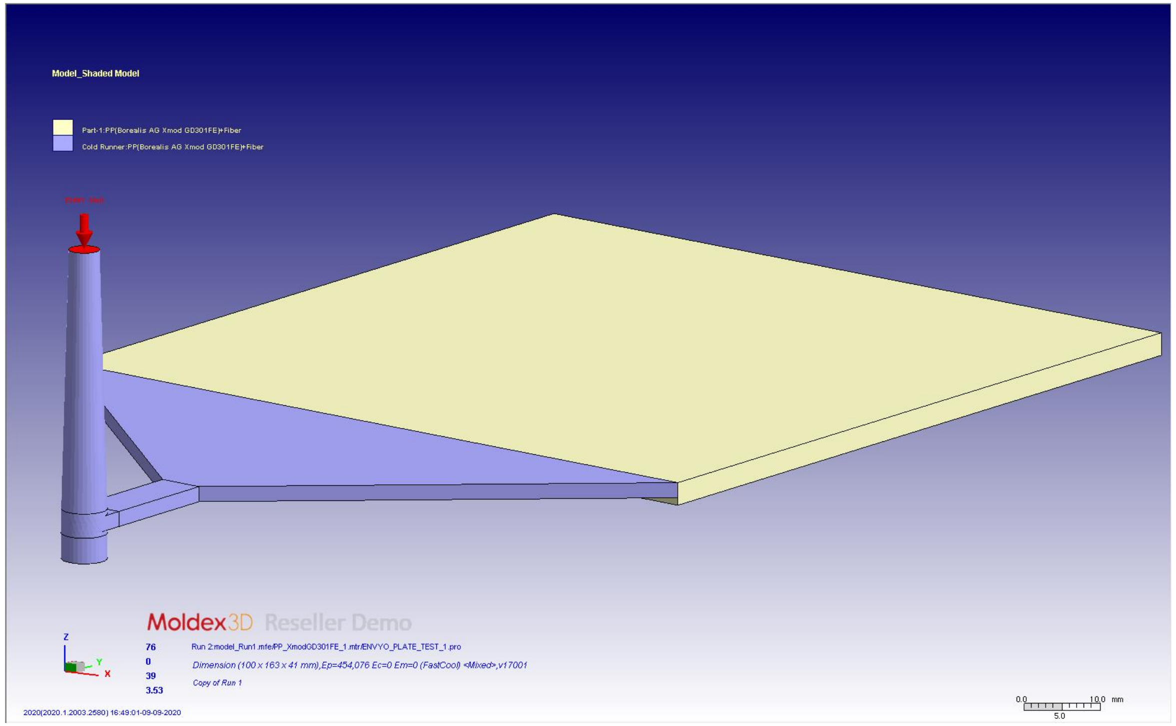


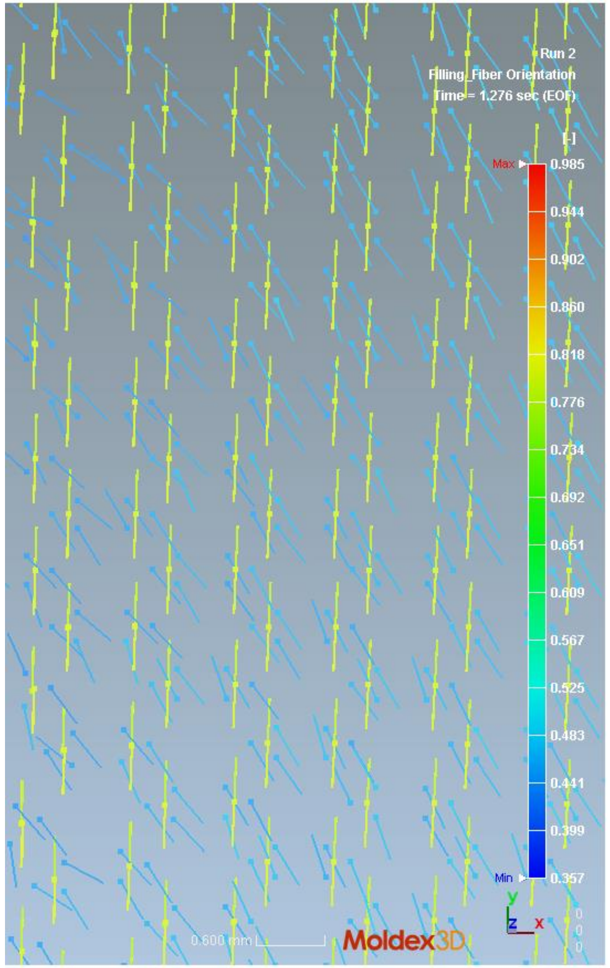
- Possible reasons for deviation:
  - Constant fiber orientation through tensile specimen assumed.
  - The assumed equation for the hardening is insufficient.
  - Limitations of shell description.

Example 1

Tensile tests from injection molded plate

- A plate is injected with material from which tensile specimen are cut out in different directions.



