Which way up?

Effects of forming on composite properties

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RISE

Process simulation of compression moulding: Integration and Implementation - Prosicomp II

- Scope and objective

A more reliable, virtual design and manufacturing system for composites that allows vehicle components to be cost effectively manufactured from composites with minimal waste

(1) **What mechanisms govern the flow and fibre orientation during compression moulding of sheet moulding compound (SMC)?**

(2) How does the forming behaviour of highly aligned fibre prepreg materials change when processed together with SMC?

(3) Can environmental benign chemicals be used to effectively recycle both inhouse and EoL composite vehicle components?

Partners and Financing

- Partners: Volvo Cars, Gestamp, Dynamore, RISE, KTH, LTU and Toray
- Financing: FFI - Sustainable Production
- Project duration: 2020-05-01 - 2023-04-21

Why composites & why compression moulding?

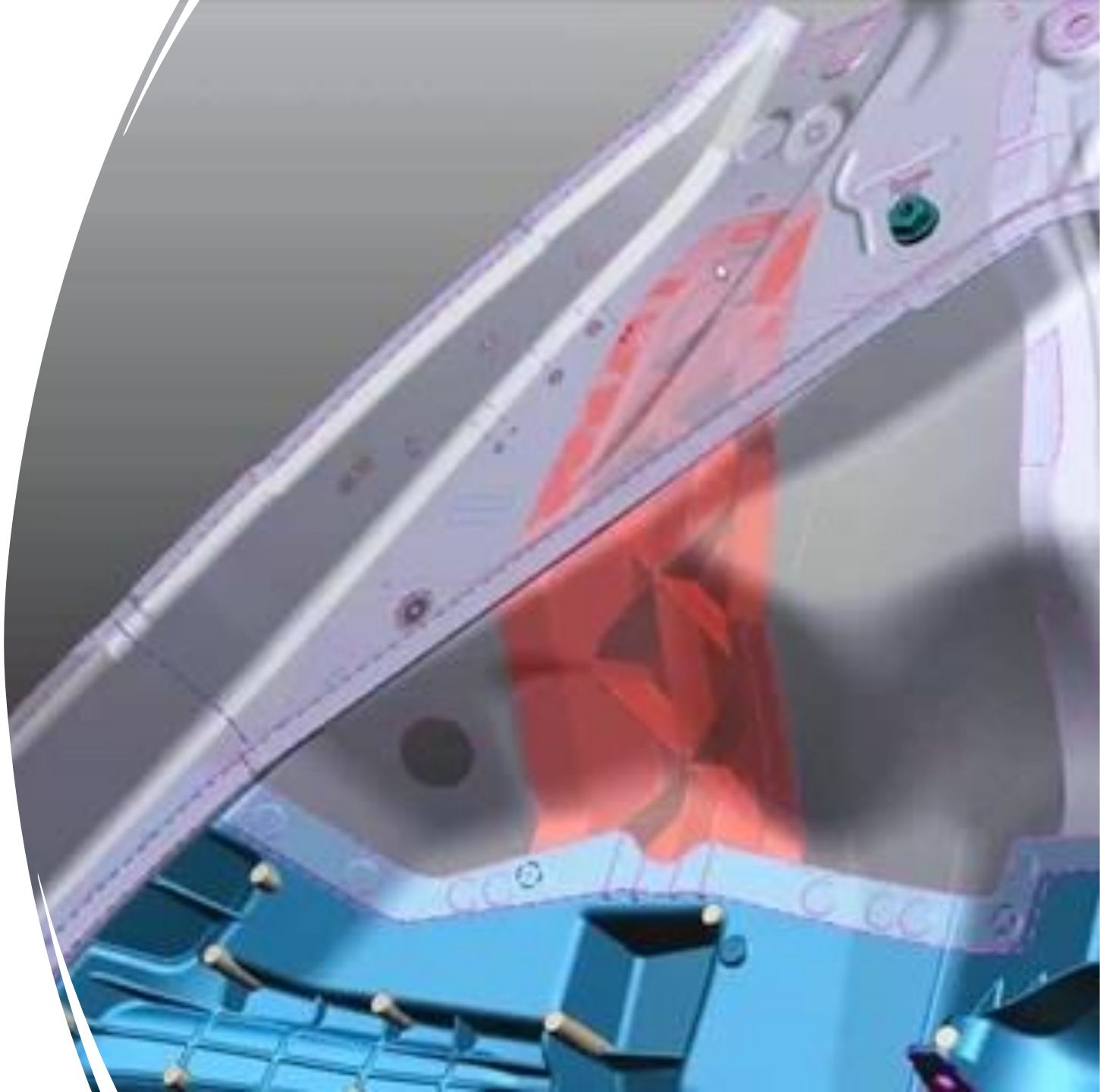
- Lightweight
- High strength-to-weight ratio
- Corrosion-resistant
- Customizable and potential to minimize part numbers
- Durable
- High production rate
- Low tooling cost
- Consistent part quality
- Good surface finish
- High fibre volume fraction

Predicting the effects of forming on composite properties

- Want to be able to design the part fit for purpose
- Want to avoid over-dimensioning

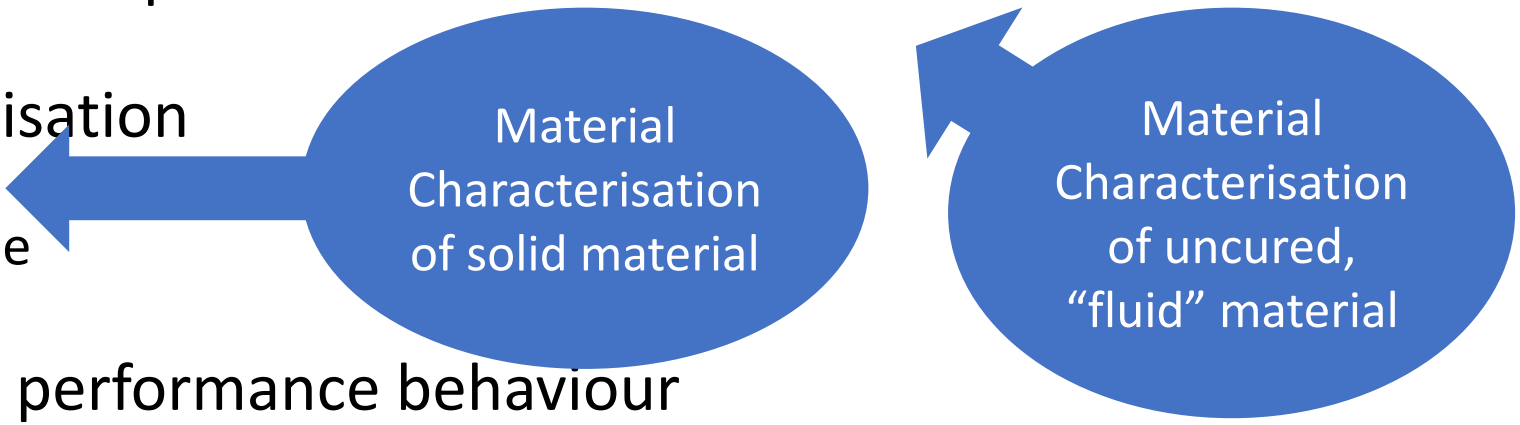
Part of this:

- Establish how good current commercial software is at predicting the effects of forming.
- Demonstrator is a component for stiffening part of a vehicle



Approach

- Made demonstrator part with two different positions of the charge using compression moulding
- Used two different software for process simulation: Moldex 3D and 3D Timon
- For mapping and homogenisation
  - For shells - used digitmat
  - For solids - used Matlab code



- Used LSDyna for predicting performance behaviour

- Compared results of using datasheet (isotropic) properties and results from commercial software with mapping.

