University of BRISTOL

Bristol Composites Institute

From CAD to defect free part:

Data-driven optimisation for zero defect consolidation of thick composites part

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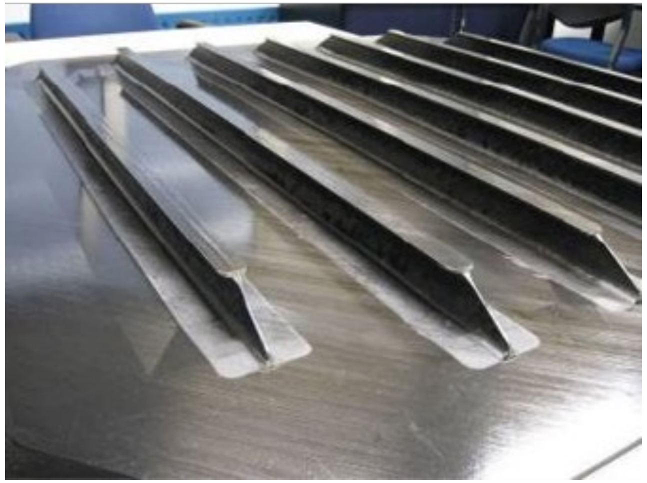
Process modelling of composites defects

- Manufacturability is a key concern in industry for composites applications with a focus on defects.
- One 'ideal' way is relying on process modelling to replace physical trail-and-error, however it is challenging, especially for thick, complex parts
  - Complex material behaviour in the cure/consolidation stage (multi-physics, nonlinearity, etc.)
  - Varied defects appearance (high-quality requirement for defects prediction)
  - Thickness deviation: tight dimensional tolerance for structures' assembly (aerospace - less than 0.25 mm)
  - Costly simulation using ply-by-ply modelling approach (in days - not possible for in-situ adjustment)
  - Time-consuming for model construction (From CAD file to FE model)

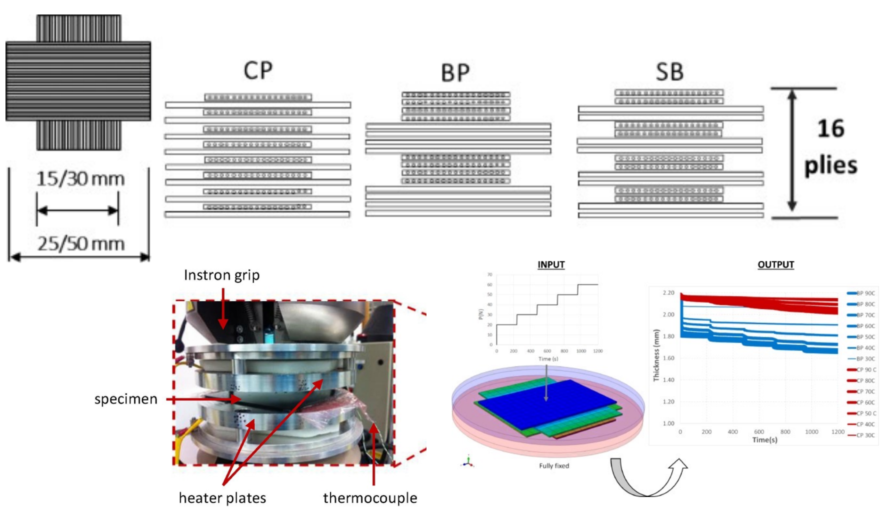


Composites stiffeners and skin

Composites fan blade

A 7 years' journey

1/



Belnoue, JP-H., et al. "A novel hyper-viscoelastic model for consolidation of toughened prepregs under processing conditions." *Mechanics of Materials* 97 (**2016**): 118-134.

