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TexGen Workshop

Dr Louise Brown

https://github.com/louisepb/NCCWorkshop2019

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General Overview of the TexGen Project

TexGen Geometric Textile Modelling Software

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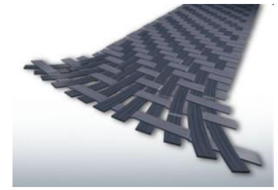
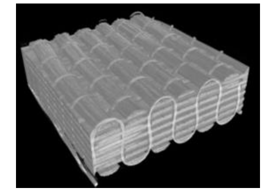
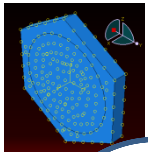


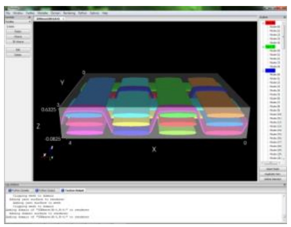


Fibre/Micro-Scale

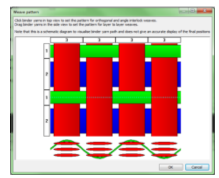


Micro-scale FEA simulations or analytical methods determine yarn properties

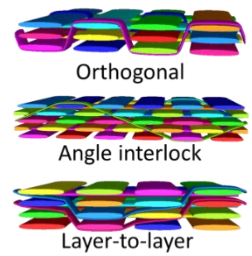
Unit Cell/Meso-Scale

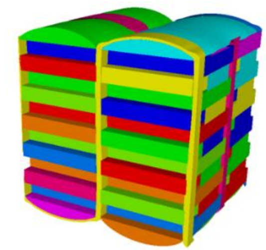


Generate textile geometry using TexGen GUI or script

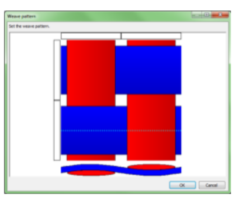


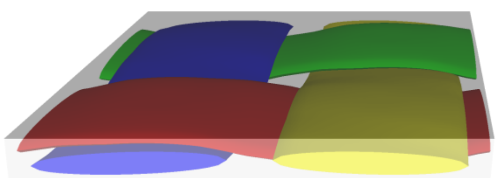
3D wizard generates idealised 3D textiles



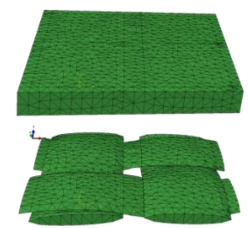


Refinement of orthogonal weave to simulate compaction



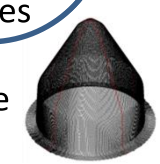


Automatically generate 2D and 2D sheared textiles



Generate mesh and input files for FEA or CFD to predict material properties

Composite material properties extracted from meso-scale predictions are used to model structural components