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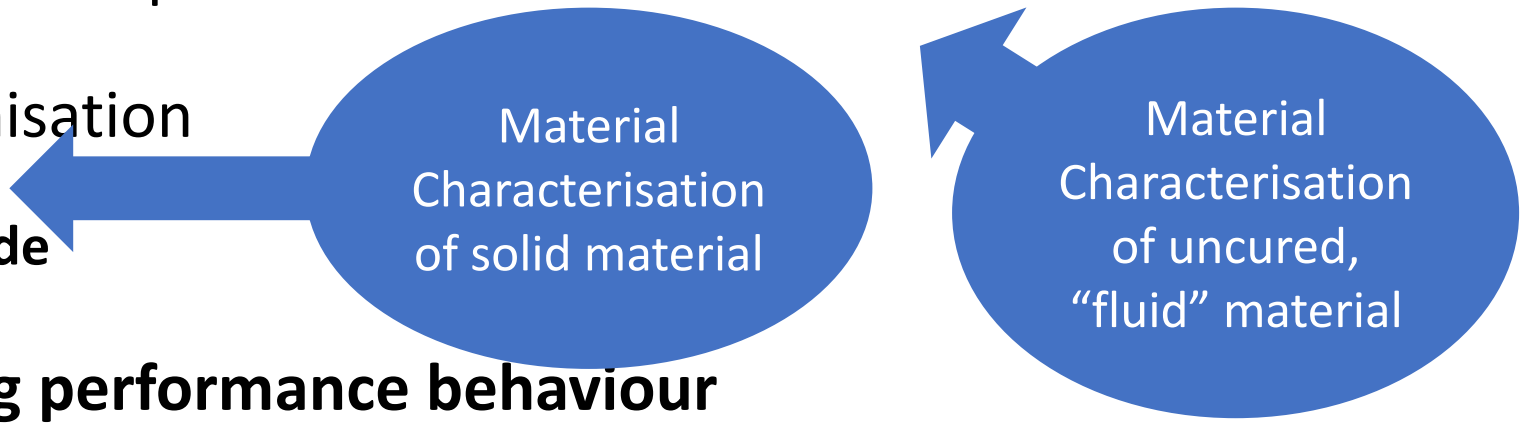

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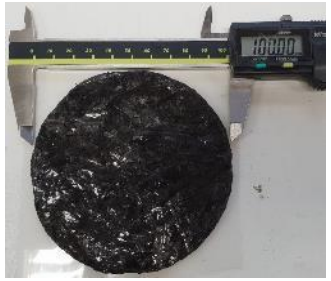
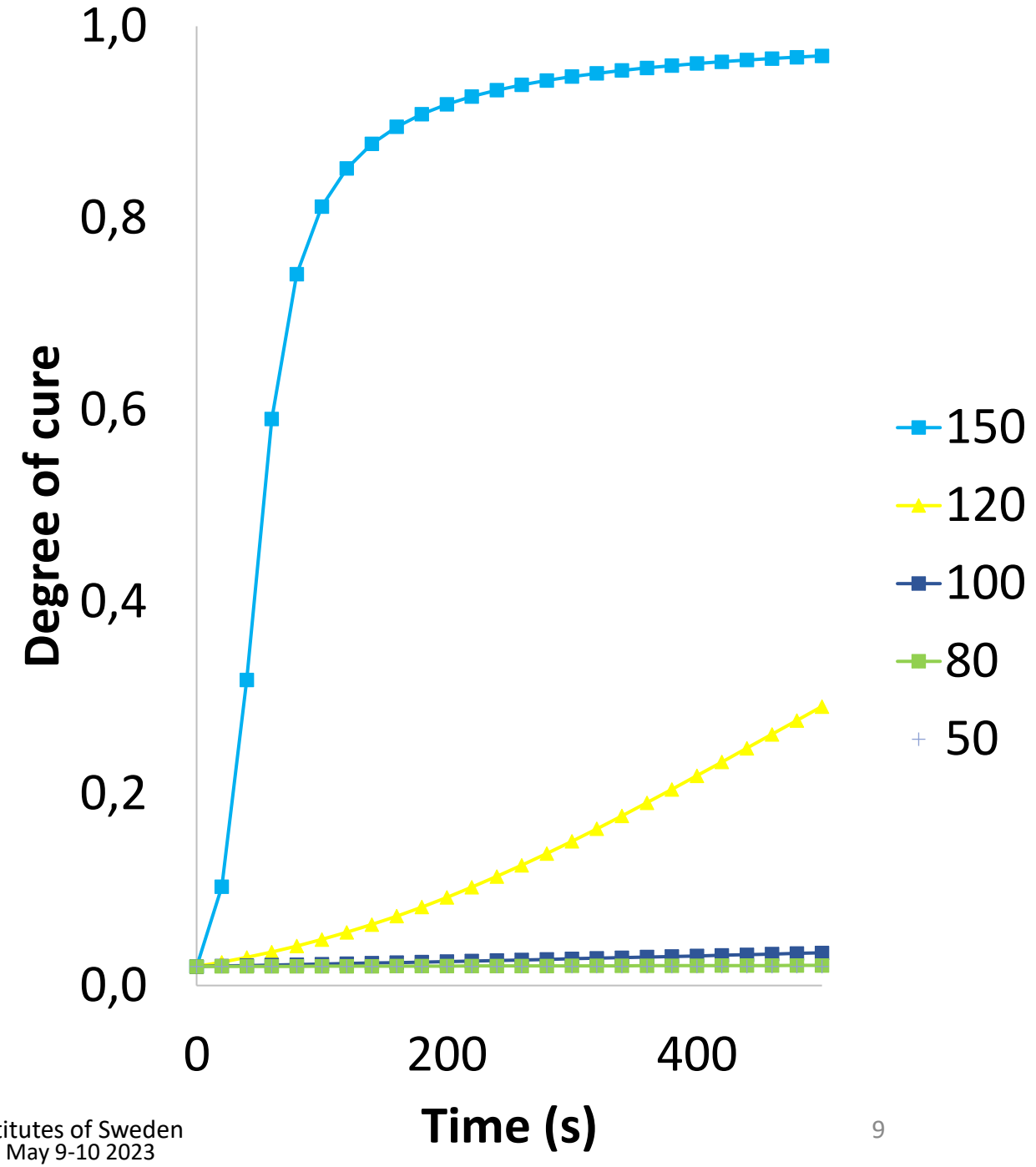
Material characterisation of uncured, “fluid” material

- Compaction tests on 100mm diameter SMC discs.
- Special compression apparatus with 100mm diameter cylinders heated (50 °C - 150°C).
- Closing speed of 0.1, 0.6, 1.2 and 2.0 mm/sec.
- Compression up to 95kN. (12 MPa)

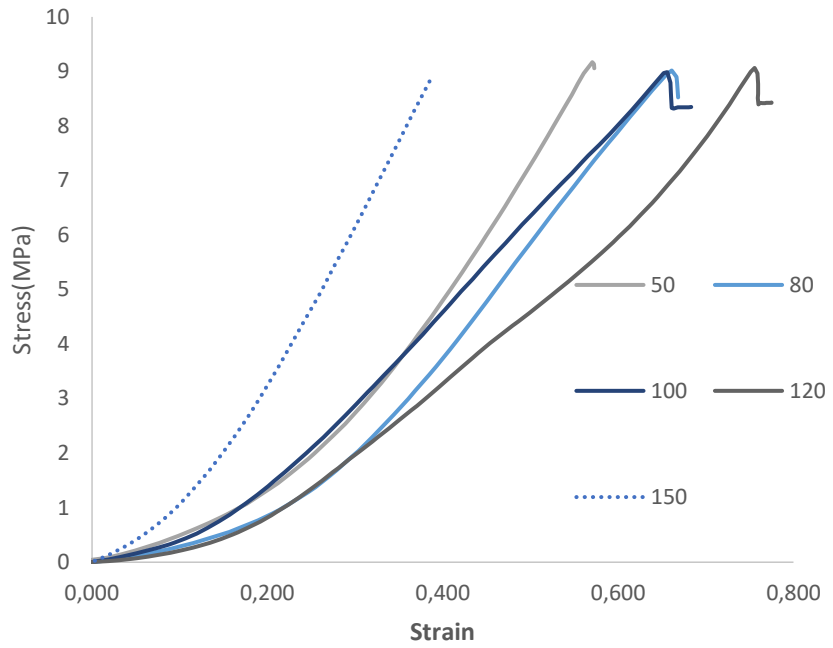


Challenges

- Material is not of a uniform thickness
- SMC cures during the tests, high temperatures→faster cure
  - At and above 130ºC, material has cured before stable temperature is reached.
- Temperature of the tool varies with approximately +/- 5ºC



Squeeze test experimental results



- At 150 degrees, material already cured so results are not relevant for forming process
- Variation in the pattern
  - material thickness variablity (should be taken into account by starting position) ,
  - fiber in material variation (using only one layer to achieve isotropic testing),
  - tool temperature variation (opening and closing of the tool affects the temperature, feedback control slow,
- Clear that visocity at 50> viscosity at 120

For flow models: Viscosity of homogeneous material

- Viscosity is dependant on:
  - Temperature
  - Degree of cure
  - Shear rate

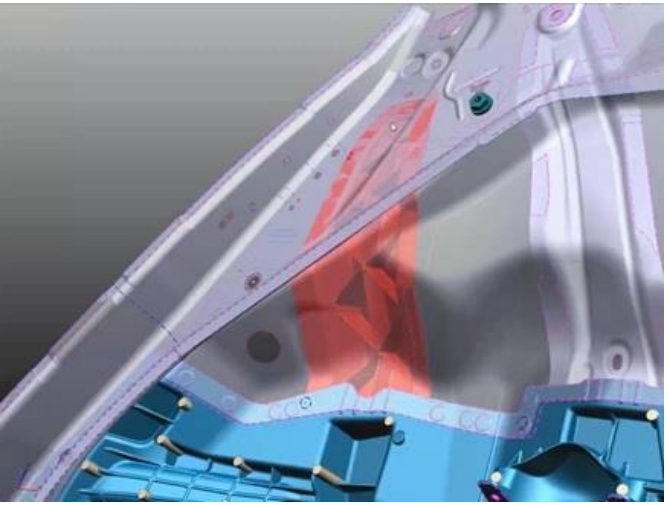
$$\eta_0 = a \exp\left(b/T_0\right)$$

$$\eta_1 = \eta_o \left(\frac{\alpha_{gel}}{\alpha_{gel} - \alpha}\right)^{(D+E\alpha)}$$