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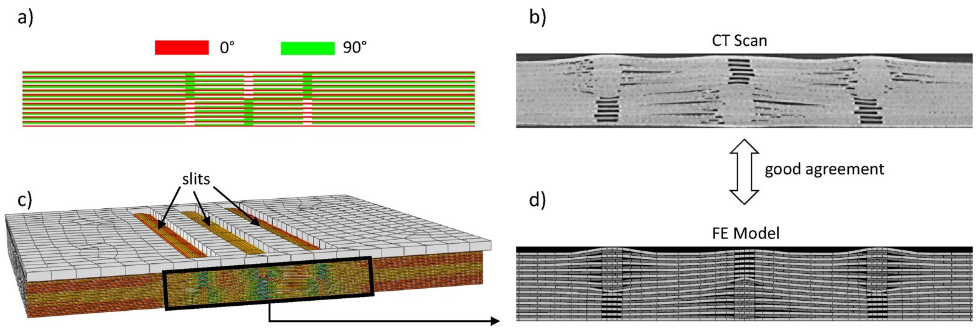

Belnoue, Jonathan P-H., et al. "Understanding and predicting defect formation in automated fibre placement pre-preg laminates." *Composites Part A: Applied Science and Manufacturing* 102 (**2017**): 196-206.

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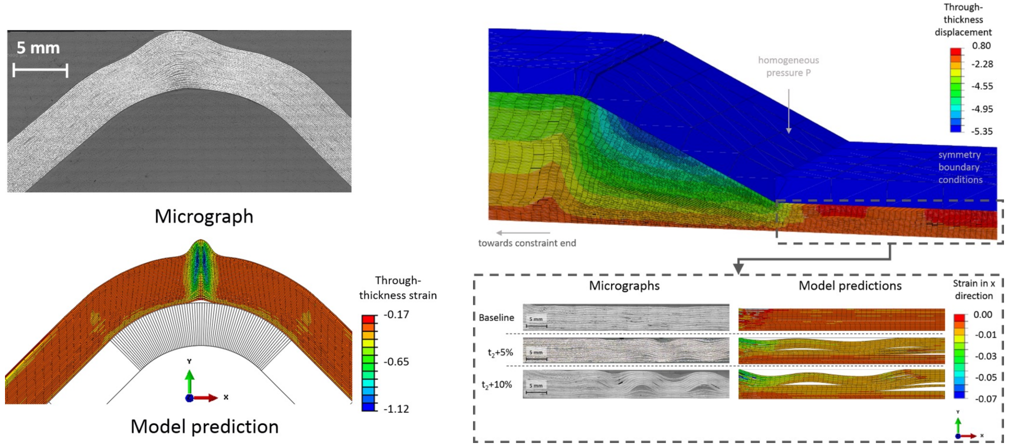

Belnoue, JP-H., et al. "Consolidation-driven defect generation in thick composite parts." *Journal of Manufacturing Science and Engineering* 140.7 (**2018**).

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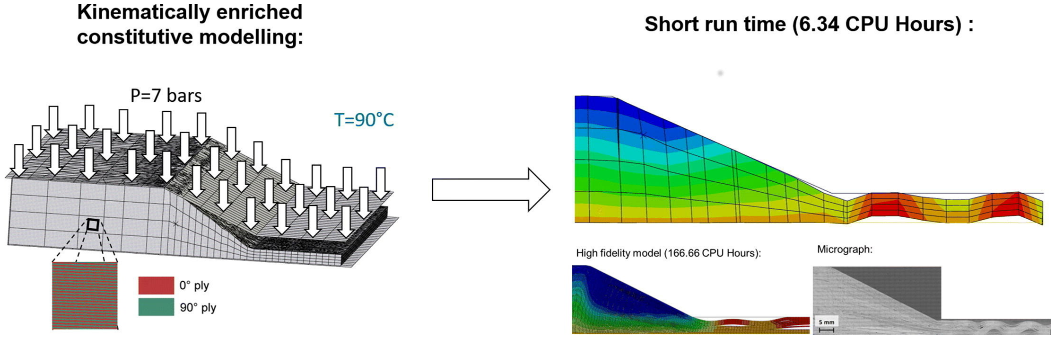


Belnoue, Jonathan P-H., and Stephen R. Hallett. "A rapid multi-scale design tool for the prediction of wrinkle defect formation in composite components." *Materials & Design* 187 (**2020**): 108388.