Component/Macro-Scale

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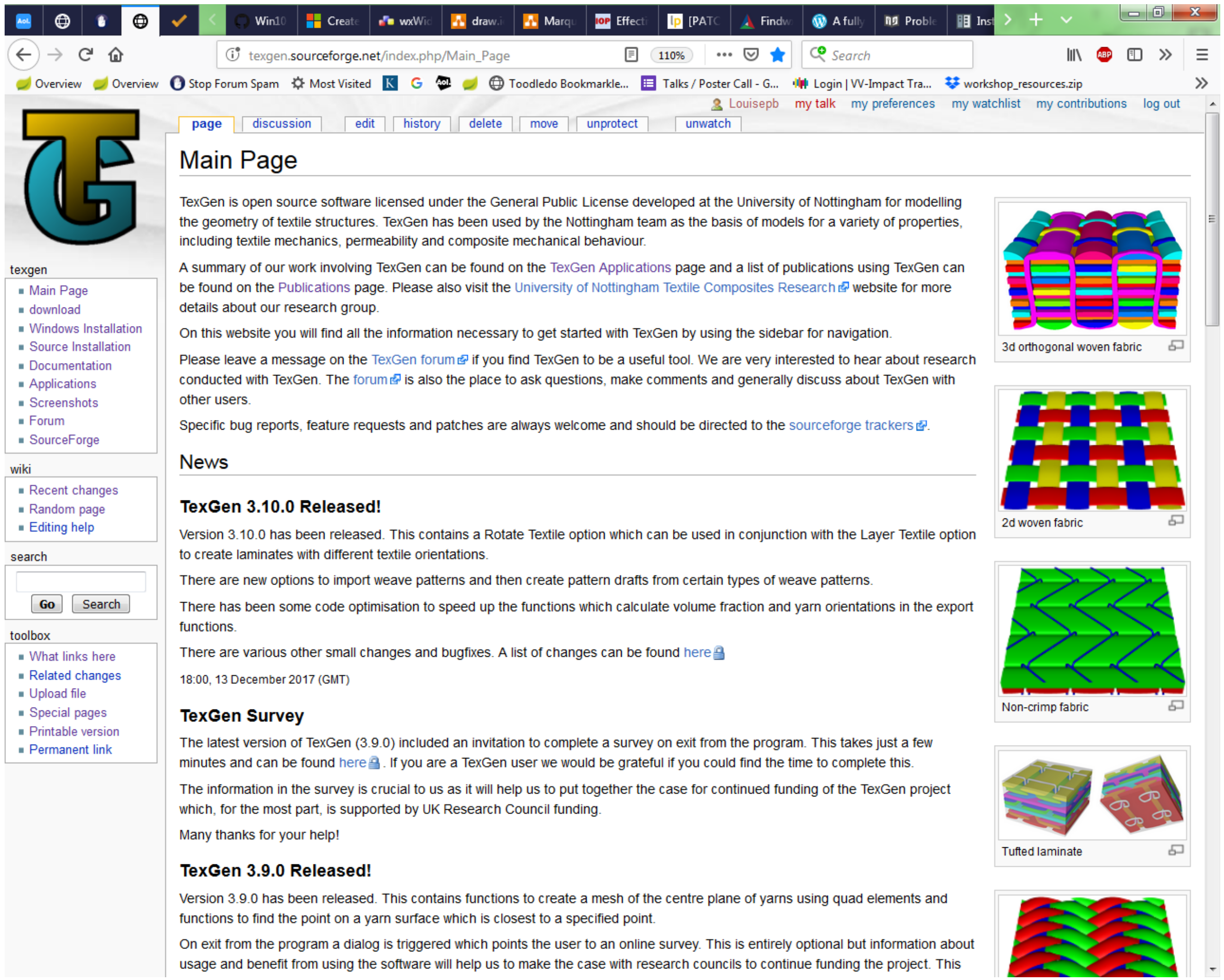
TexGen Webpage

www.texgen.sourceforge.net



texgen.sourceforge.net/index.php/Main_Page

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Main Page

TexGen is open source software licensed under the General Public License developed at the University of Nottingham for modelling the geometry of textile structures. TexGen has been used by the Nottingham team as the basis of models for a variety of properties, including textile mechanics, permeability and composite mechanical behaviour.

A summary of our work involving TexGen can be found on the TexGen Applications page and a list of publications using TexGen can be found on the Publications page. Please also visit the University of Nottingham Textile Composites Research website for more details about our research group.

On this website you will find all the information necessary to get started with TexGen by using the sidebar for navigation.

Please leave a message on the TexGen forum if you find TexGen to be a useful tool. We are very interested to hear about research conducted with TexGen. The forum is also the place to ask questions, make comments and generally discuss about TexGen with other users.

Specific bug reports, feature requests and patches are always welcome and should be directed to the sourceforge trackers.

3d orthogonal woven fabric

2d woven fabric

Non-crimp fabric

Tufted laminate

News

TexGen 3.10.0 Released!

Version 3.10.0 has been released. This contains a Rotate Textile option which can be used in conjunction with the Layer Textile option to create laminates with different textile orientations.

There are new options to import weave patterns and then create pattern drafts from certain types of weave patterns.

There has been some code optimisation to speed up the functions which calculate volume fraction and yarn orientations in the export functions.

