MICROSTRUCTURAL MODELLING OF COMPLEX SHAPED COMPOSITE PRODUCTS

Edwin Lamers
Reden bv, Hengelo, the Netherlands
www.reden.nl

Content

- Introduction
- Modelling Approach
- Composite Failure
- Coupon tests
- F-shape
- Summary and Conclusion

Introduction

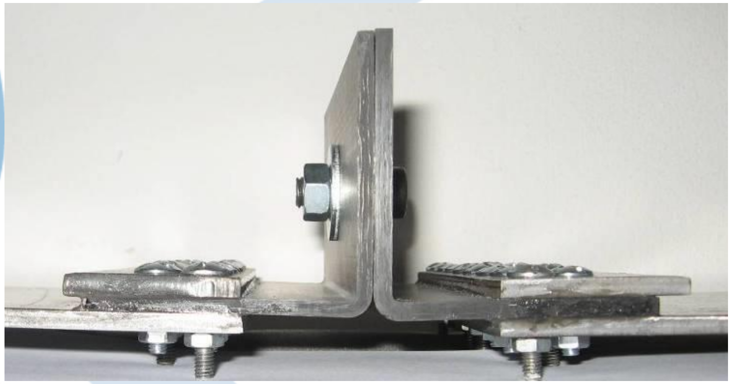
F-Shape

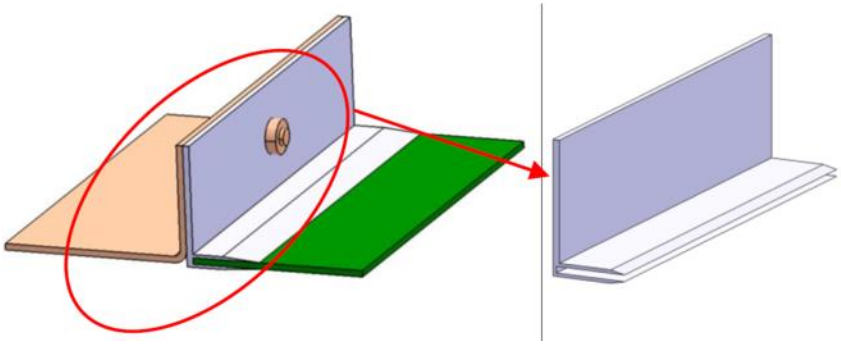
MapicC 3D

- Accurately model the performance of a composite structure (F-Shape)
- Fibres are used for a woven structure

Example:

Replace existing metallic junction system by lighter composite material with same or better mechanical performance, using warp interlock fabrics



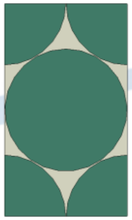


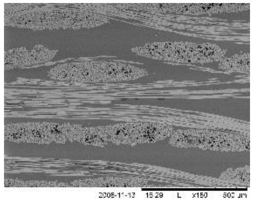
Introduction

Composite levels

Micro level

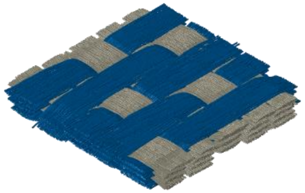
- Material properties
  - Fibers
  - Matrix
- Fiber directions
- Fiber volume fractions





Meso level

- Weave, Braid structure
  - Type (plain, satin, twill)
  - Process parameters
  - Yarns



Macro level

- Ply level
  - orientation
  - thickness

Structural level

- Part level
  - fixation
  - loading

Modelling approach

Simulation of composite failure

To simulate failure of a composite product at the micro level, the micro, meso and macro level should be represented in one simulation.

Ideas:

- Model the microstructure in a macroscopic model
  x large meshes, large computation times
  x often impossible to create a mesh (areas between fibers)
- Material homogenization at meso level
  x local information is lost

A **voxel cell approach** is chosen for the simulations. Each voxel cell is an element in a FEM mesh of the composite product. Each voxel cell gets assigned homogenized properties, based on the underlying micro structure.