Schematic of overall workflow

Virtual Layup → **Virtual Autoclave** → **Virtual Inspection**

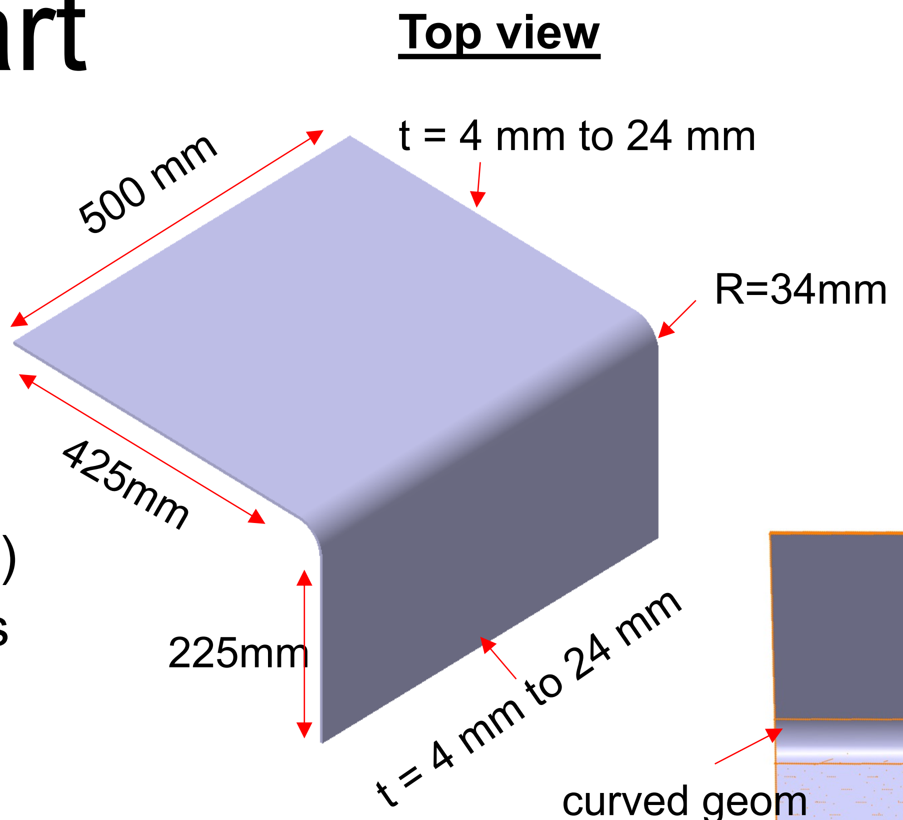
Virtual Layup
- Generate the 'As-layup' geometry
- From complex CAD geometry to homogeneous approach-based FE model