There are various other small changes and bugfixes. A list of changes can be found here

18:00, 13 December 2017 (GMT)

TexGen Survey

The latest version of TexGen (3.9.0) included an invitation to complete a survey on exit from the program. This takes just a few minutes and can be found here. If you are a TexGen user we would be grateful if you could find the time to complete this.

The information in the survey is crucial to us as it will help us to put together the case for continued funding of the TexGen project which, for the most part, is supported by UK Research Council funding.

Many thanks for your help!

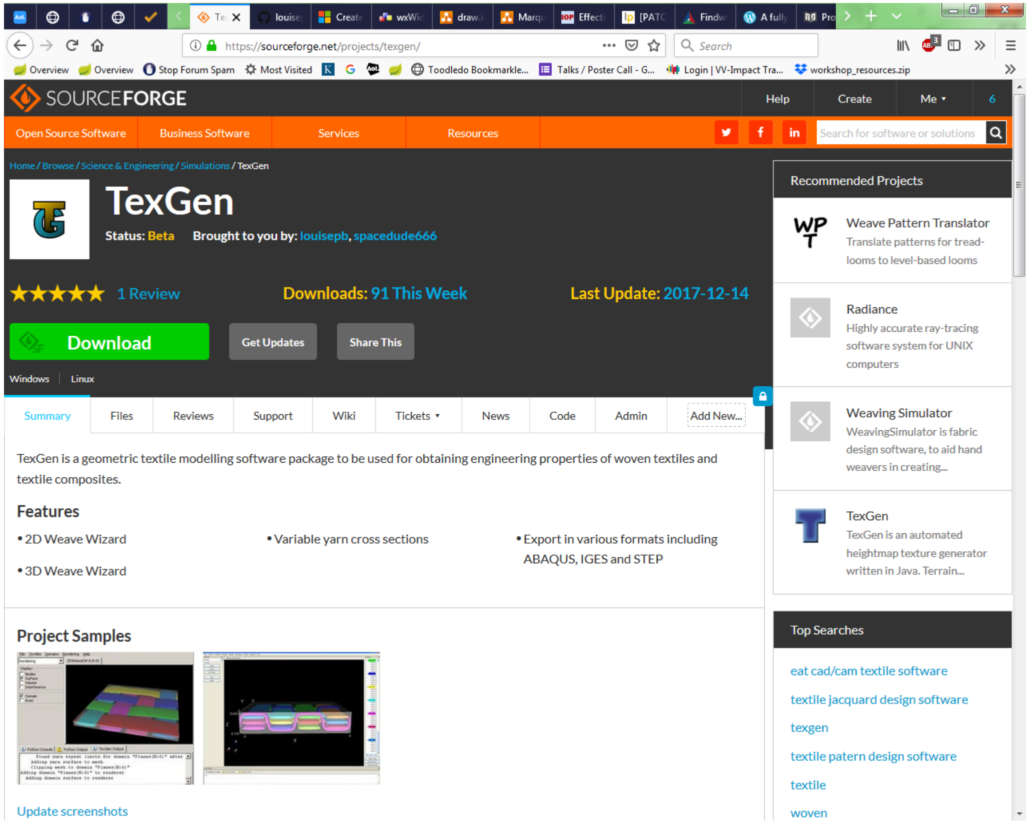
TexGen 3.9.0 Released!

Version 3.9.0 has been released. This contains functions to create a mesh of the centre plane of yarns using quad elements and functions to find the point on a yarn surface which is closest to a specified point.

On exit from the program a dialog is triggered which points the user to an online survey. This is entirely optional but information about usage and benefit from using the software will help us to make the case with research councils to continue funding the project. This

Download TexGen

https://sourceforge.net/projects/texgen/



Use the Files tab to access different versions and installation files with and without bundled Python

Code on GitHub

Source code is stored on GitHub

https://github.com/louisepb/TexGen

Instructions for compiling from source for both Windows and Linux are here:

http://texgen.sourceforge.net/index.php/Compiling_from_Source

Bugs/issues can be reported here:

https://github.com/louisepb/TexGen/issues

Sample scripts are here:

https://github.com/louisepb/TexGenScripts

TexGen Forum

Queries about TexGen can be directed via the TexGen forum
http://texgen.sourceforge.net/phpBB3/index.php