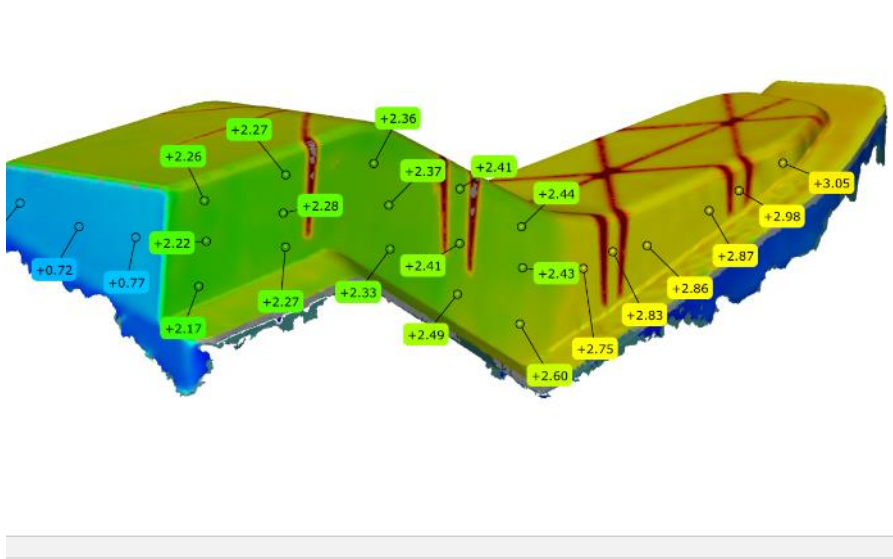
$$\eta = \frac{\eta_1}{1 + \left(\frac{\eta_1 \dot{\gamma}}{\tau^*}\right)^{(1-n)}}$$

Flow simulations with commercial software: 3D Timon

- Setup
  - Material characterisation
  - Position of charge
  - Mesh
- Simulation
  - Filled mould
  - Time of analysis
- Analysis
  - Weld lines
  - Clamp force
  - Fibre orientation and distribution



511 material thickness



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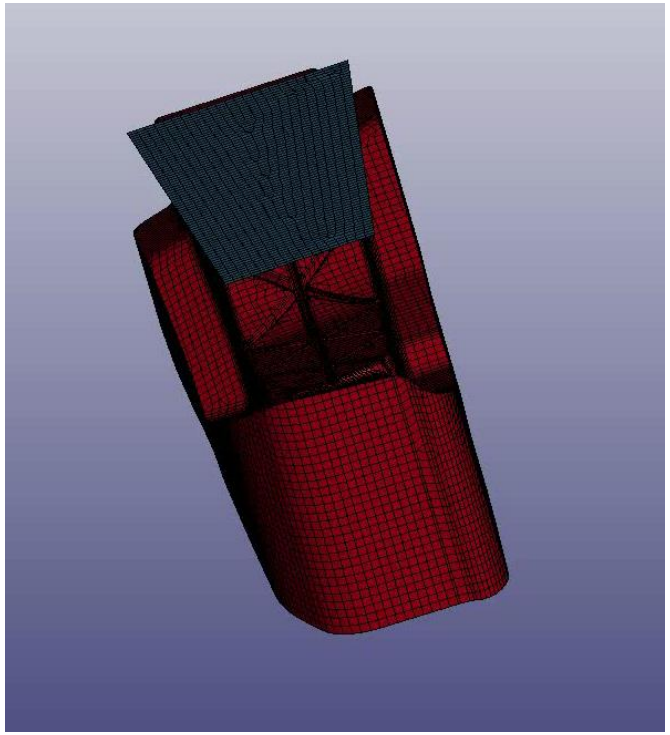
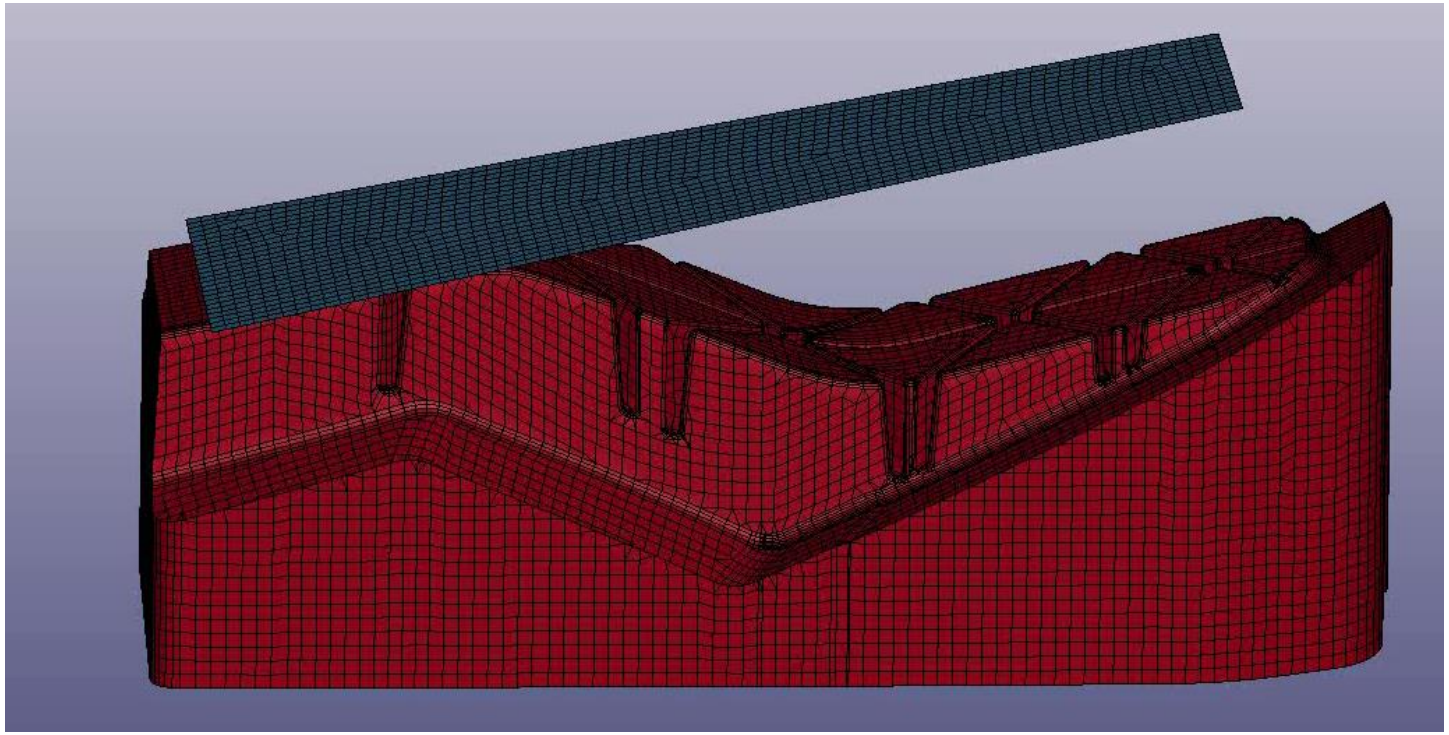
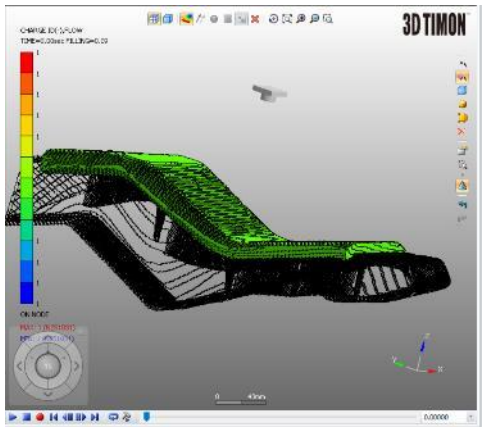
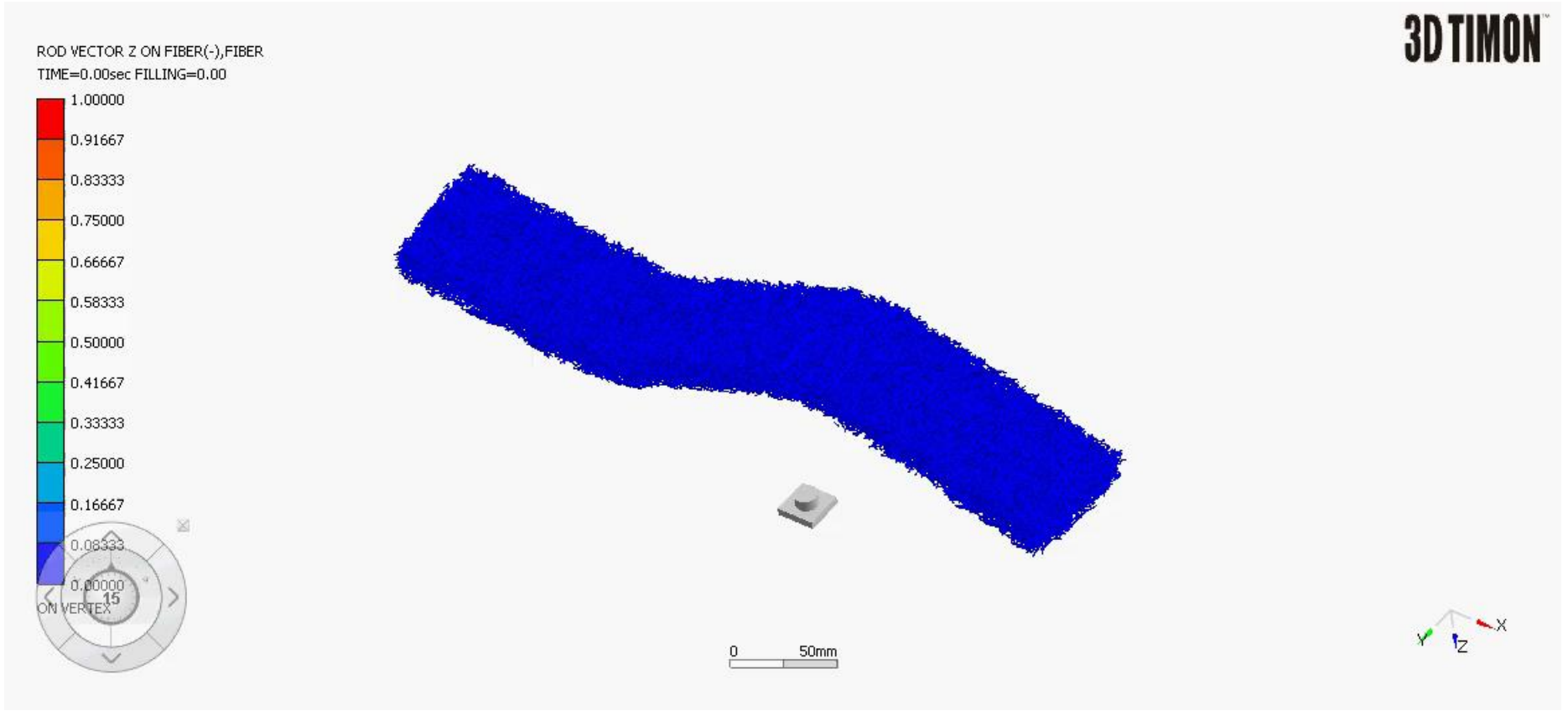
Positioning the charge for simulation