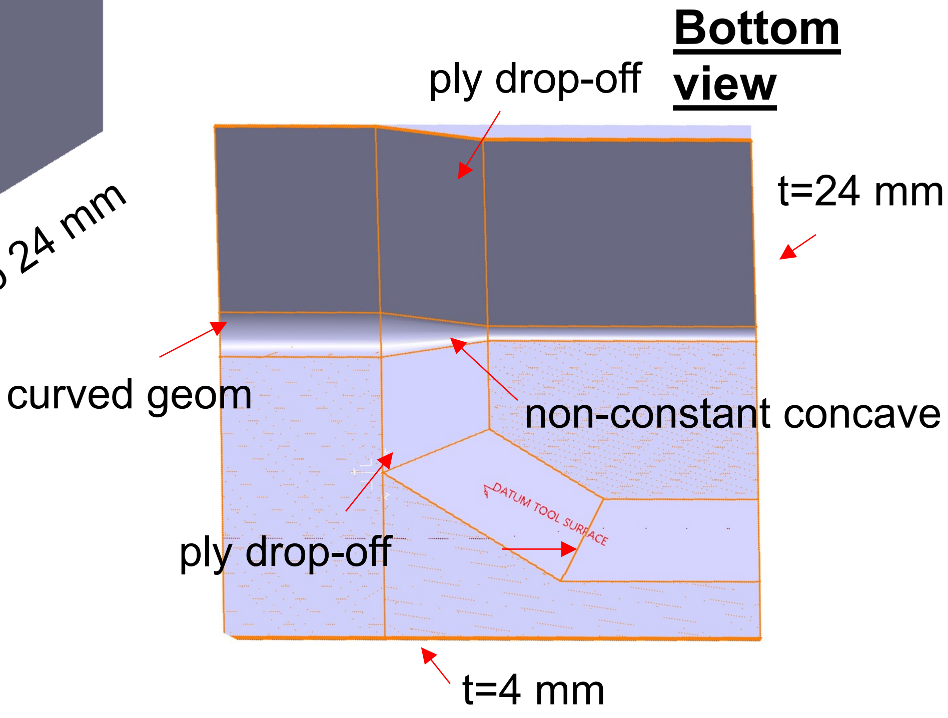
Virtual Autoclave
- Generate the 'As-manufactured' geometry
- Cure/consolidation simulation with designed cycle of the material

Virtual Inspection
- Generate the 'Part quality' metric
- Post-processing of the result files to check the thickness tolerance and volume fraction

The selection of part

- Provided by NCC
- Industrial dimension:
  500 x 425 x 225 mm
- Complex geometry
  - Curved composites- L-shaped
  - Very thick part (24 mm - 130 plies)
  - Ply drop-offs in different directions
- Type of material
  - Toughened thermoset prepreg- IMA/M21
  - Ply thickness: 0.22 mm (uncured), 0.185 mm (cured)
- Stacking sequence: $[0[45/-45/0/90]_{16}]_s$

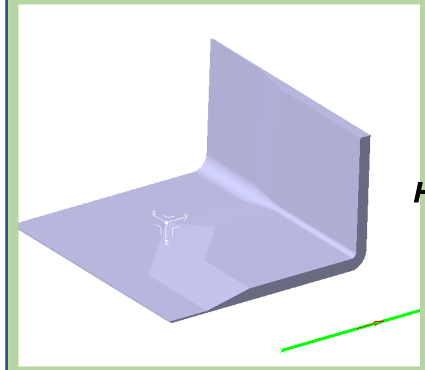




Package 1: Virtual Layup (pre-processor)

Inputs

CAD definition of 3D desired part (*CATPart)

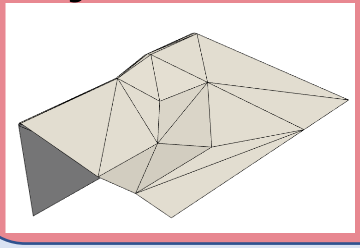


- Nodes/elements info
- Ply thickness
- Layup info of ply

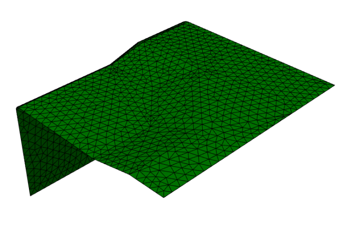
Hdf5 file

Python processor

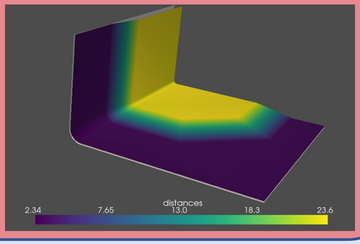
layer surface generation



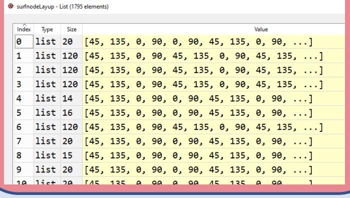
Remesh bottom surface



Distance calculation between layers



Layup on ply


surfnodeLayup - List (1795 elements)