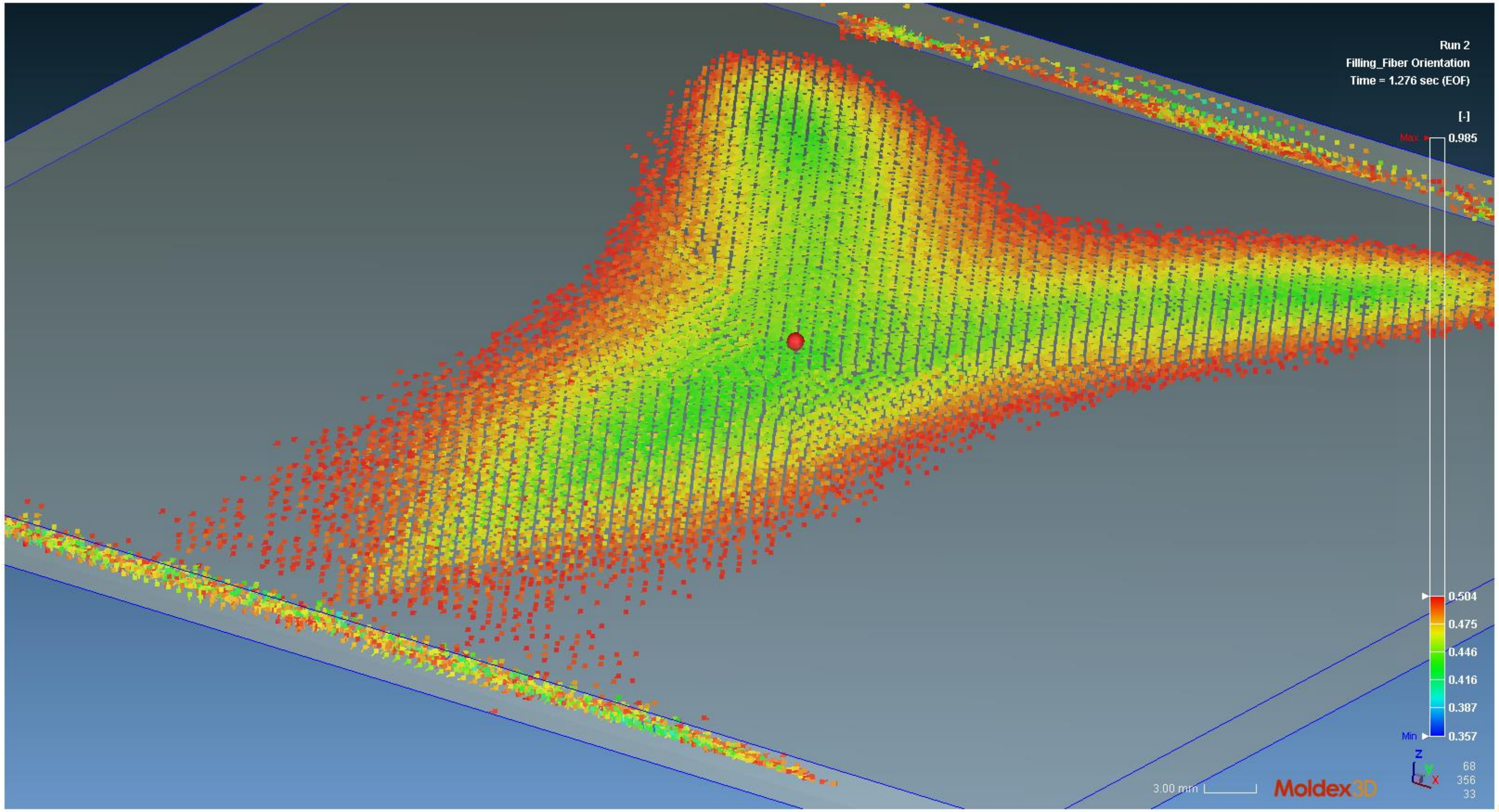


- The fibers are mostly oriented in the y direction…

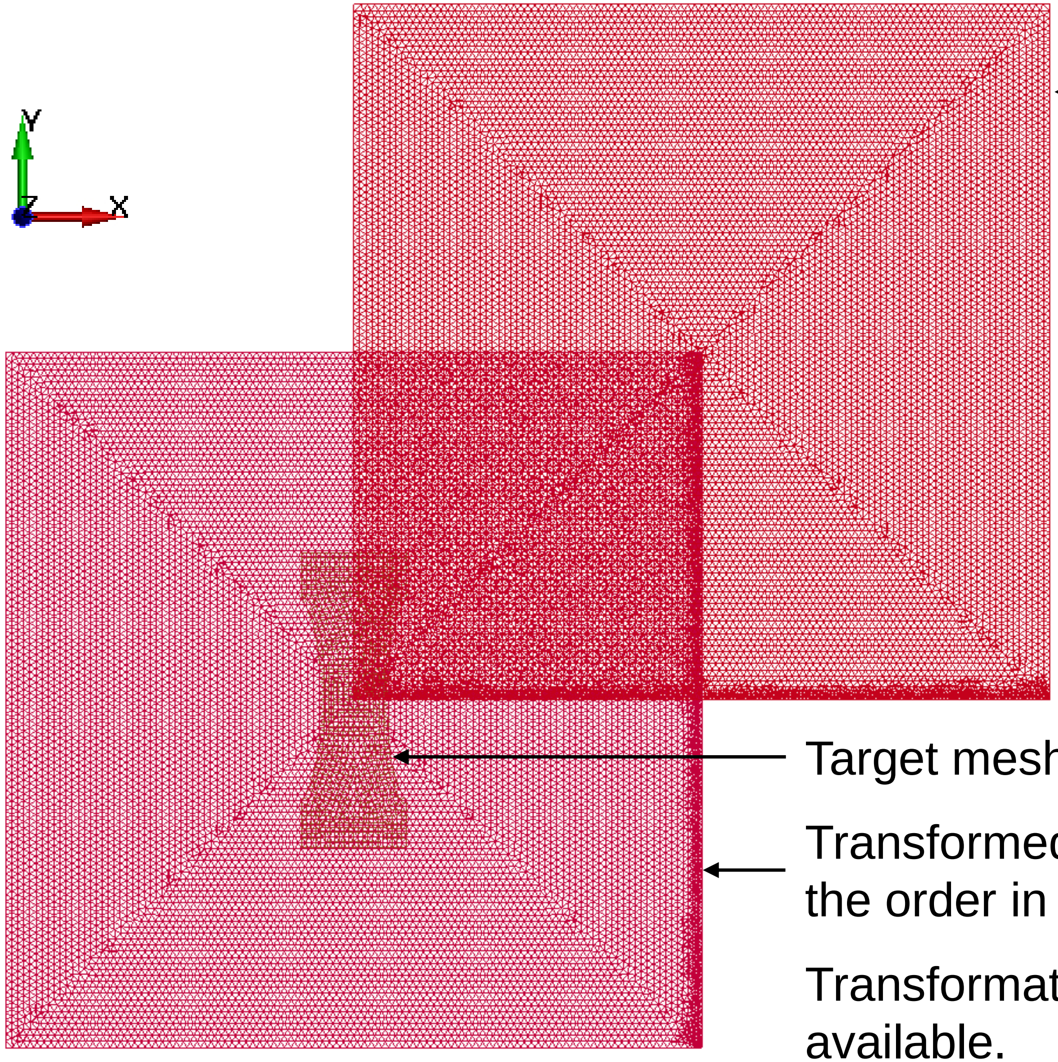
Example 1

Tensile tests from injection molded plate

… except for the mid layer which is not as oriented.