Simulation results of demonstrator

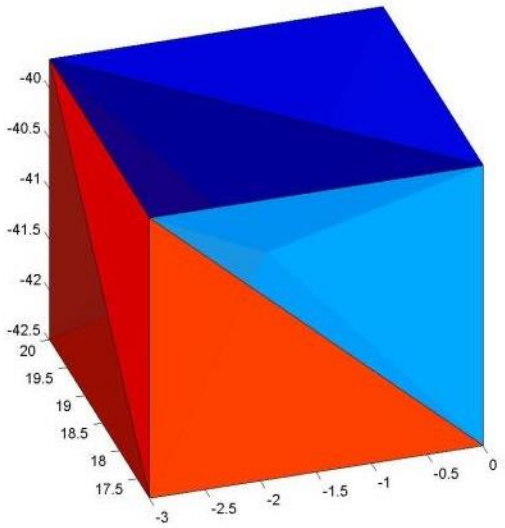




Processing to Structural performance

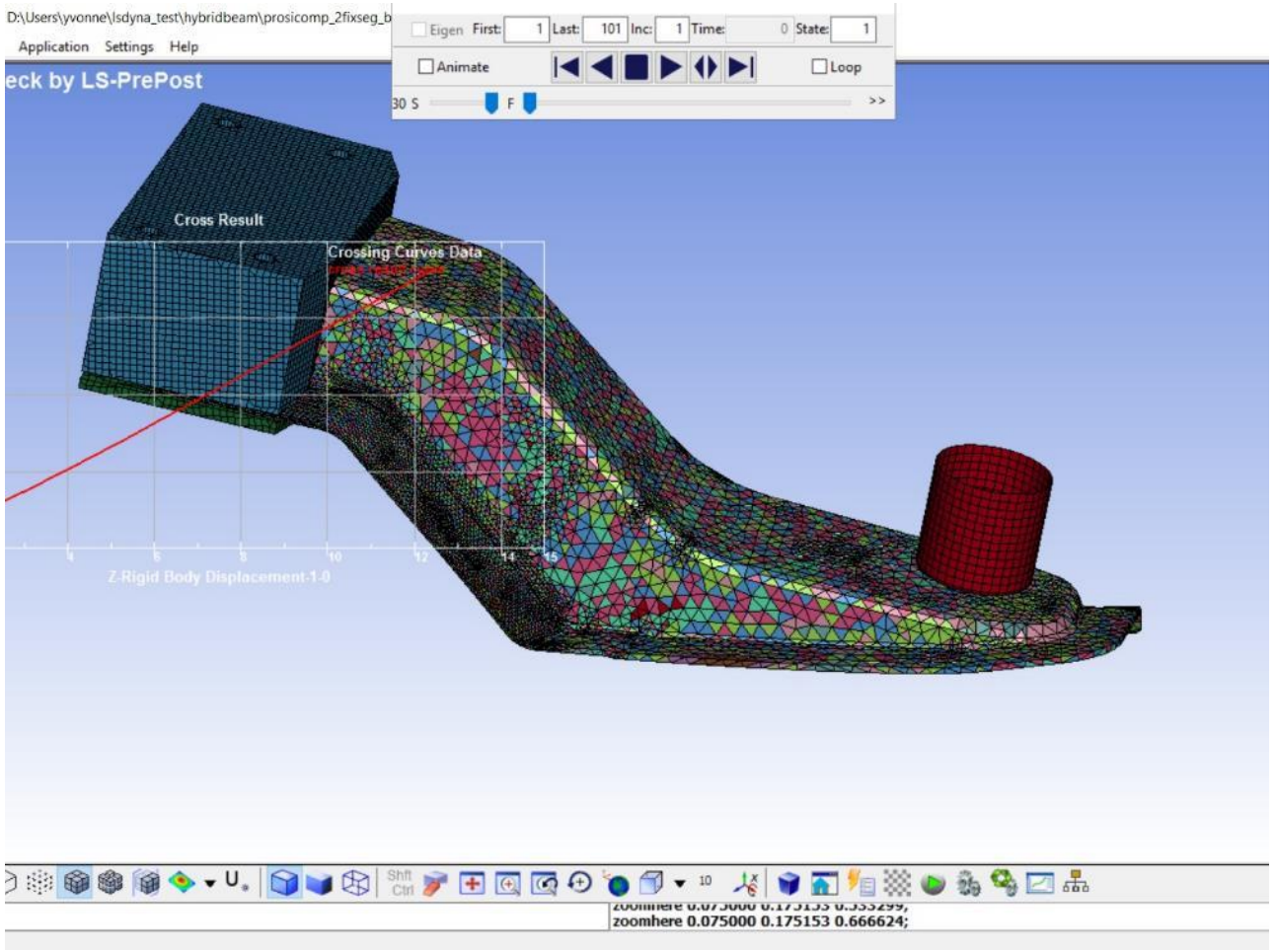
- Stage 1: mapping of properties
  - Uses the well developed search criteria based on Delaunay triangulation
  - Create a tetrahedron based on the LSDyna solid element nodes
  - Search the 3Timon mesh for points that lie in that space