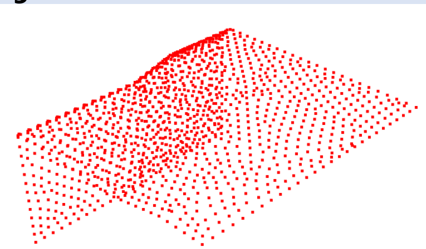
Index	Type	Size	Value
0	list	20	[45, 135, 0, 90, 0, 90, 45, 135, 0, 90, ...]
1	list	120	[45, 135, 0, 90, 45, 135, 0, 90, 45, 135, ...]
2	list	120	[45, 135, 0, 90, 45, 135, 0, 90, 45, 135, ...]
3	list	120	[45, 135, 0, 90, 45, 135, 0, 90, 45, 135, ...]
4	list	14	[45, 135, 0, 90, 0, 90, 45, 135, 0, 90, ...]
5	list	16	[45, 135, 0, 90, 0, 90, 45, 135, 0, 90, ...]
6	list	120	[45, 135, 0, 90, 45, 135, 0, 90, 45, 135, ...]
7	list	20	[45, 135, 0, 90, 0, 90, 45, 135, 0, 90, ...]
8	list	15	[45, 135, 0, 90, 0, 90, 45, 135, 0, 90, ...]
9	list	20	[45, 135, 0, 90, 0, 90, 45, 135, 0, 90, ...]
10	list	20	[45, 135, 0, 90, 0, 90, 45, 135, 0, 90, ...]

Layup mapping

Nodes

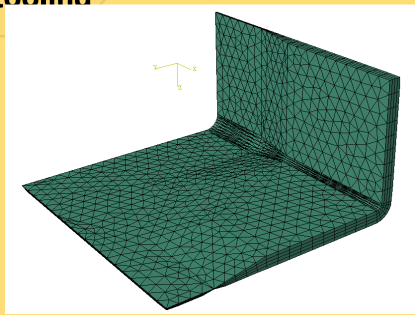
Thickness mapping

(uncured state to cured state update)



Outputs

3D FE uncured part with layup info and tooling



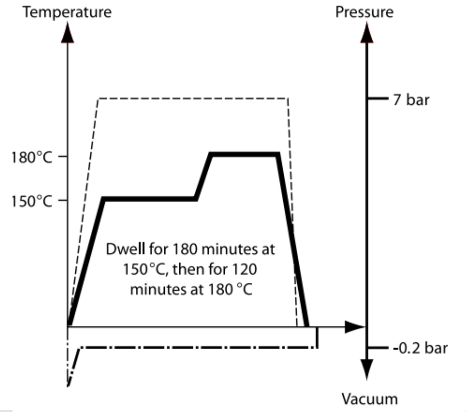
- Key functions:
  - Multi-ply reconstructed in Python
  - Mesh refinement
  - Update the ply from cured to uncured (surface distance calculation)
  - Layup information collection
  - Feature detection/projection