Modelling approach

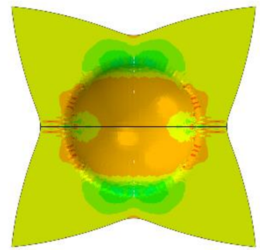
Weaving parameters

FEM weaving

Elementary tests

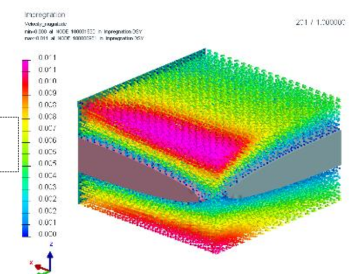
E, G, t

Forming



Processing parameters

Impregnation

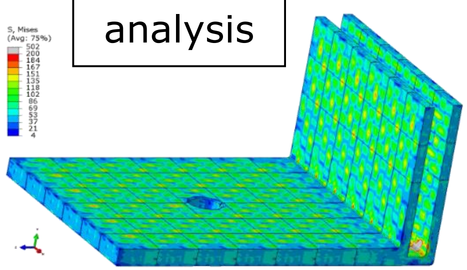


3D weave properties

E, G, etc

Stresses, strains

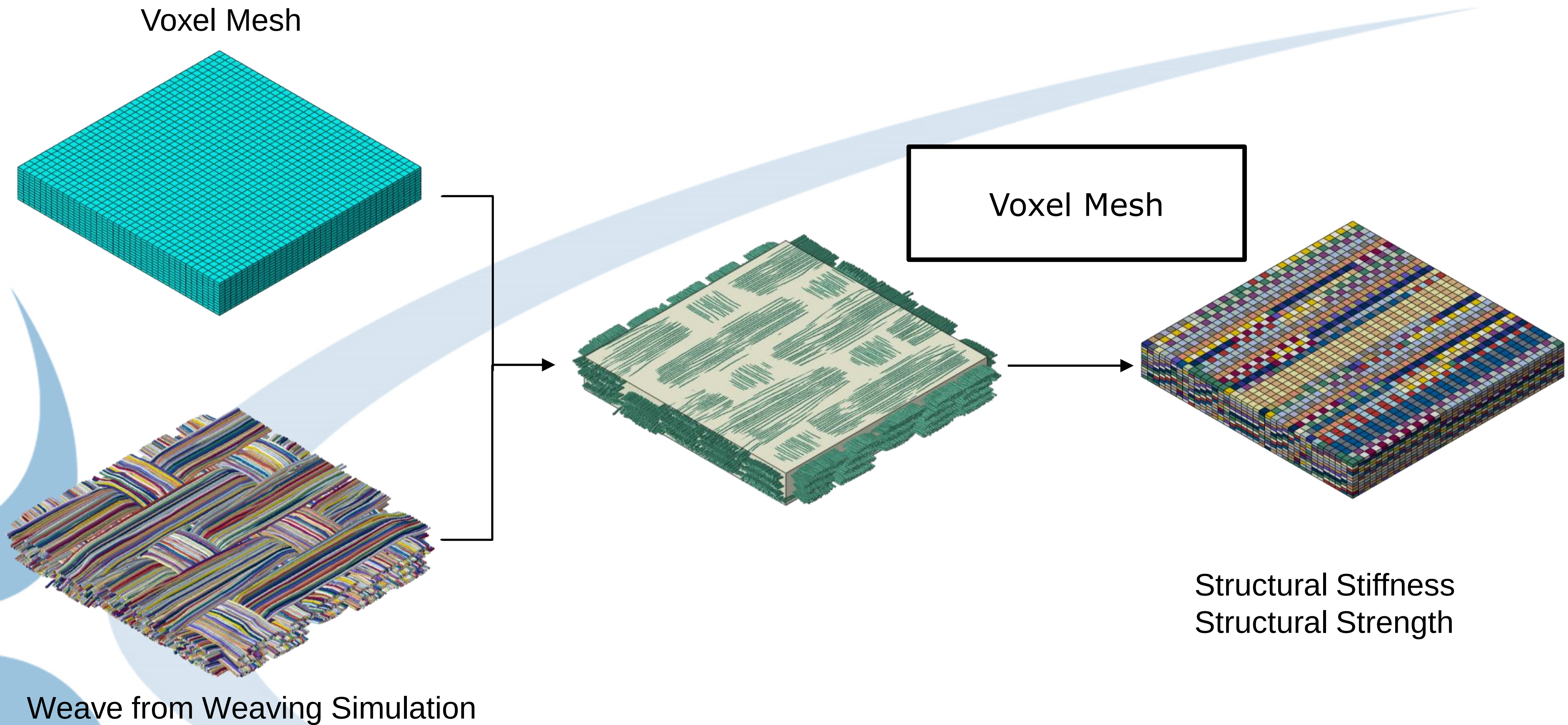
Structural analysis



Shape distortions

Modelling approach

Voxel cells



Modelling approach

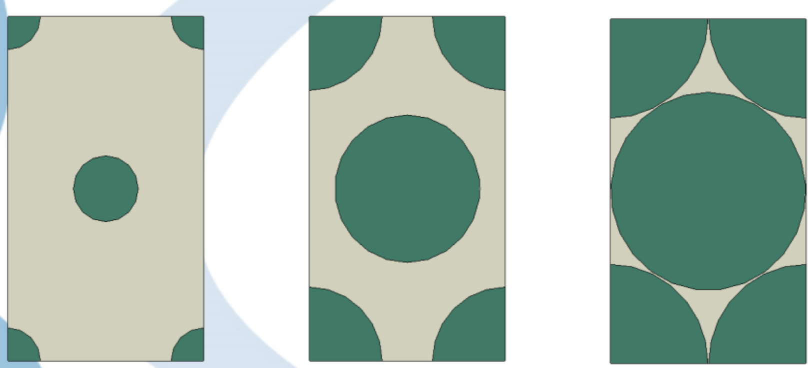
Micro – Macro

Hexagonal Unit Cells with volume fractions [0.1; 0.9] subjected to:

- Tension
- Shear
- Temperature Loading

The unit cells are modelled

- with their complete microstructure
- using voxel cell approach



Their stiffness predictions are compared as results:

- E_L Young’s modulus in fibre direction
- E_T Young’s modulus transverse on the fibre direction
- G_{LT} Shear modulus for in-plane shear
- G_{TT} Shear modulus for through-thickness shear G_{TT}
- α_L Coefficient of thermal expansion in fibre direction
- α_T Coefficient of thermal expansion transverse to fibre direction

Composite's strength

Overview

Stiffness can be predicted well with micromechanics

How to predict composite's strength?

- Puck's theory is chosen for strength predictions
- Puck's theory was one of the theories investigated in the World Wide Failure Excercise
- Puck's Theory predicts failure of UD laminates
- Puck's theory uses the stress exposure factor f_E which is the current stress state compared to the maximum allowable stress state (strength) at failure

  $f_E < 1$ no failure

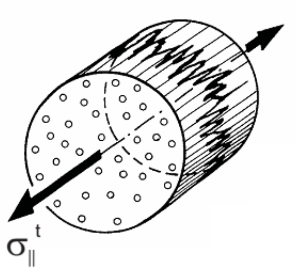
  $f_E = 1$ point of failure

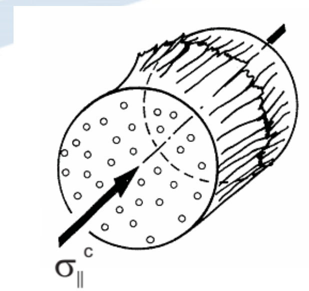
  $f_E > 1$ material has failed
- Puck's theory distinguishes between fibre failure and inter-fibre failure (failure of the resin material)

Composite's strength

Puck's Failure Theory (FF)

- In Fibre failure only the stress in fibre direction σ_L is regarded
- The fibres can fail under
  - tension $\sigma_L > 0$ - compression $\sigma_L < 0$





- The stress in fibre direction is related to the UD laminates strength in fibre direction R_L to obtain the failure exposure factor

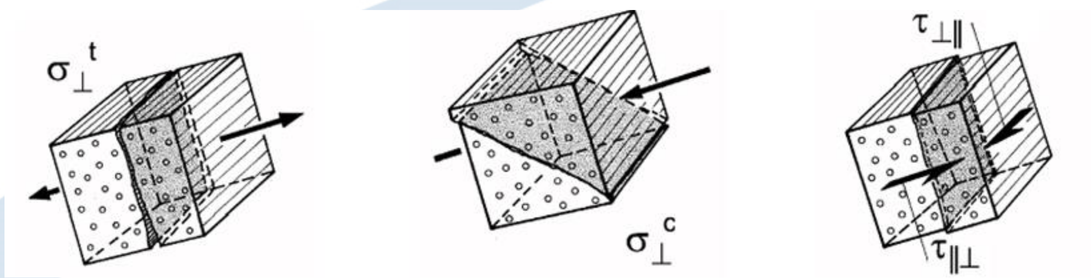
$$f_{E\,FF} = \frac{\sigma_L}{R_L^t}$$

$$f_{E\,FF} = -\frac{\sigma_L}{R_L^c}$$

Composite’s strength

Puck’s Failure Theory (IFF)