Stage 2: homogenization - averaging of values based on number of part chosen



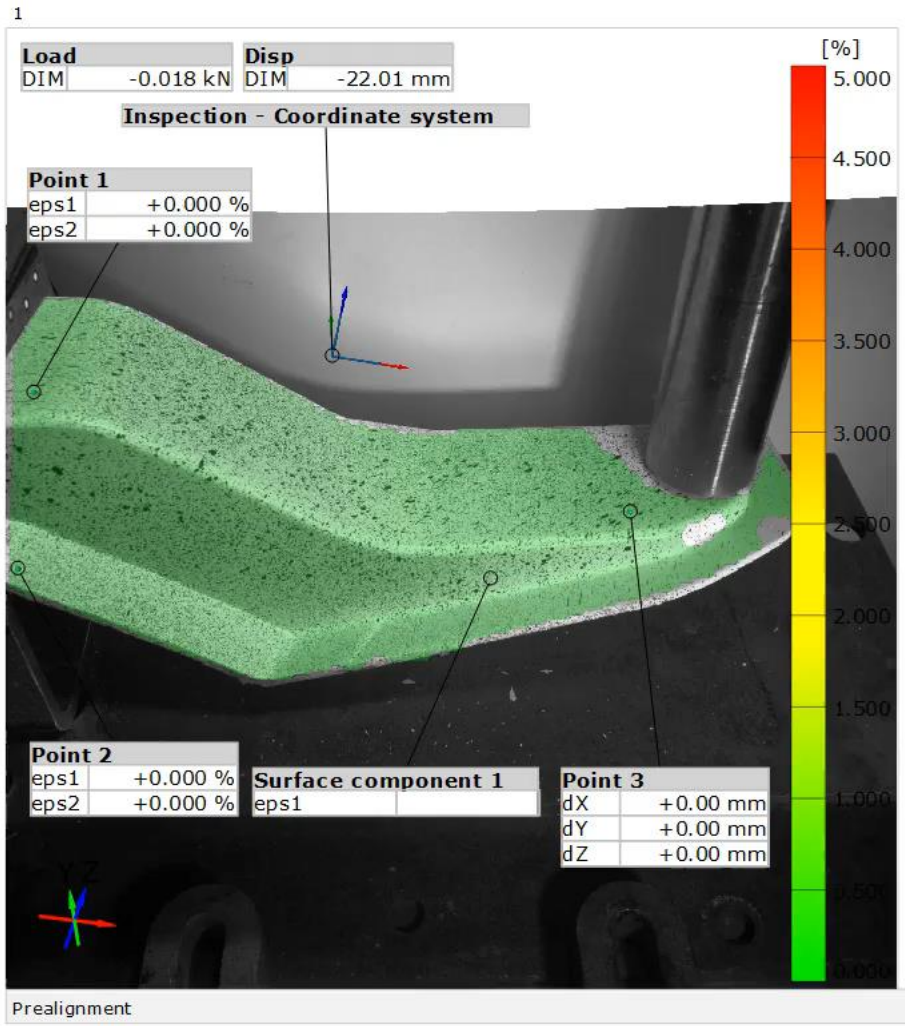
Number of parts…

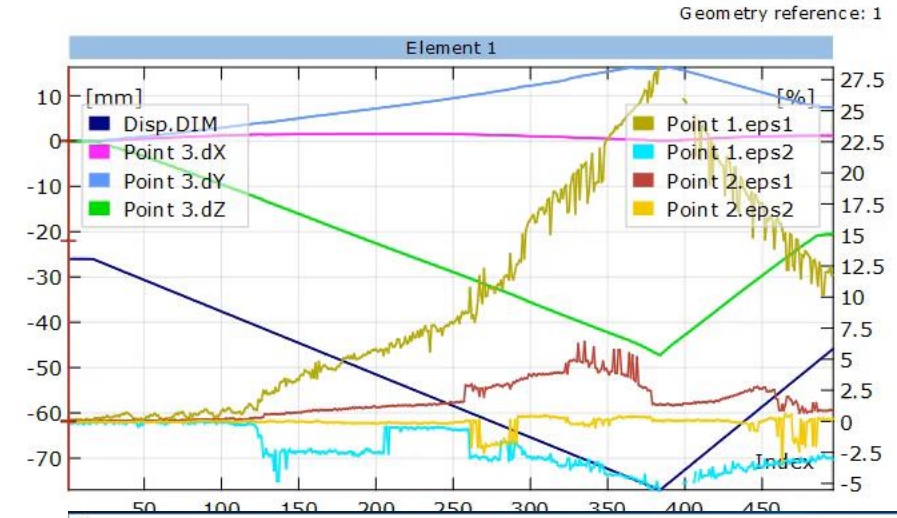
- Check to see effect of increase and decreasing parts