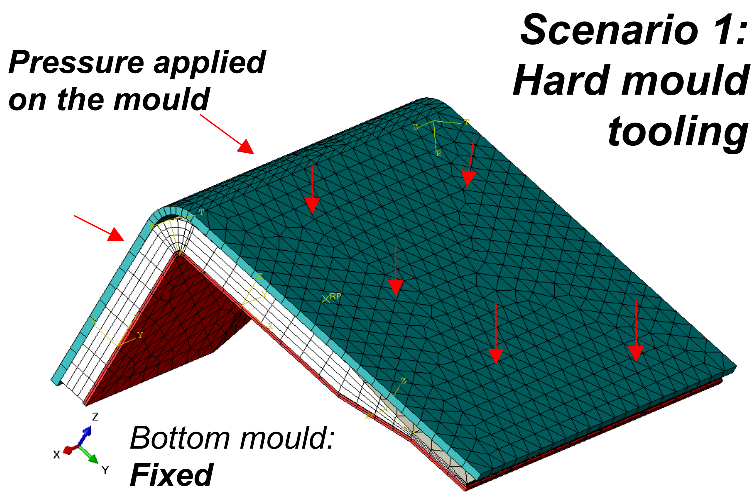
Complete in around 3 mins

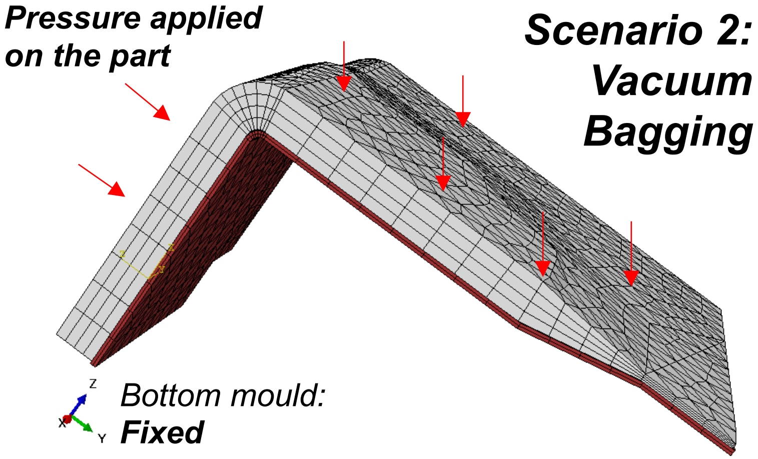
Package 2: Virtual Autoclave

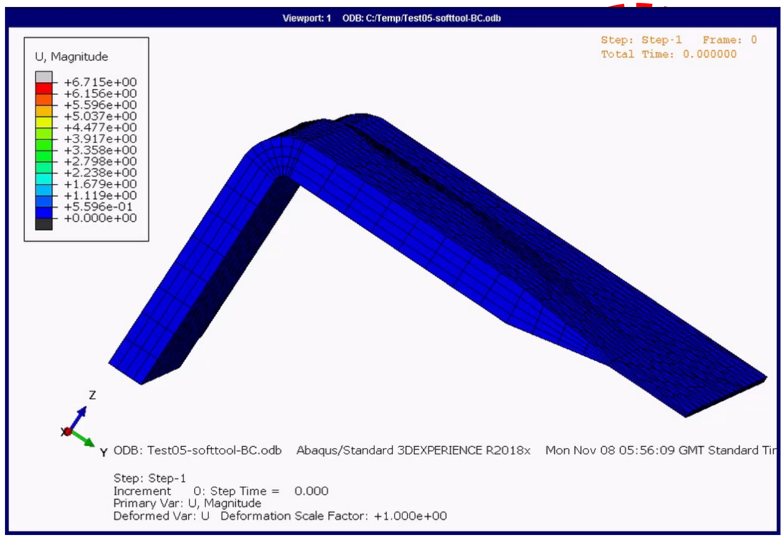
FE Model

- Boundary conditions and cure cycle set as reality
- Material behaviour defined by UMAT [2]
- Homogeneous modelling approach - 1000 times faster - lays the base for optimization [1]
- High fidelity material model in consolidation/cure simulation [2]