- In Puck’s IFF all stresses are regarded but the stress in fibre direction
- In IFF the laminate fails in a plane parallel to the fibre direction
- Strength in different directions are needed as input. They are obtained experimentally by tension and shear tests on the laminate



- The stresses are combined in one formula for the failure exposure factor, where they are compared to strength in different directions

Composite’s strength

Puck’s Failure Theory

- Puck’s failure theory is applicable for UD laminates
- Each voxel cell in a voxel cell simulation can be seen as an UD laminate
- Puck’s theory is applied to each voxel cell individually

however

- Puck’s theory needs strength data from experiments as input

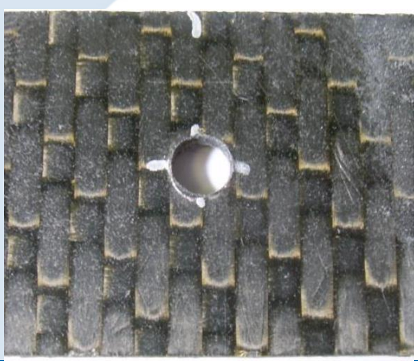
therefore

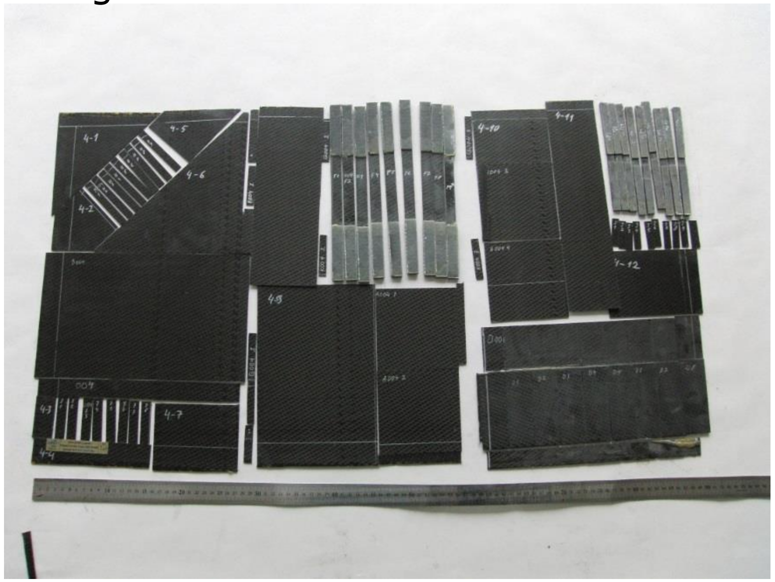
- For the voxel cell approach the strength are obtained by micromechanical model simulations
- The strength is a function of material parameters and volume fraction
- Puck’s theory is implemented to be used as a post-processing step on voxel cell simulation results

Coupon tests

Validation

- Production of composites
  - Weaving (ENSAIT) + RTM (coexpair)
- Coupon tests (Riga)
  - Experiments on panels to measure stiffness and strength
  - 9 standard tests for composites with different loading conditions
- Simulations (Reden)
  - Prediction of composite properties
  - Use previously presented approach

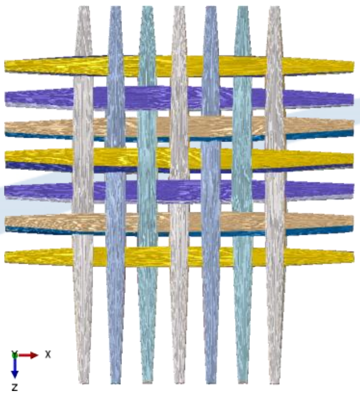


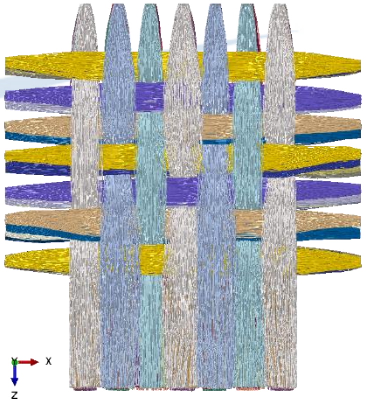


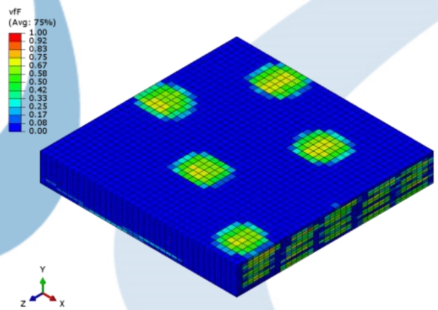
Coupon tests

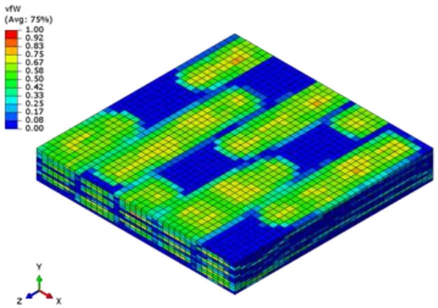
Manufacturing

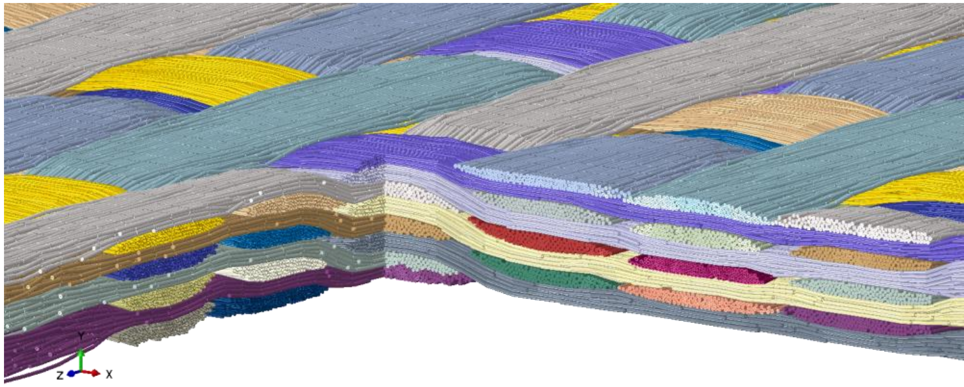
- Weaving simulation
  - 4 layer warp interlock
  - 5Harness sateen weave
  - Squeeze to composite thickness
- Run voxel mesh program
  - Selection of voxel size
- Combine units to coupon dimensions