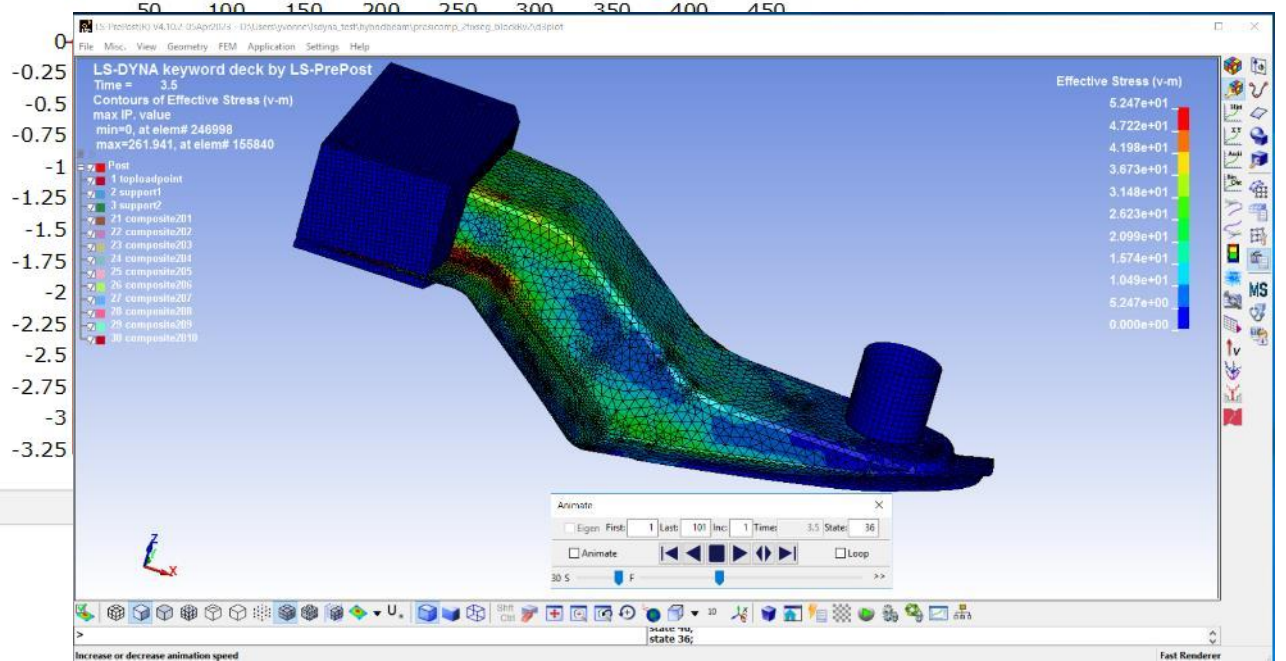


Netshape

Carbon_13,

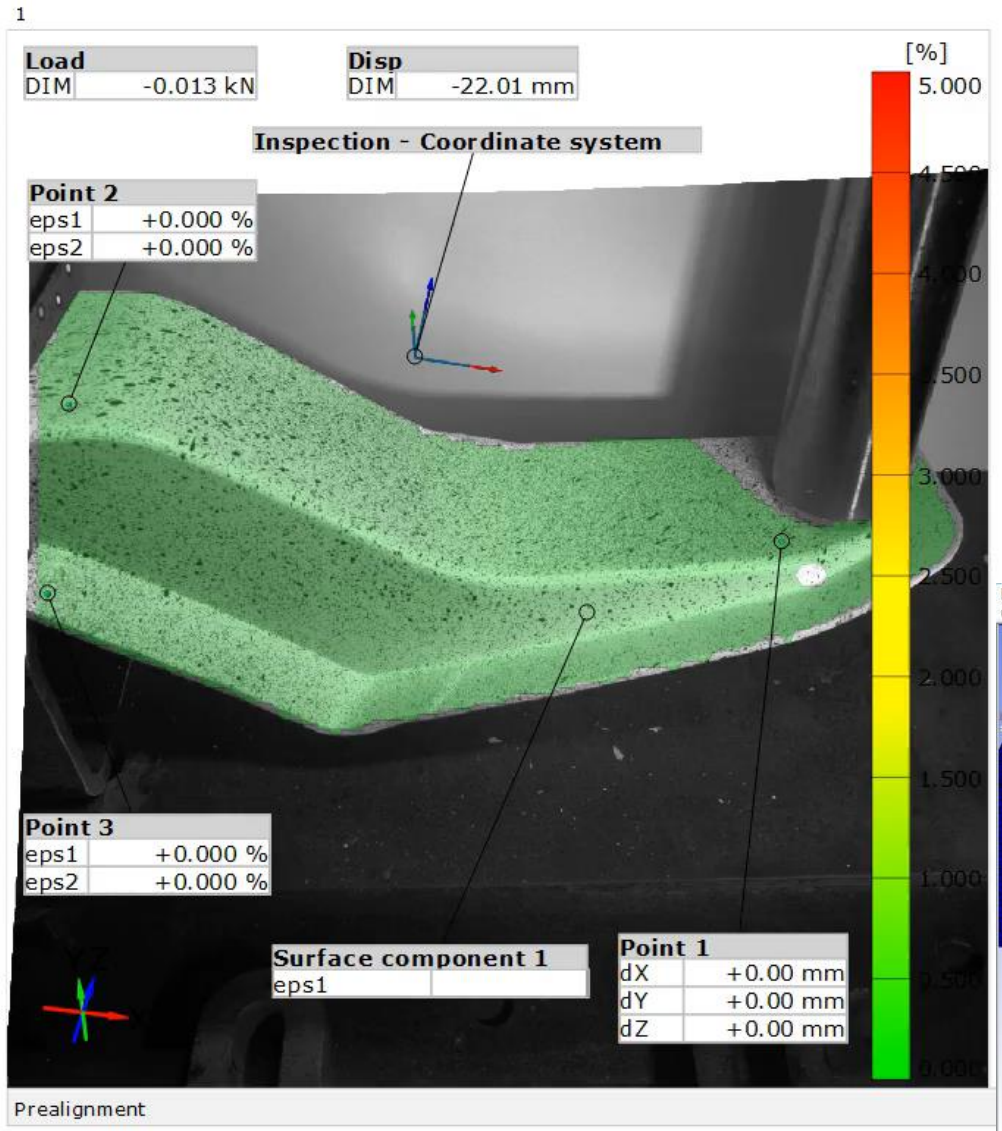


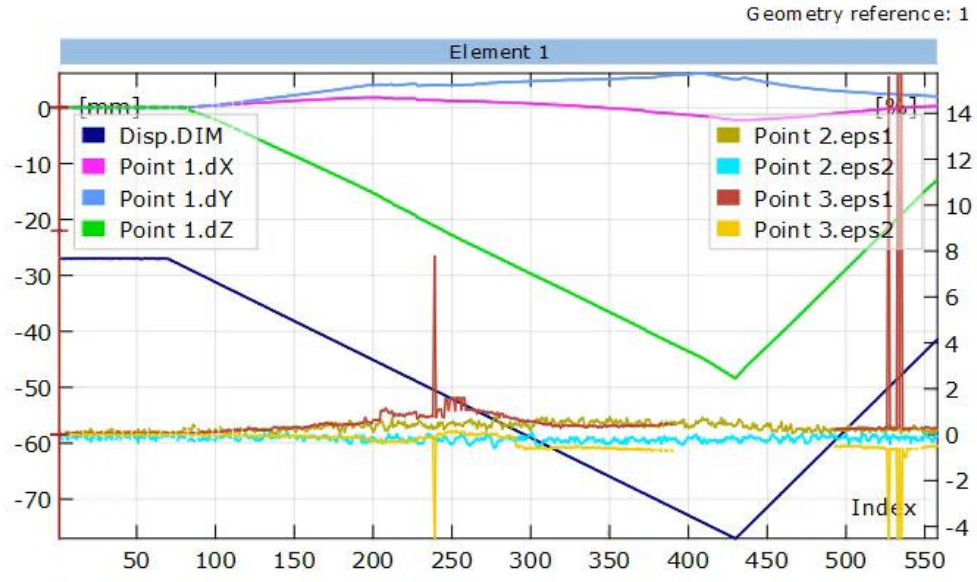


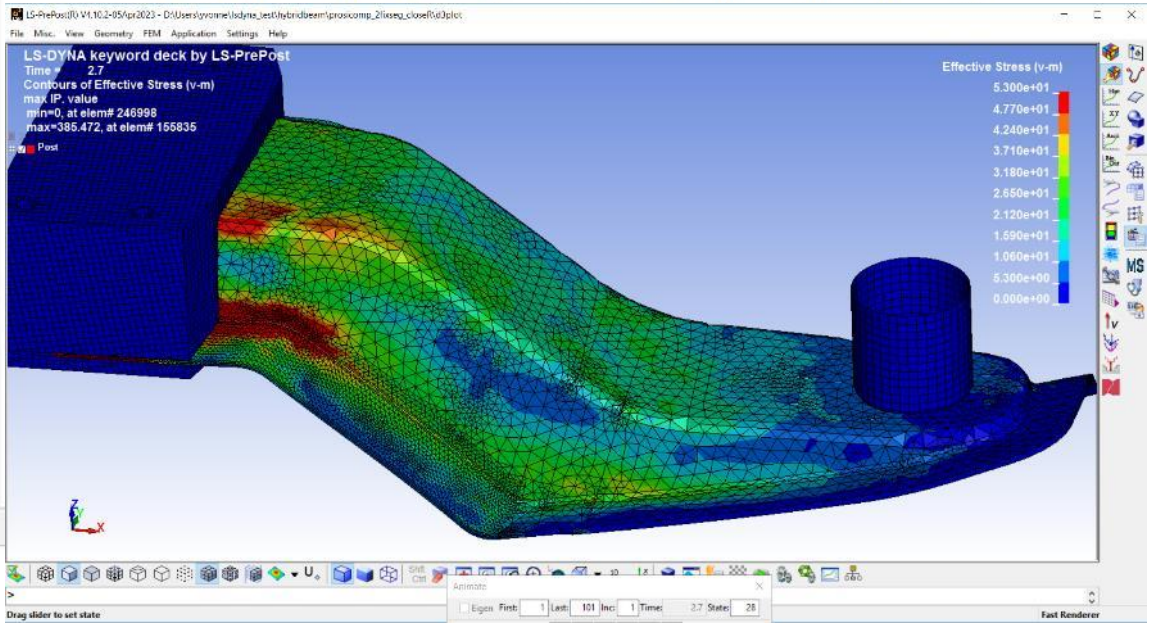


Block

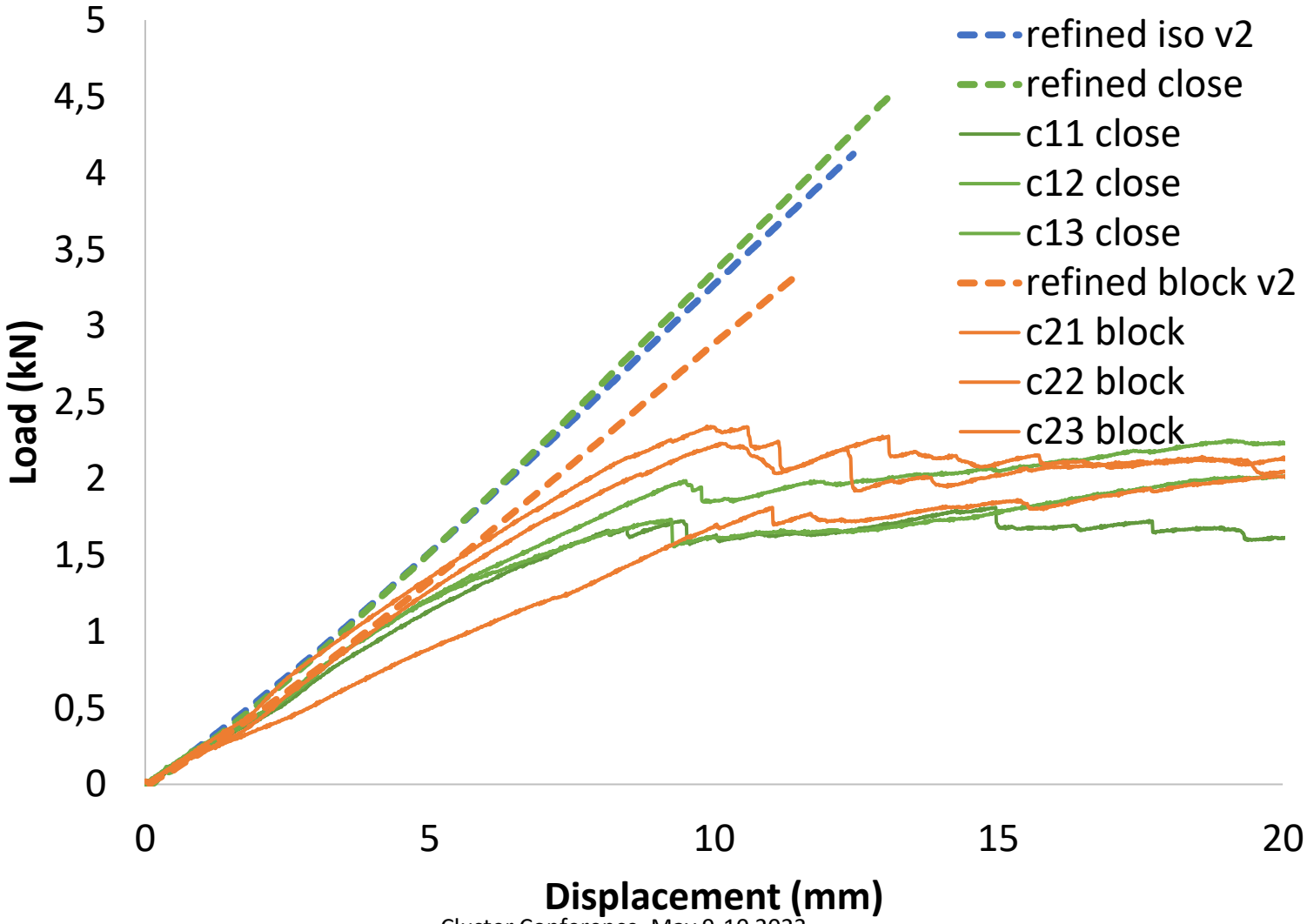
Carbon_21



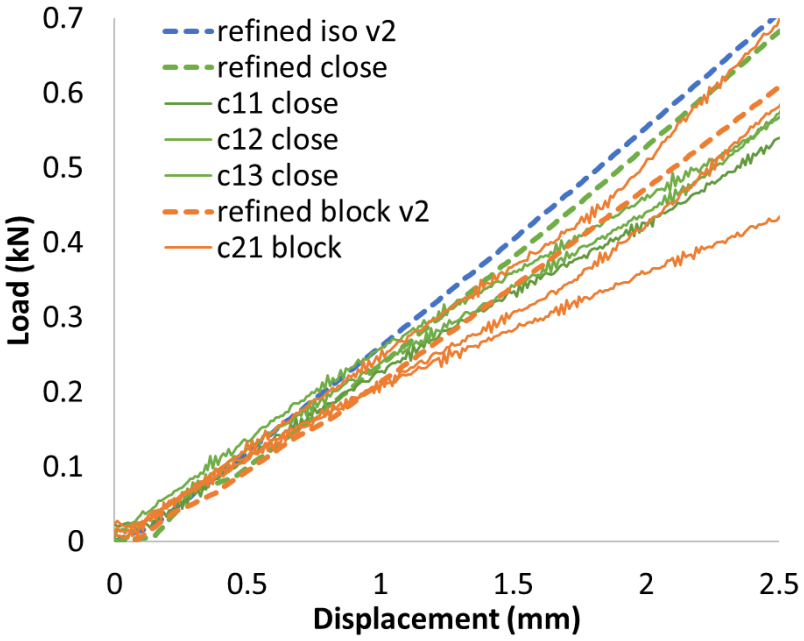


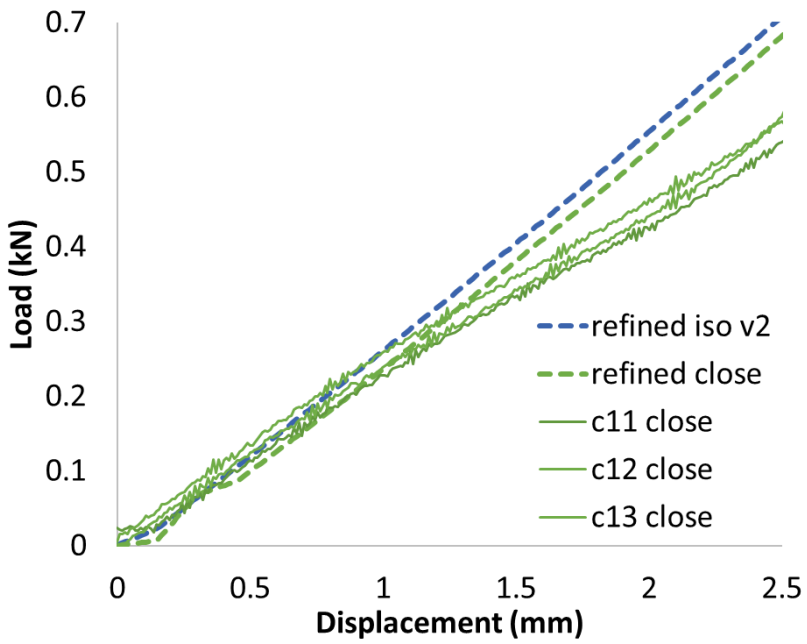


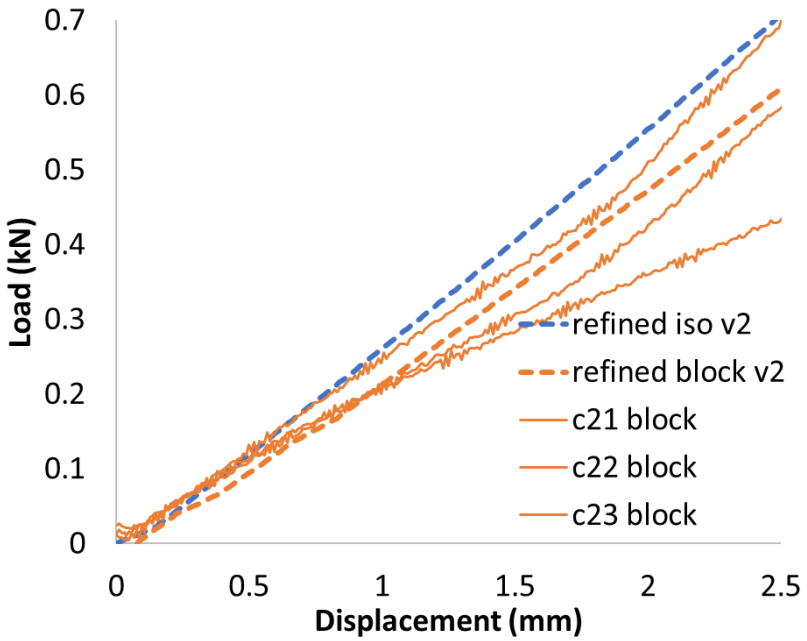
Effect of global stiffness