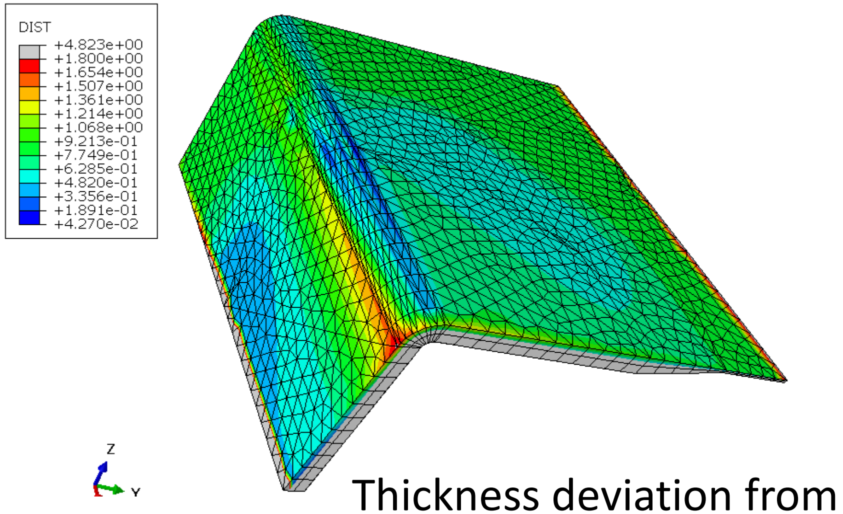


The output of the Virtual Autoclave with a representative result from vacuum bagging

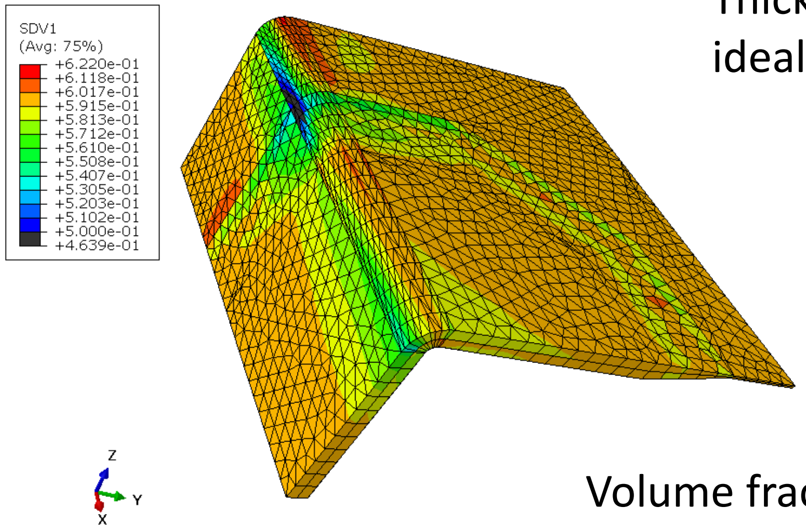
3.5 hrs simulation time

Package 3: Visual Inspection (post-processor)

- *Check the defects (wrinkle) formation output*
- *Compare the predicted thickness with desired*
- Quality indicators
  - Average thickness deviation
  - Maximum thickness deviation
  - Fibre volume fraction
- Flag for poor quality
  - Thickness deviation > 1 mm
  - Fibre volume fraction < 55%
- Achieved automatically through a dedicated python script