Transformations in Envyo, e.g. 90º rotation



Original mesh of plate

```
TRANSFORMATION=YES
RotateSRC=90.0;Z
MoveSRC=50.0 -50.0 0.0
Transformback=NO
WriteTransformedMesh=YES
ChangeUnitSystem=NO
```

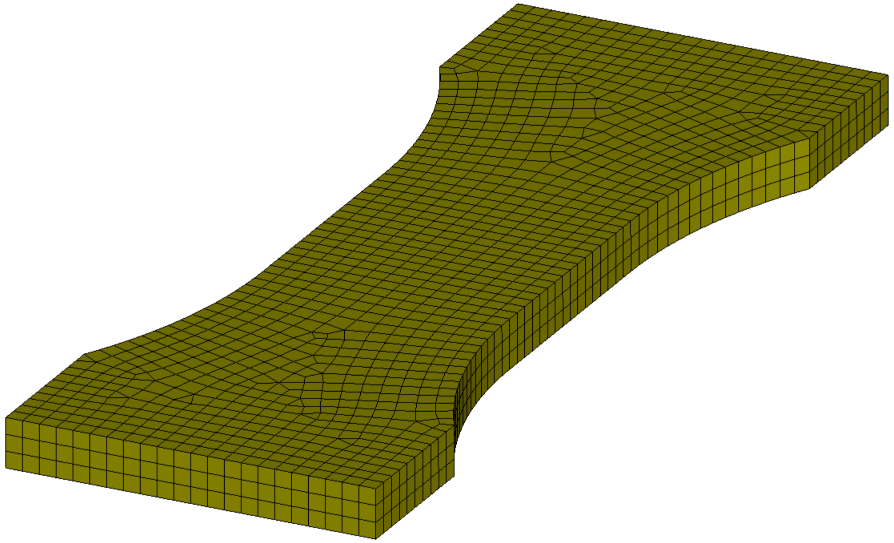
Target mesh tensile specimen

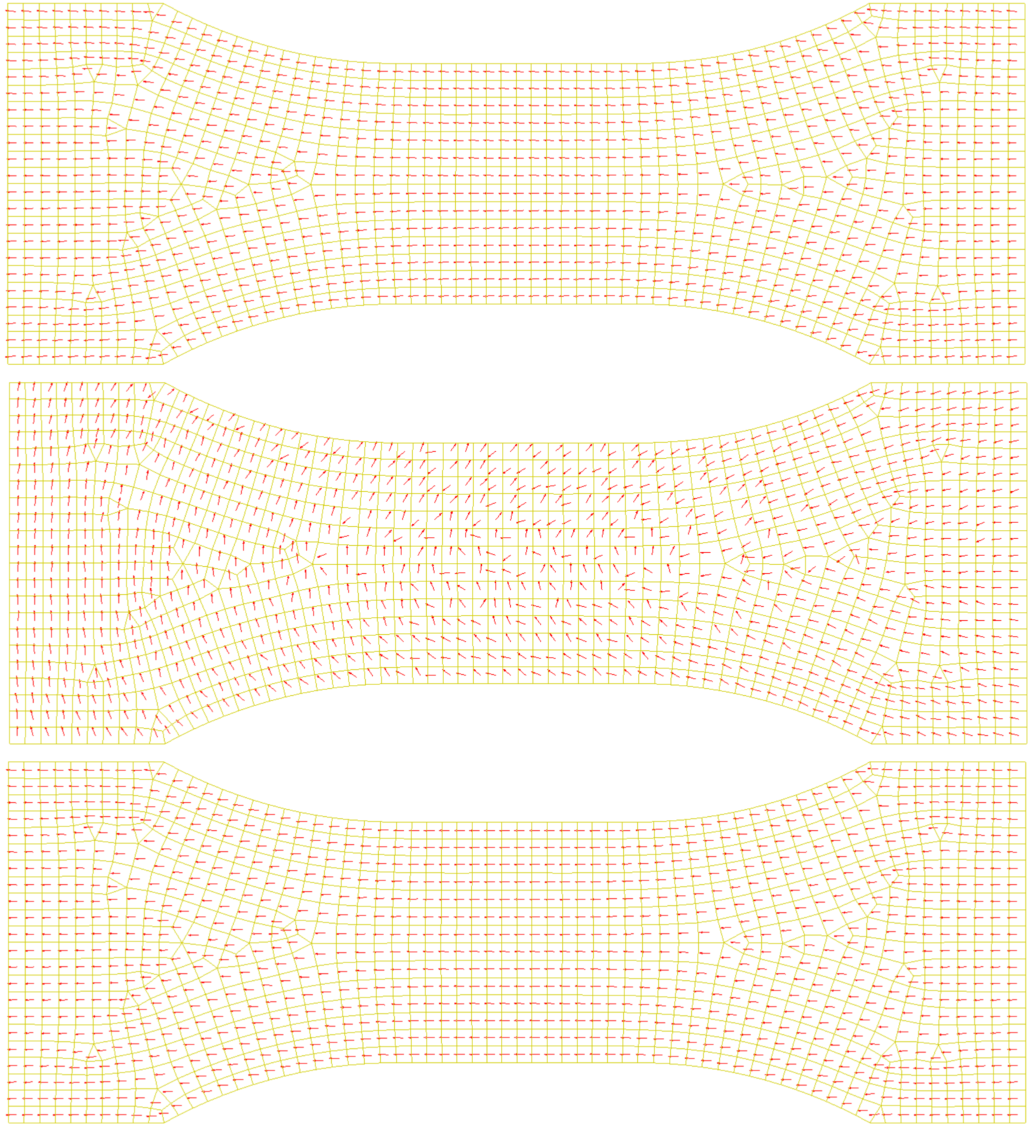
Transformed plate, transformations applied in the order in which they are defined.