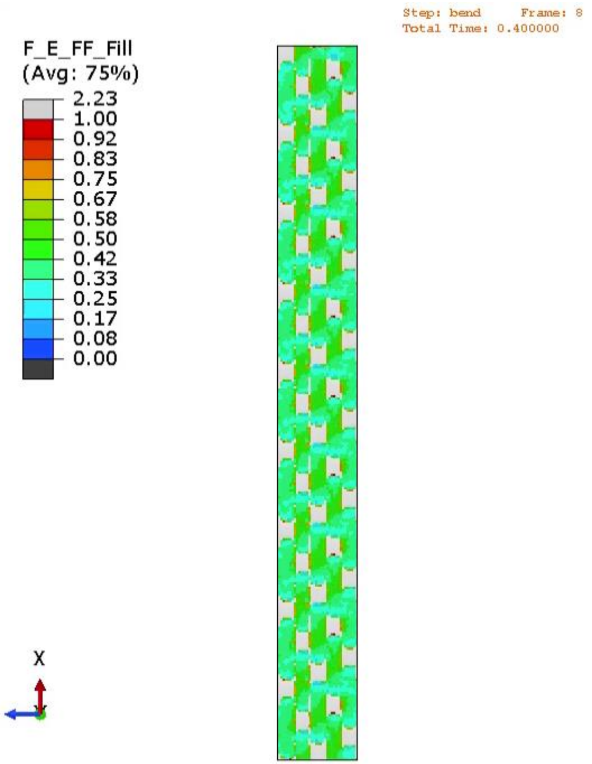


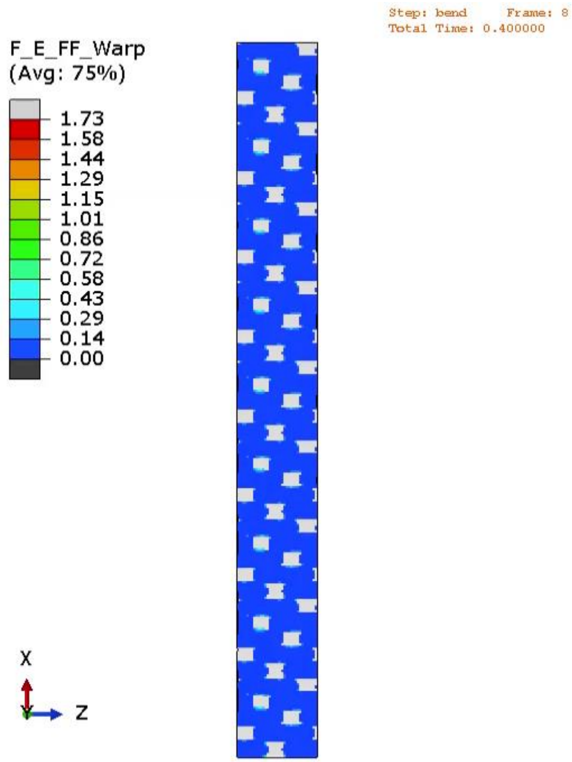


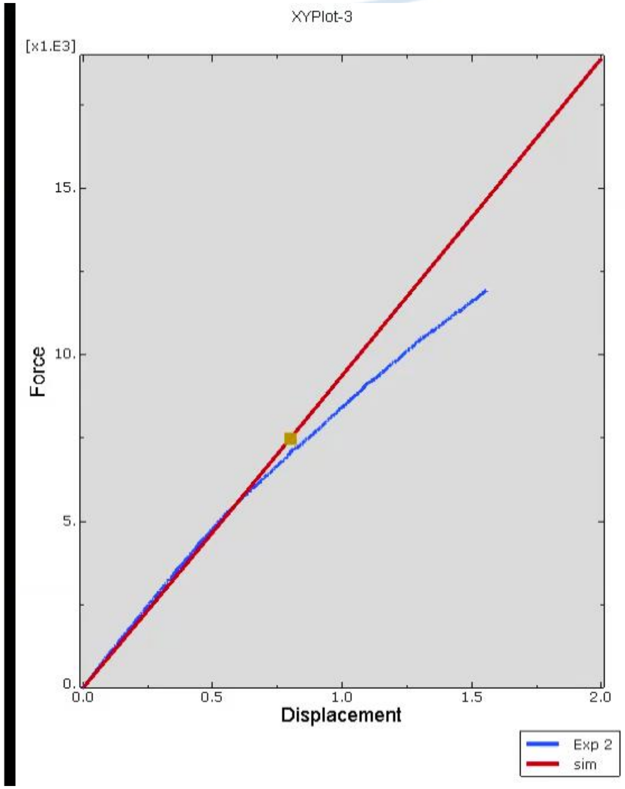


Coupon tests

Tensile tests



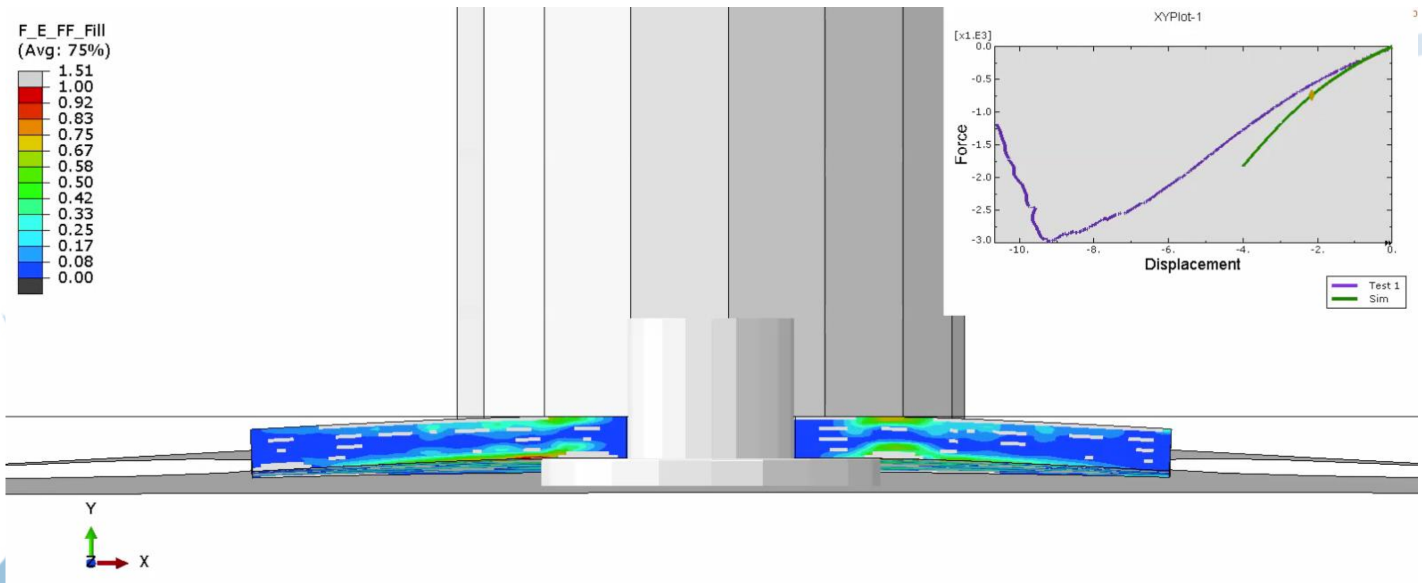




Non uniform deformation patterns

Coupon tests

Bolt pull-through tests



Coupon tests

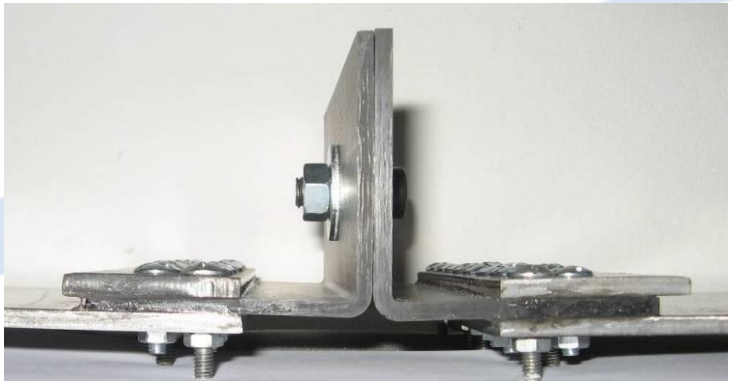
Summary

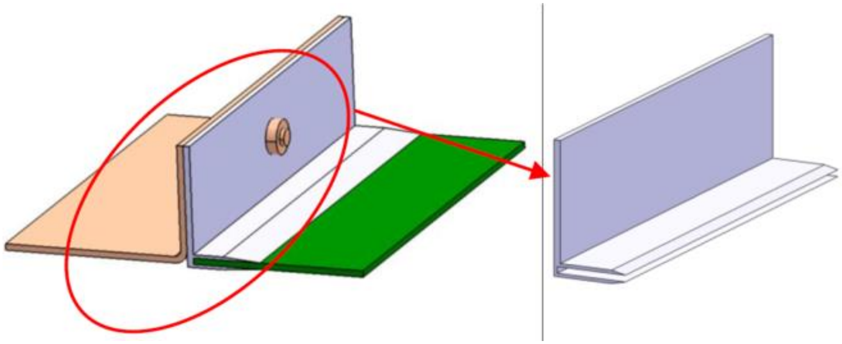
- Stiffnesses
  - Can be predicted from simulations on unit cell of weave pattern.
  - Non-uniform deformations due to weave microstructure
    - Strain measurements harder to interpretate
  - Shear moduli and poisson ratio need more research
  - Bolt model has some extra unknowns => to be refined?
- Strength
  - Inter Fiber Failure preceeds Fiber Failure
  - Onset of Fiber Failure is indictation of failure
    - Coincides with deviation Force-displ curves
  - Prediction of ultimate load needs complete failure model
    - Degradation of voxel properties in case of IFF or FF

- Procedure can be repeated for other types of composite

F-Shape

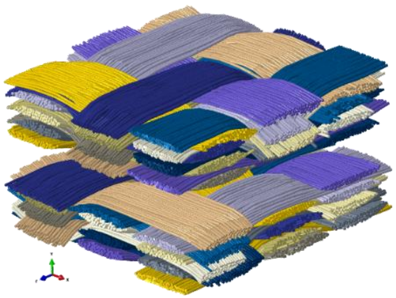
Replace existing metallic junction system by lighter composite material with same mechanical resistance