Linear region

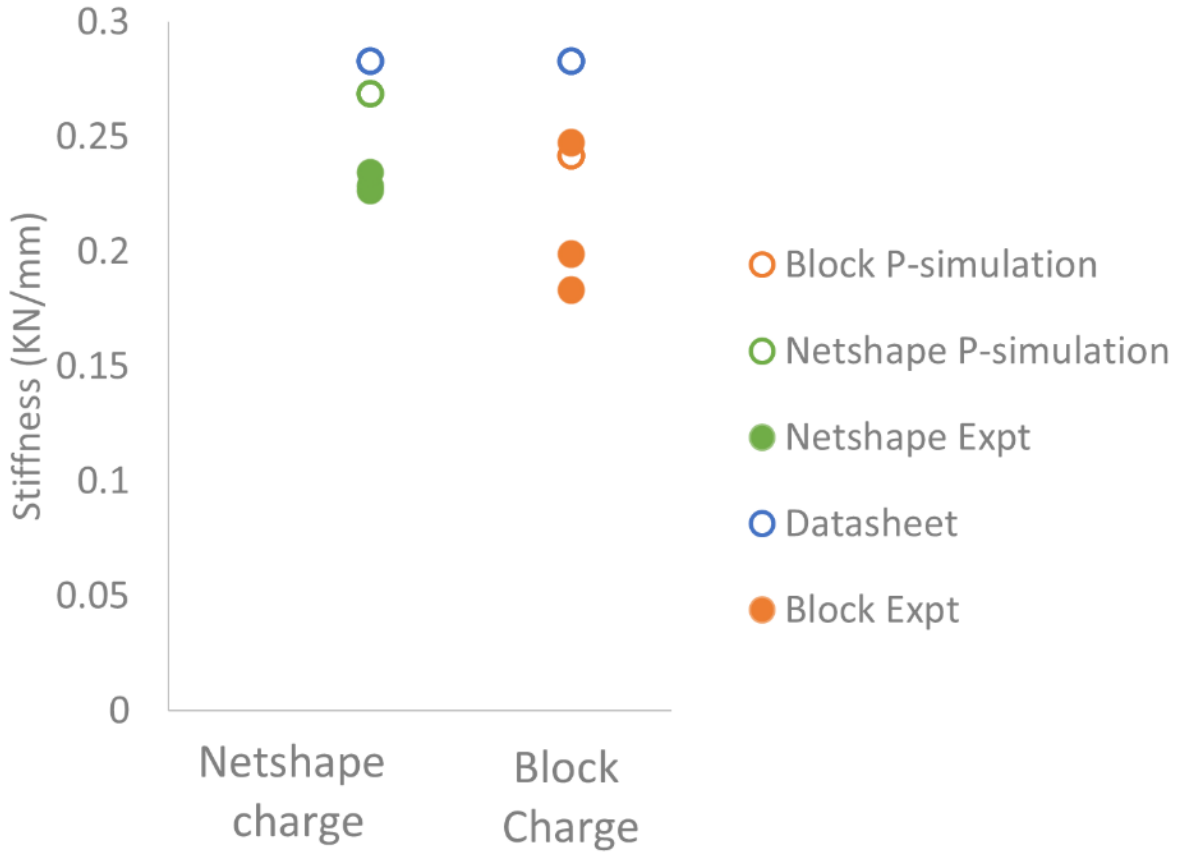






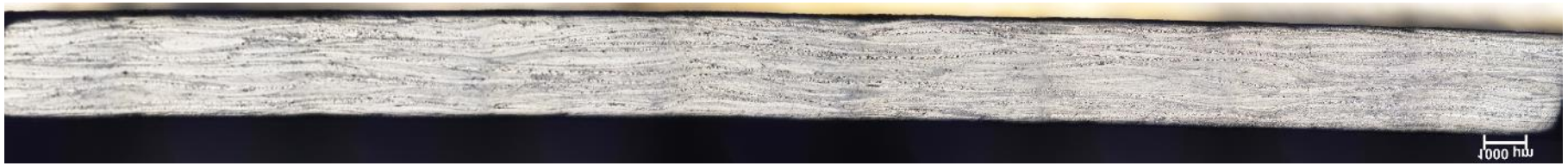
Stiffness results

- Greater variation in the block charge in experimental results
- Process simulation for block is closer to experiments than isotropic results
- Process simulation for netshape is closer to experiments than datasheet also but to a lesser extend than for block.