Transformation using nodal pairs is also available.

Fiber orientation after mapping

Illustration of 0° sample





Bottom layer

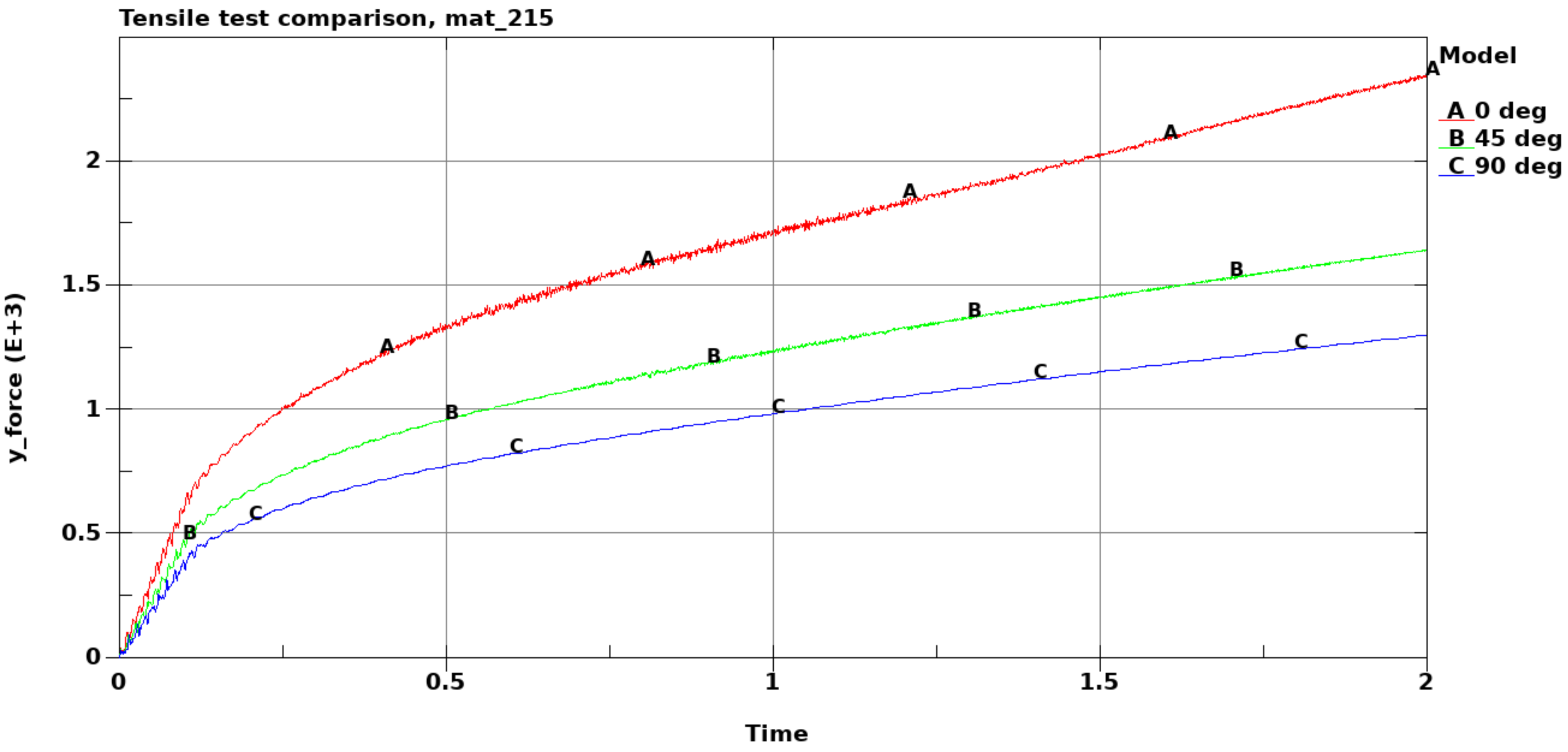
Middle layer

Top layer

Tensile simulation results

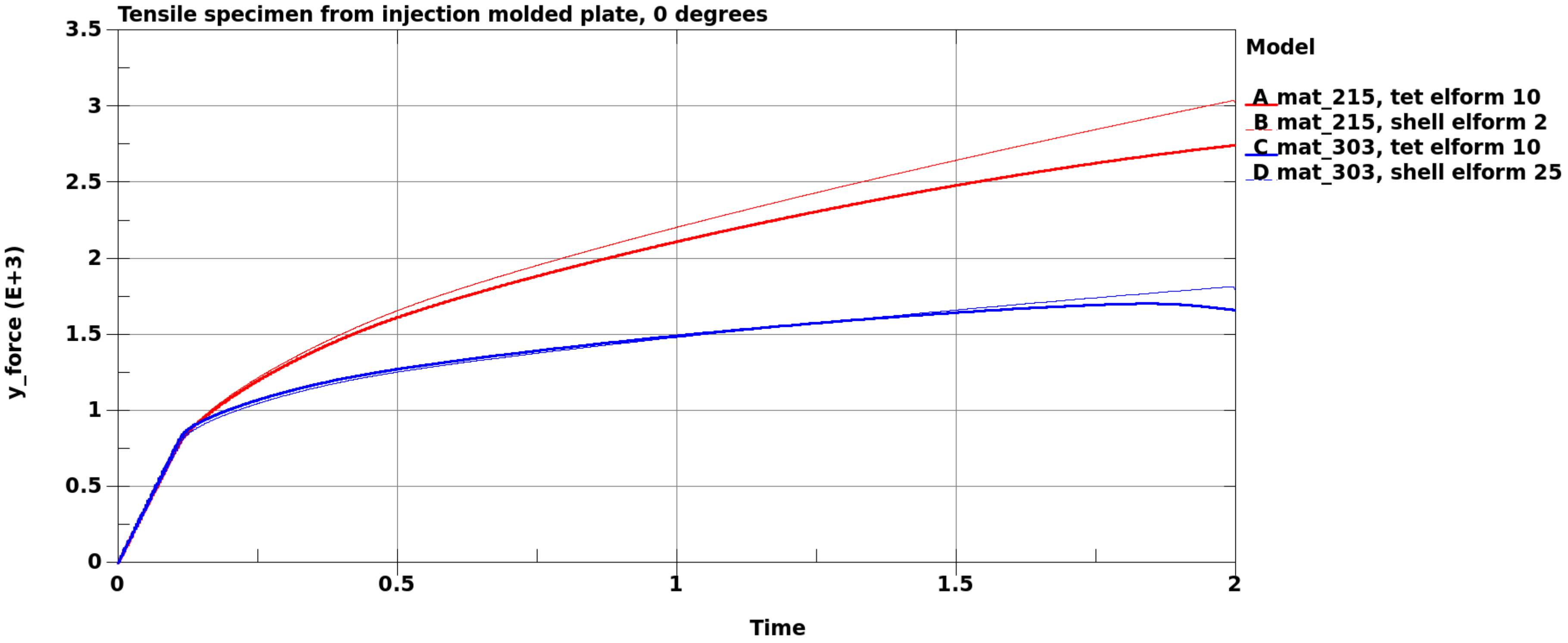