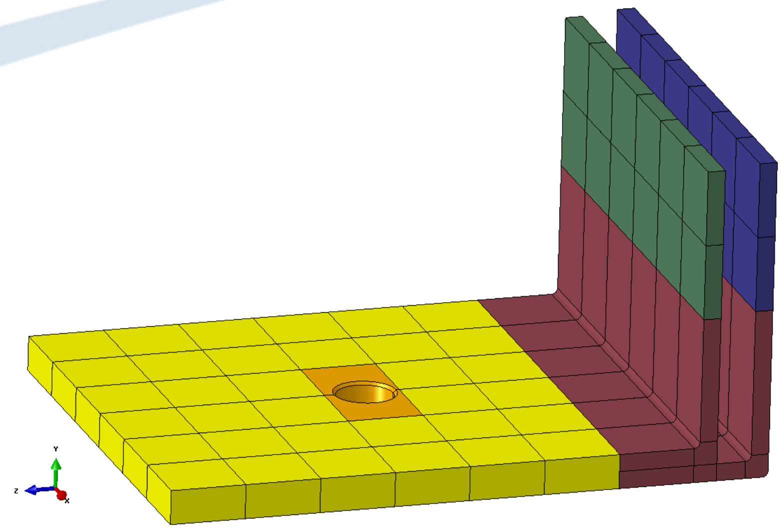
F-Shape

Weaving of the F-Shape Preform



Branch Top and Branch Bot

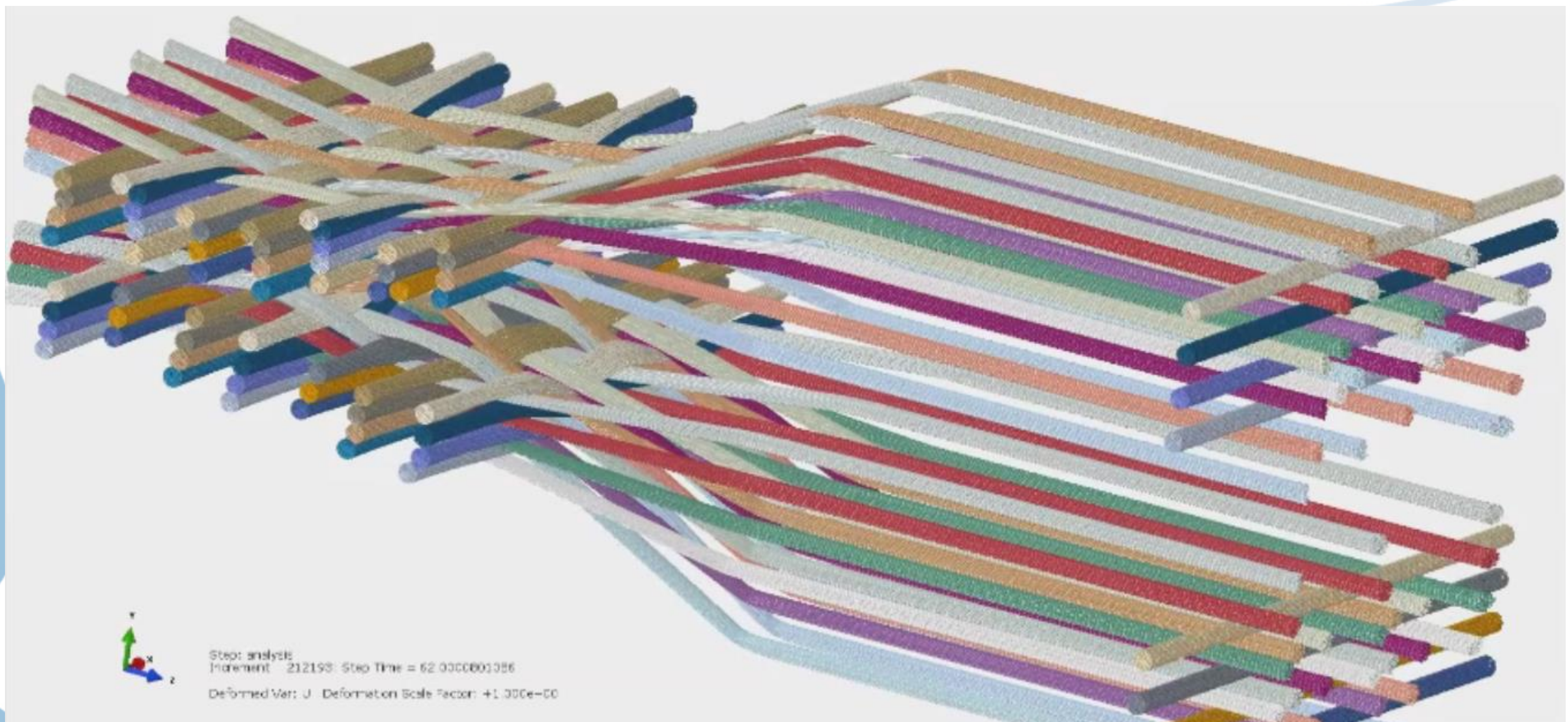
Flange



Fold Area

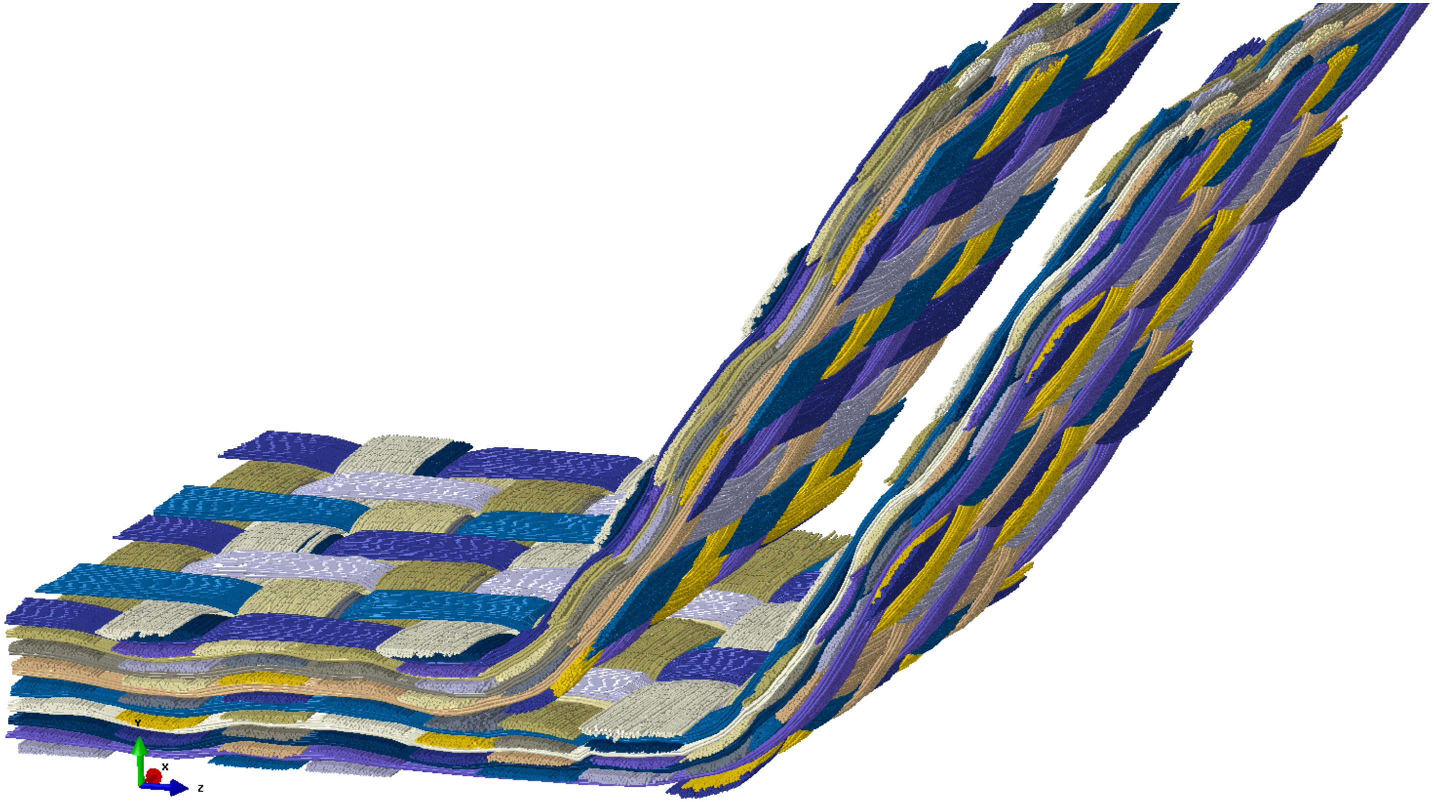
F-Shape

Weaving



F-Shape

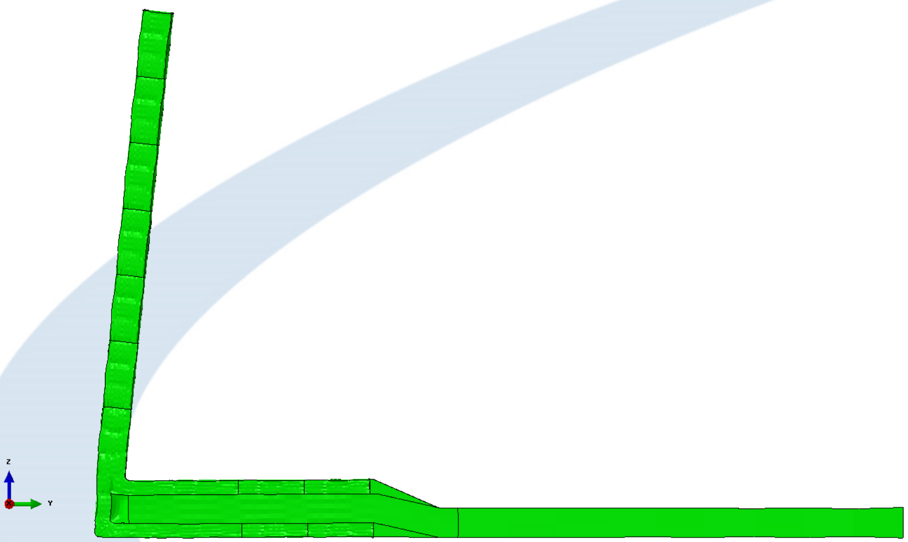
Folding



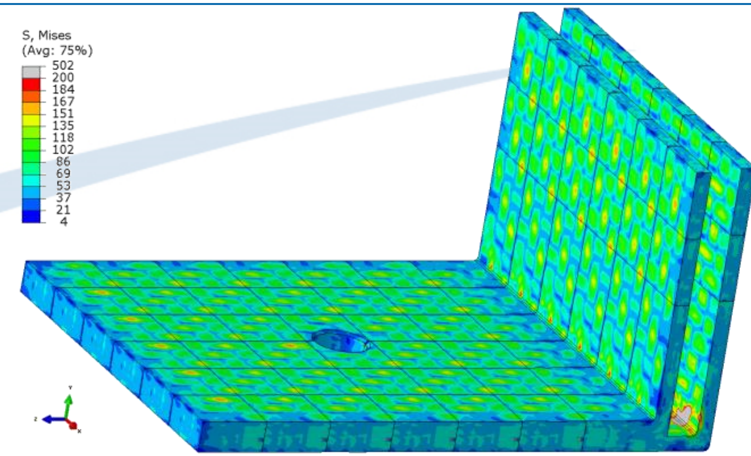
F-Shape

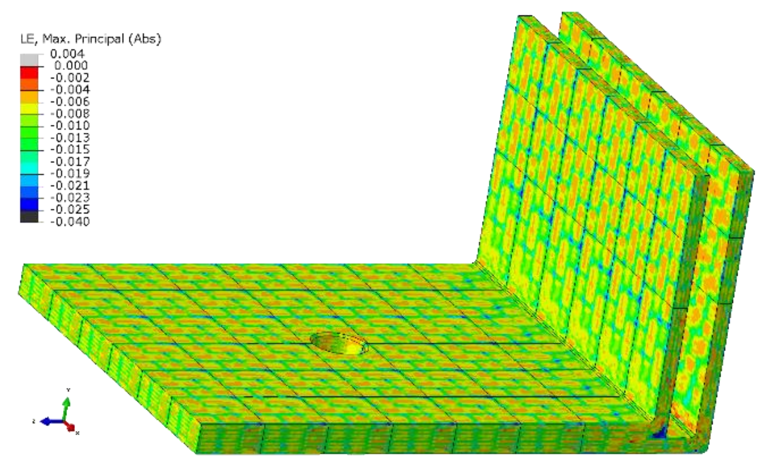
Curing and Cooling