Error for modelled and experiments:
for close between -14.8% and -19.1% and for iso -20.9% and -25.3%
for block between 0.6% and -37.1% and for iso -16.3% and -60.4%

Analysis of the fibre orientation on going but…



Netshape

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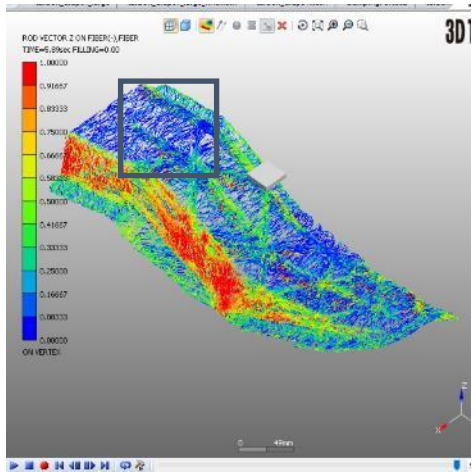
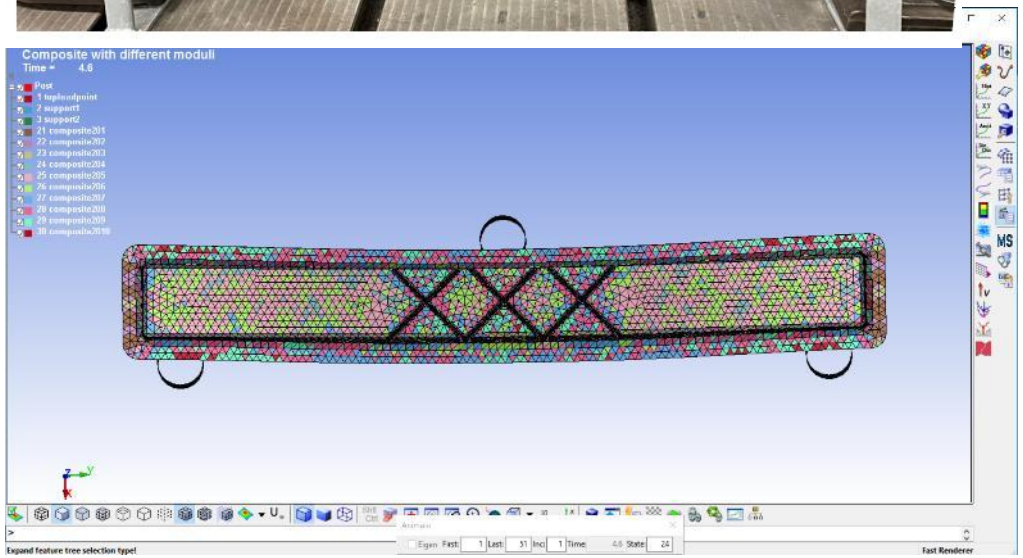
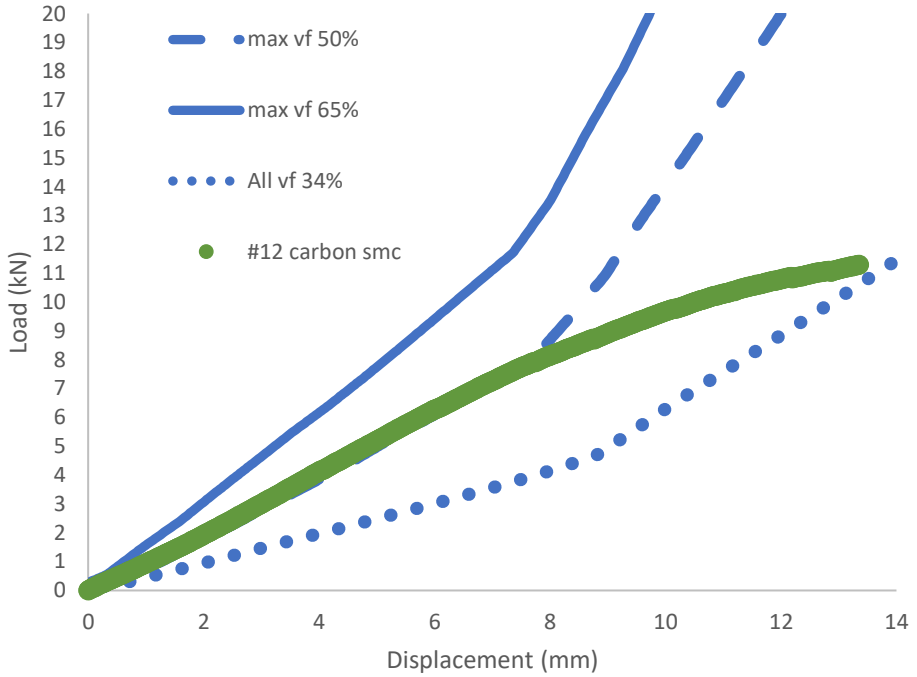


Block

Another geometry and loading case



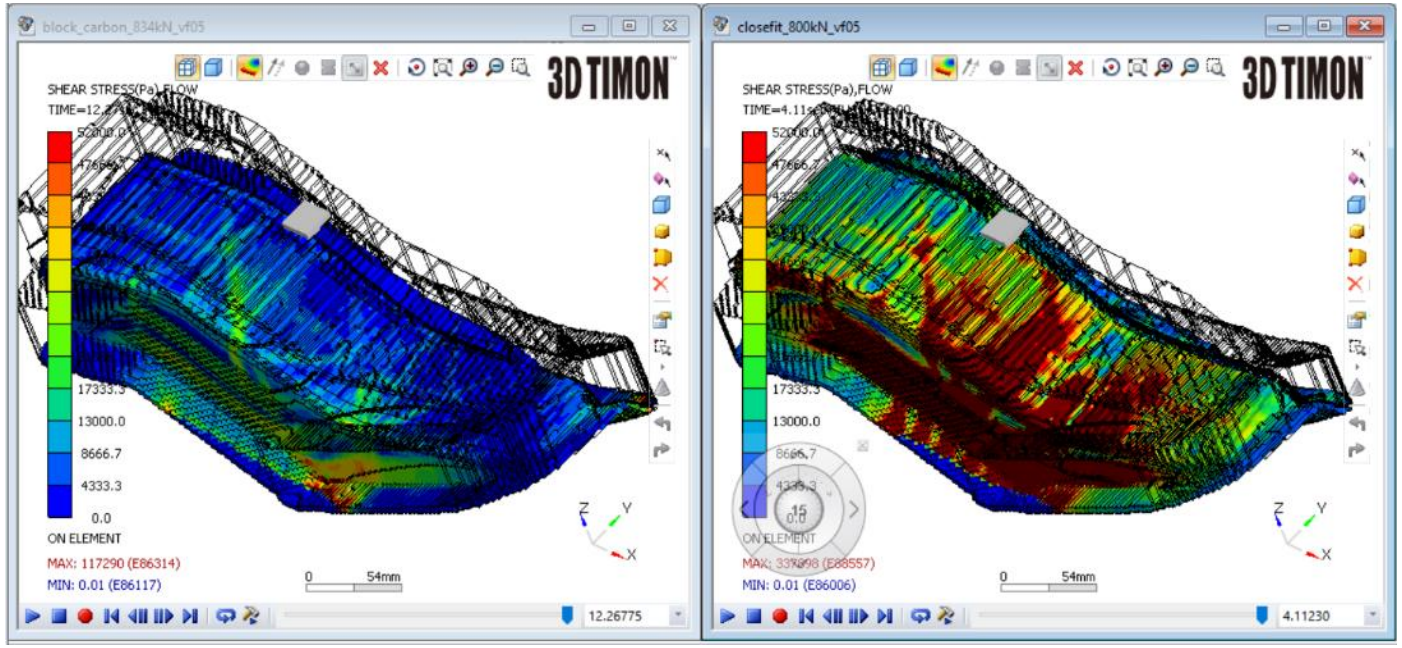


Conclusions

- A lot of work for a straight line? – yes but the line is close to being in the right place!
- Results have good agreement for different geometries and loading cases
- Seems fibre distribution has a significant effect

Remaining challenges

Need to make sure we can capture fractures in the forming process…can we use stress in flow? Doesn't look like it.



Next steps:

- Add failure,
- Comparison to shell models (Digimat),
- Forming using LSDyna

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