Example using the calibrated *MAT_215

- Simulations of cut out tensile specimens from the plate.



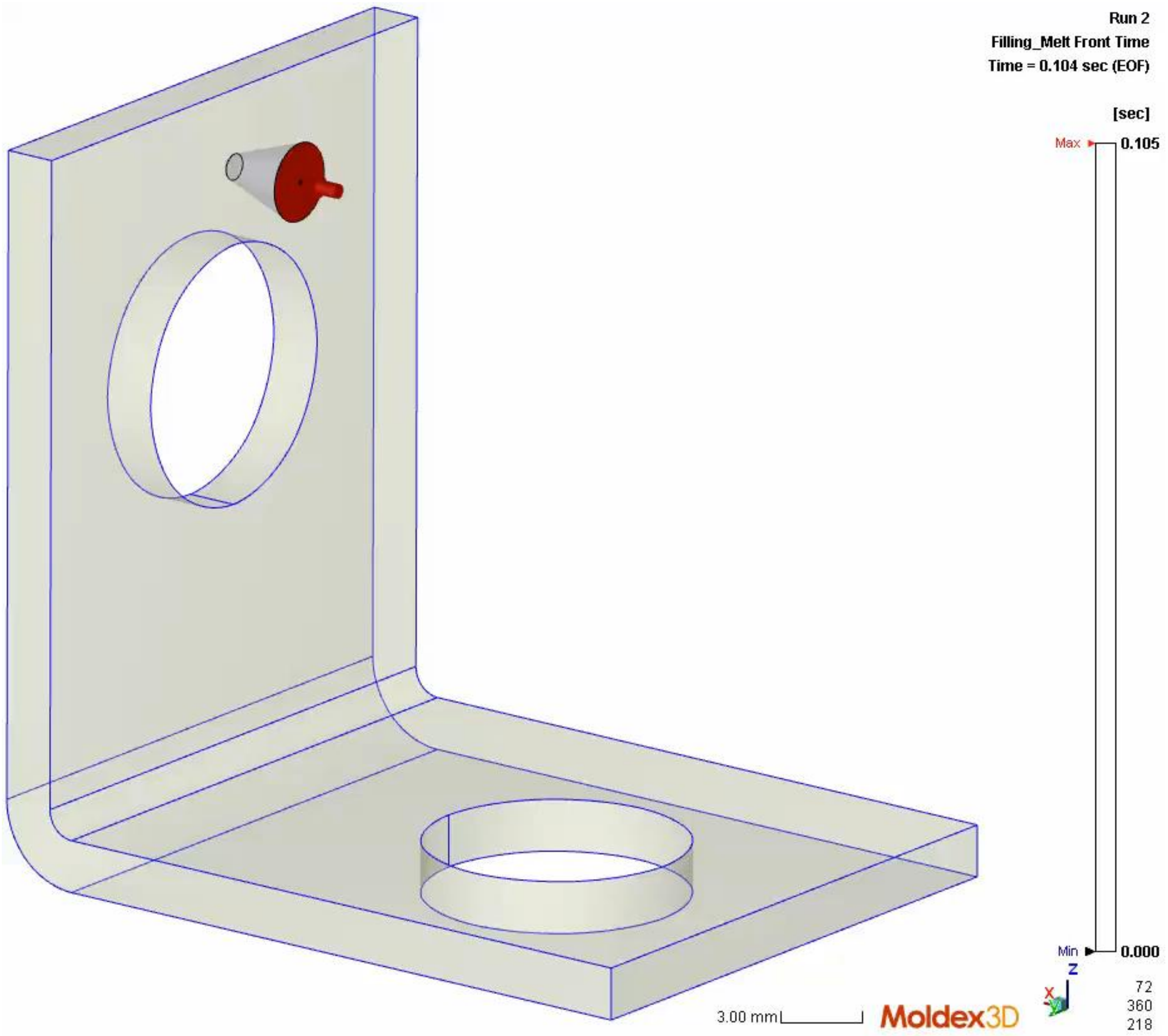
Test of *MAT_303

- The same input for mat_215 and mat_303 give different results. Calibrations of base material properties might be necessary.