Curing and Cooling is modelled to take production induced stresses into account



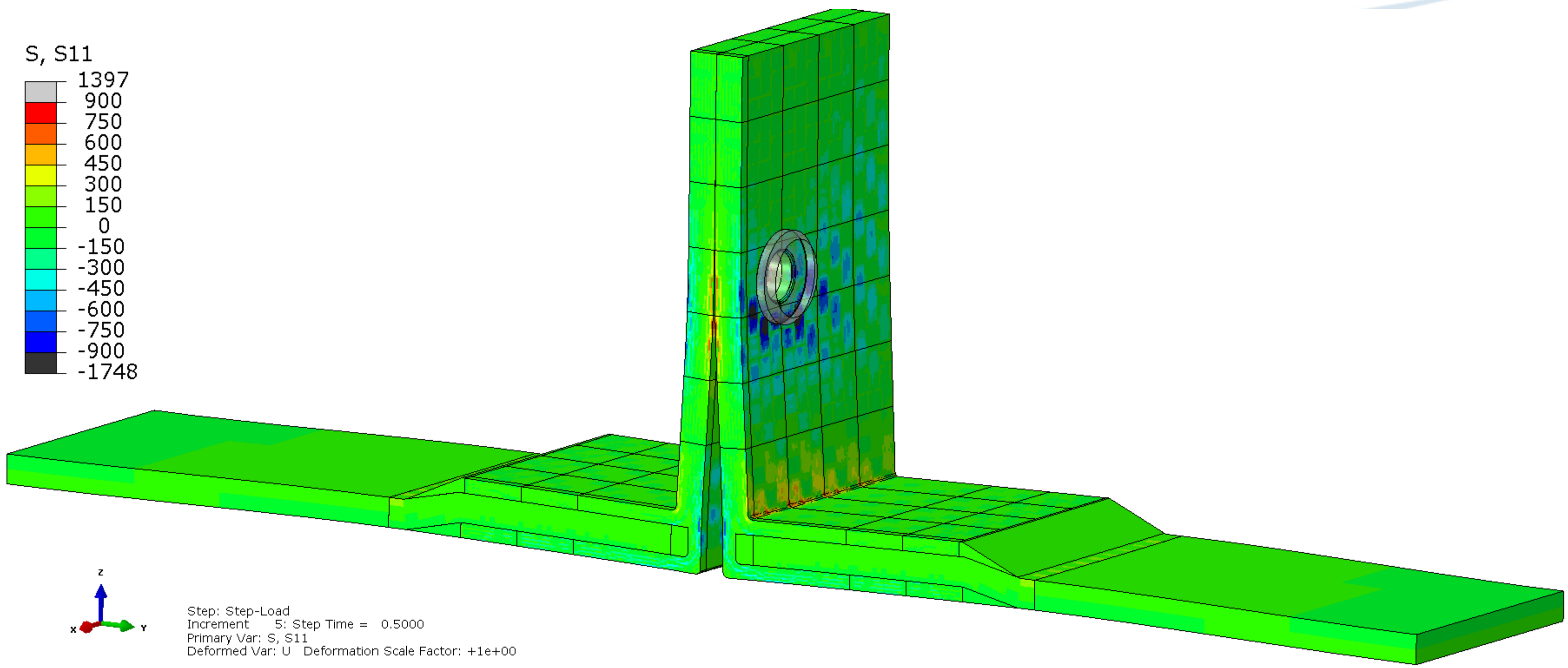
Spring Forward





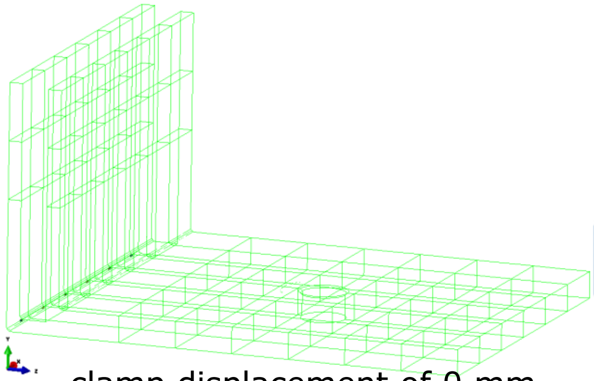
F-shape

Pull-through

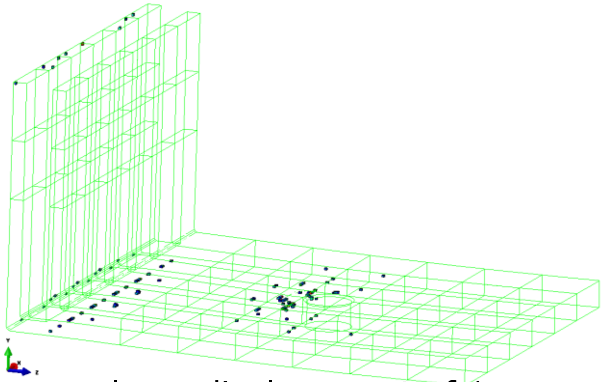


F-shape

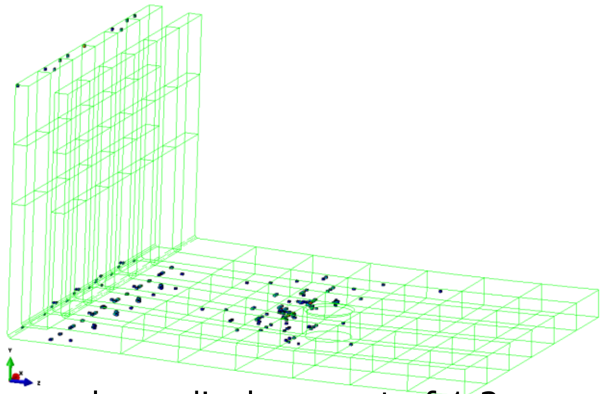
Failure indicators



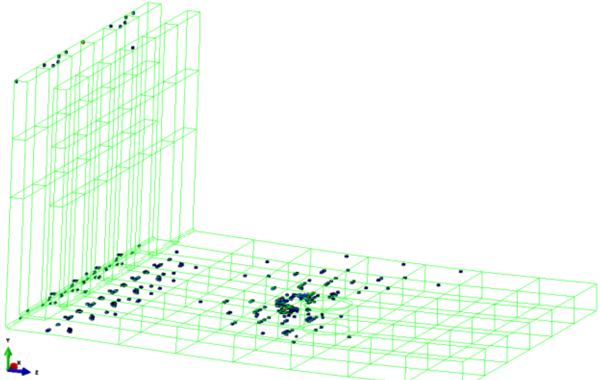
clamp displacement of 0 mm



clamp displacement of 1 mm



clamp displacement of 1.3 mm



clamp displacement of 1.6 mm

Summary

- Processing/Product Models:
  - Weaving simulations
  - Structural stiffness and strenght
- All model input is known in the design stage:
  - Fiber and matrix properties
  - Process setttings
- Gives prediction of:
  - Springforward
  - Global stiffness
  - Local strains, stiffness
  - Onset of failure

Thank you for your attention!

Questions?

Thanks to:
Edwin, Harm, Martijn, Lisa, and our MapicC 3D partners