Thickness deviation from ideal design

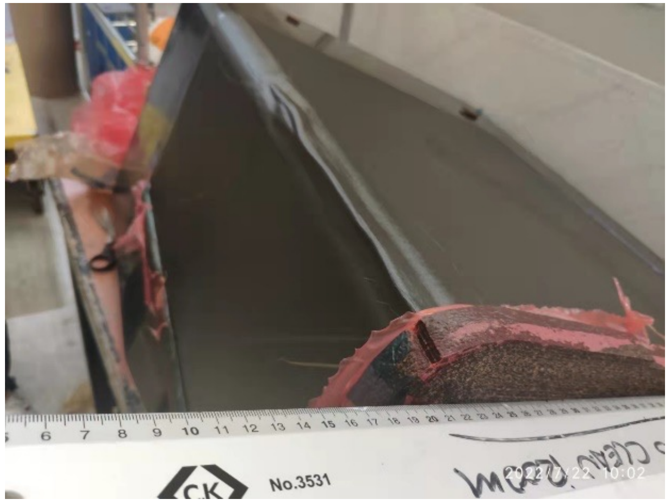


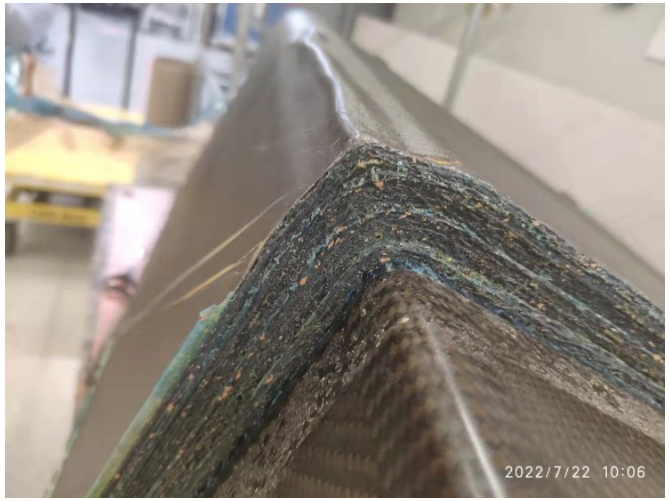
Volume fraction distribution

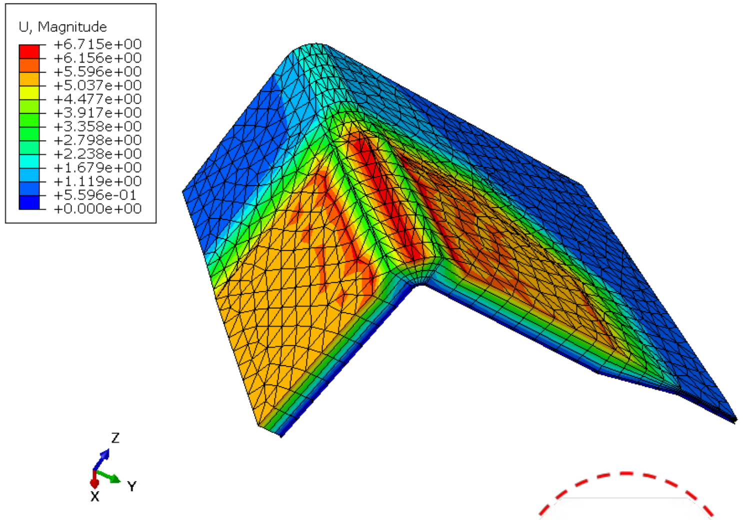
Package 4: Experimental validation

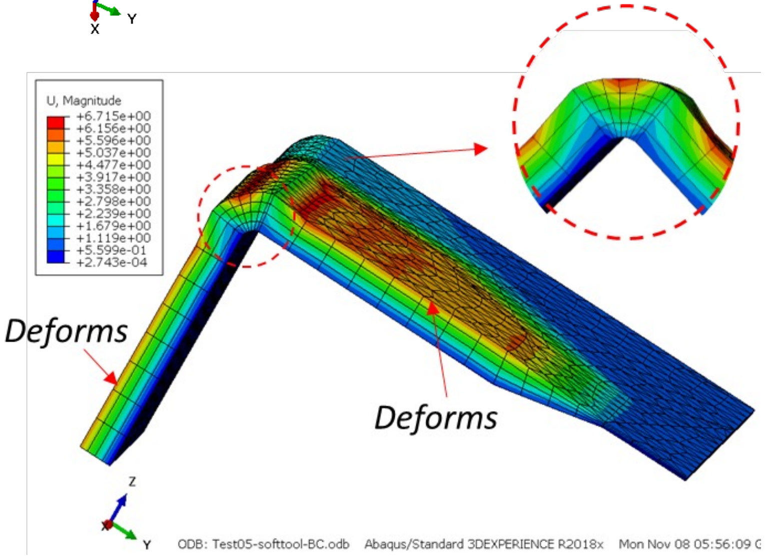
- Physical demonstrator

Package 4: Experimental validation









Comparison between the physical part and model prediction in defect generation