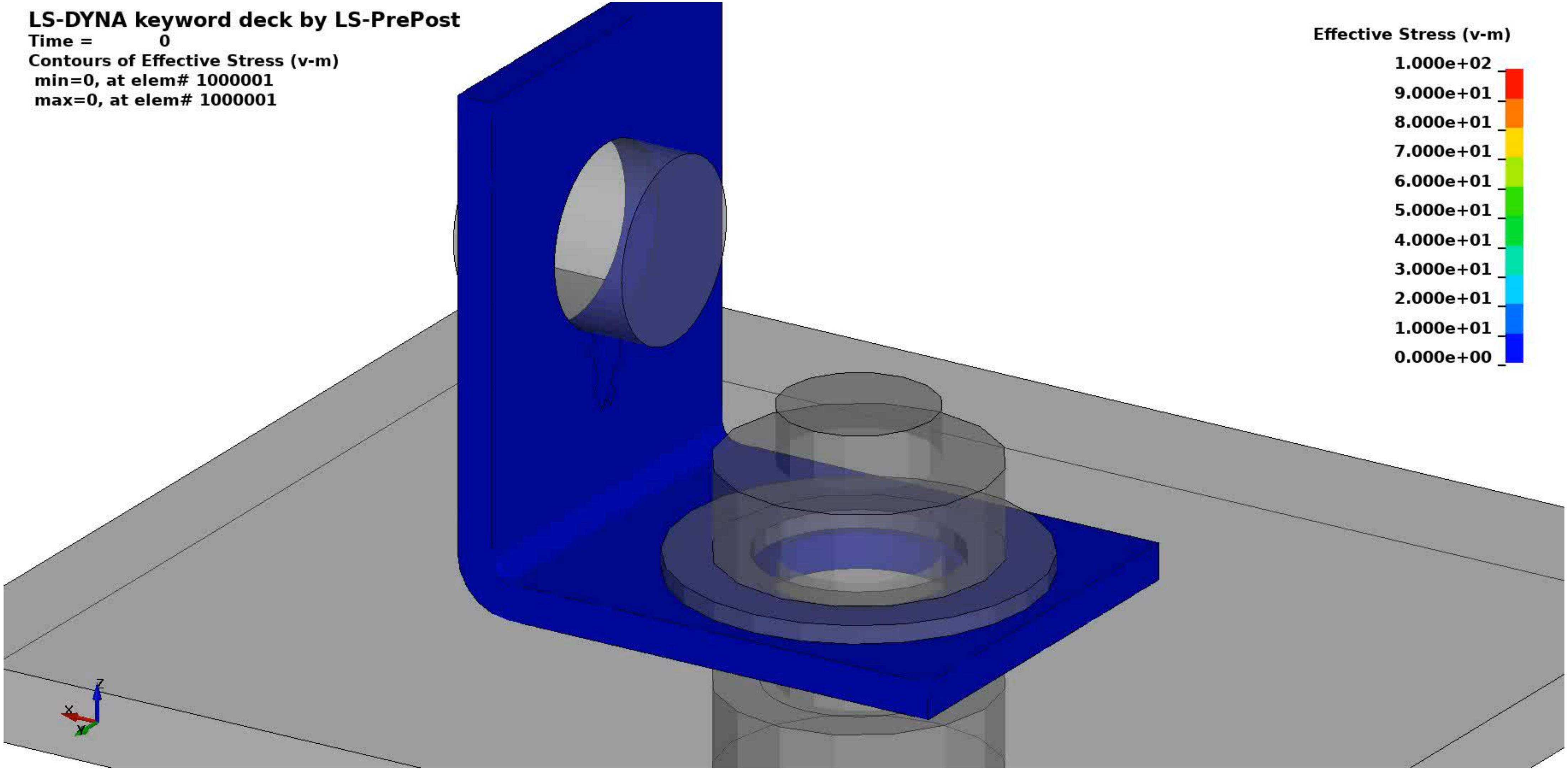
Example 2

Bracket



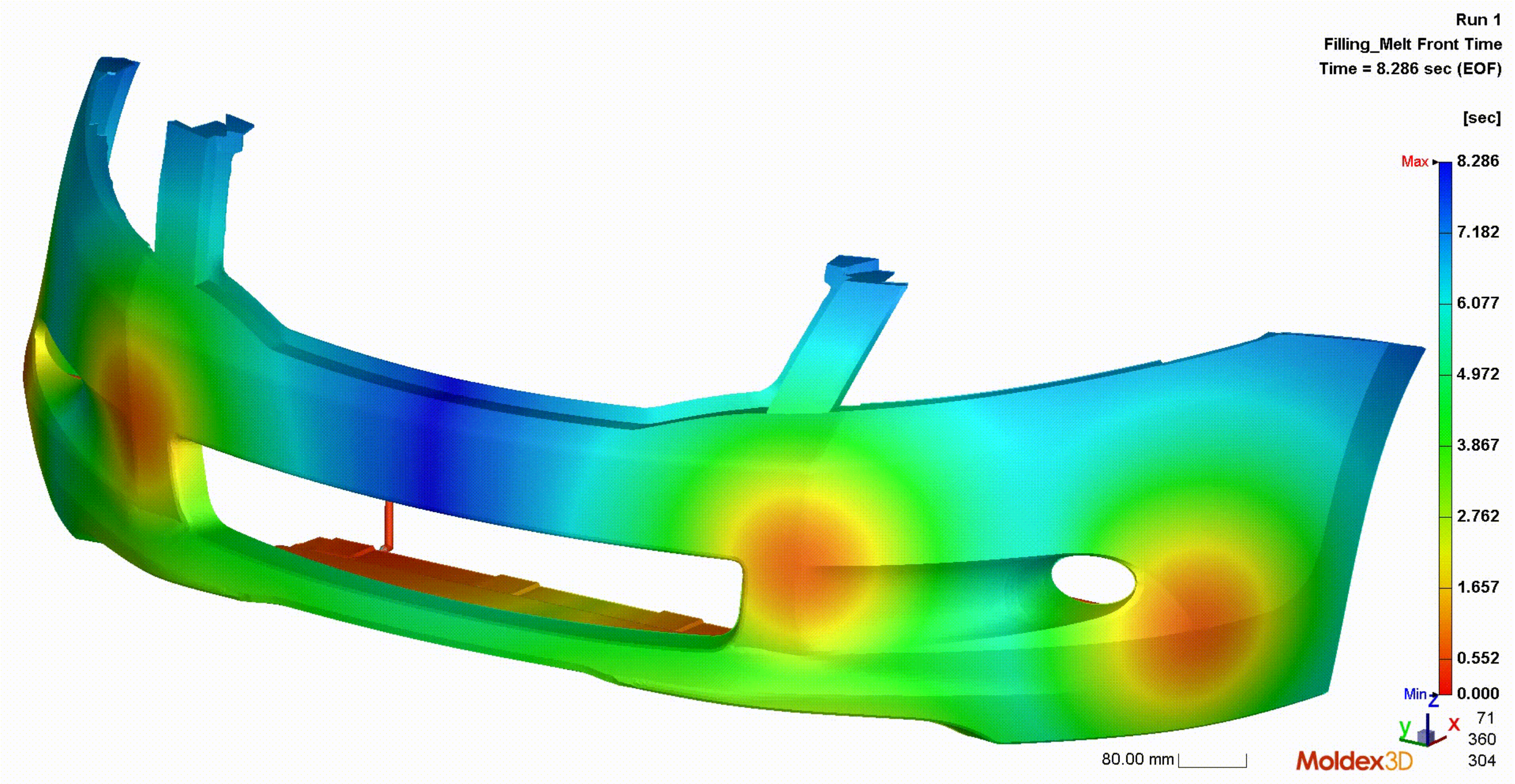
Example 2

Bracket



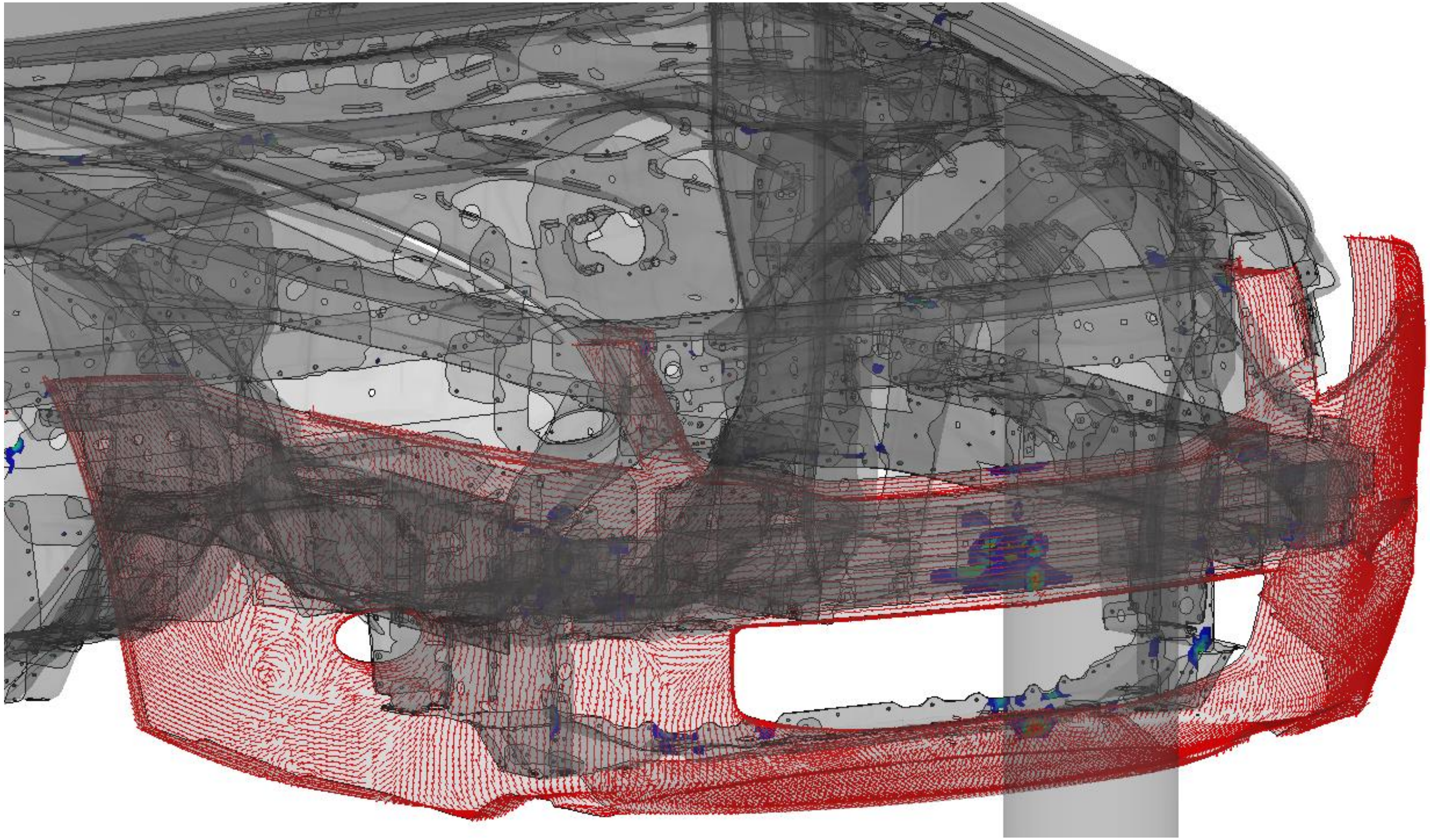
Example 3

Bumper



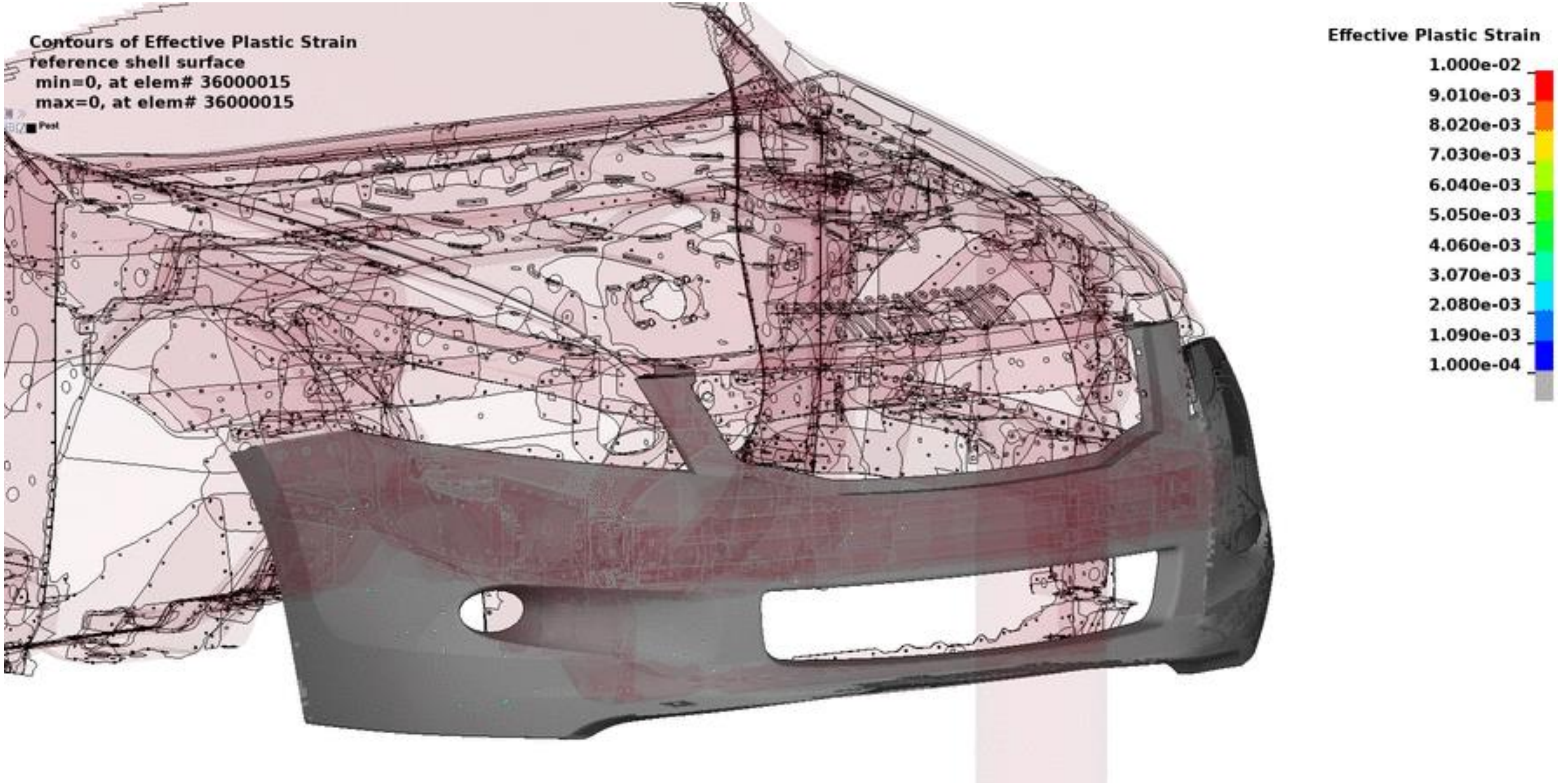
Example 3

Bumper



Example 3

Bumper



The car used in this demonstration is a modified version of the publicly available Honda Accord model, provided by NHTSA, https://www.nhtsa.gov/crash-simulation-vehicle-models.

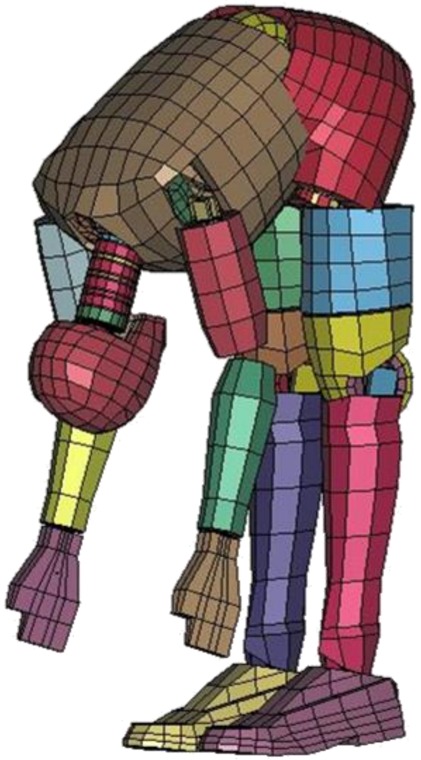
Final remarks

- Additional experimental results are needed for calibration of
  - Strain rate dependencies
  - *MAT_157 for solid elements
  - Failure, e.g. triaxiality dependent (*MAT_ADD_DAMAGE_DIEM/GISSMO) or even anisotropic damage (*MAT_ADD_GENERALIZED_DAMAGE)
- Some suggestions for additional experiments
  - Bending tests (load concentrated on top and bottom of specimen where fibers are more oriented)
  - Puncture test (biaxial stress state for calibration of triaxiality dependent failure)
  - Samples created with intentional weld lines (calibration of reduced strength in weld lines)
- A component validation of the calibrated material is recommended
  - How much resolution is required through the thickness to incorporate effects from fiber tensor variations?

Further information

- Course in “Simulation of short fiber reinforced composites”, DYNAmore GmbH.
- Closing Incompatibilities in Constitutive Modeling and Spatial Discretization with envyo, Liebold C., Erhart A., 10th European LS-DYNA Conference, Würzburg, 2015.
- process2product simulation: Closing Incompatibilities in Constitutive Modeling and Spatial Discretization with envyo®, Liebold C., Haufe A., 15th International LS-DYNA Conference, Detroit, 2018.
- DYNAmore Express: Envyo – Mapping capabilities and recent developments, https://youtu.be/DvOchqNhaZA
- Free webinar: ENVYO – current status, https://youtu.be/8RY3Fd9BYCU
- DYNAmore Express: Modeling plastics in LS DYNA (Part 2) - Anisotropic Modelling of Thermoplastics, https://youtu.be/WiL4K-5pvRU

Thank You



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