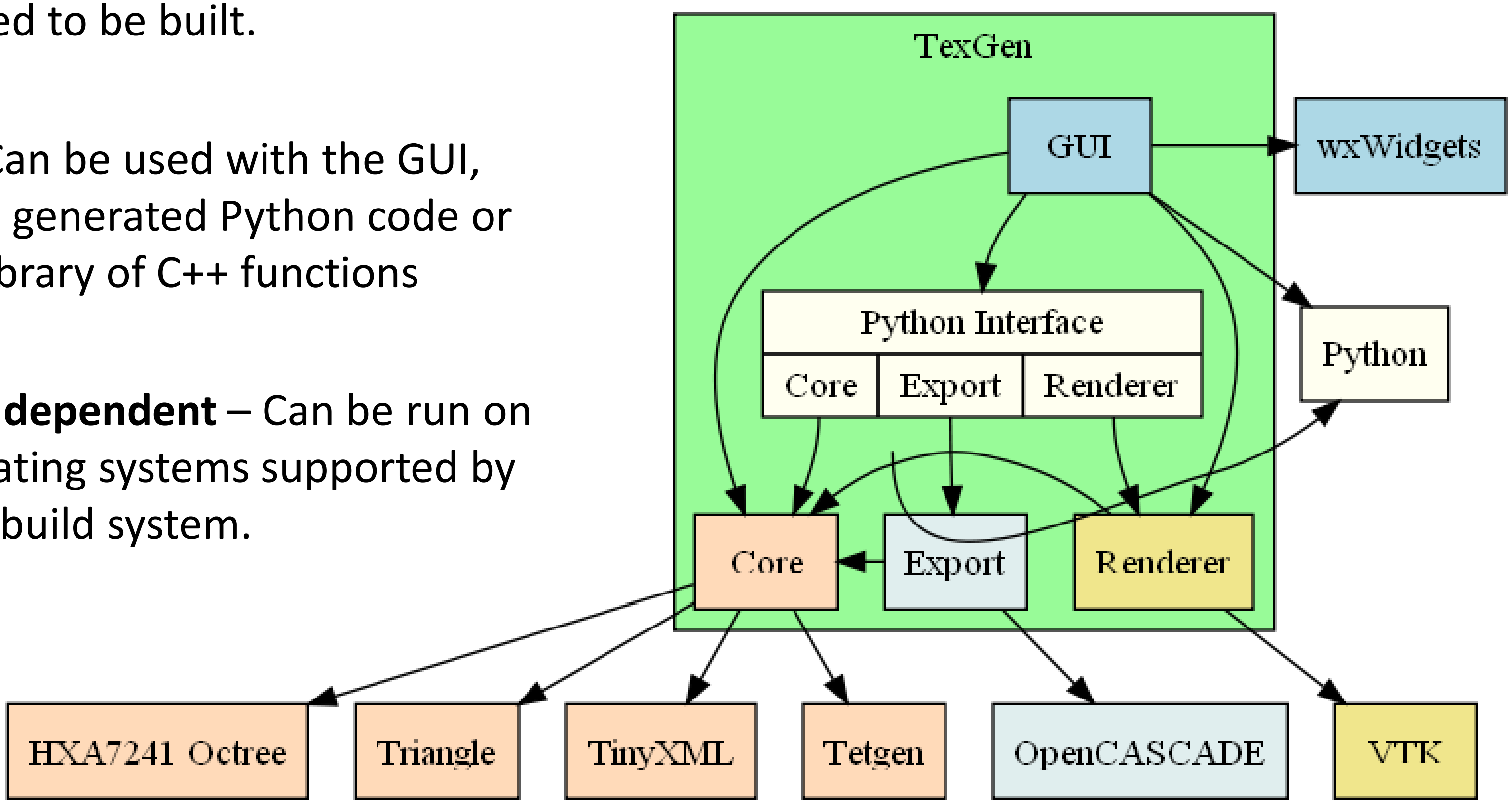
This is also a useful source of information and gives a record of queries and discussion by other TexGen users

Implementation

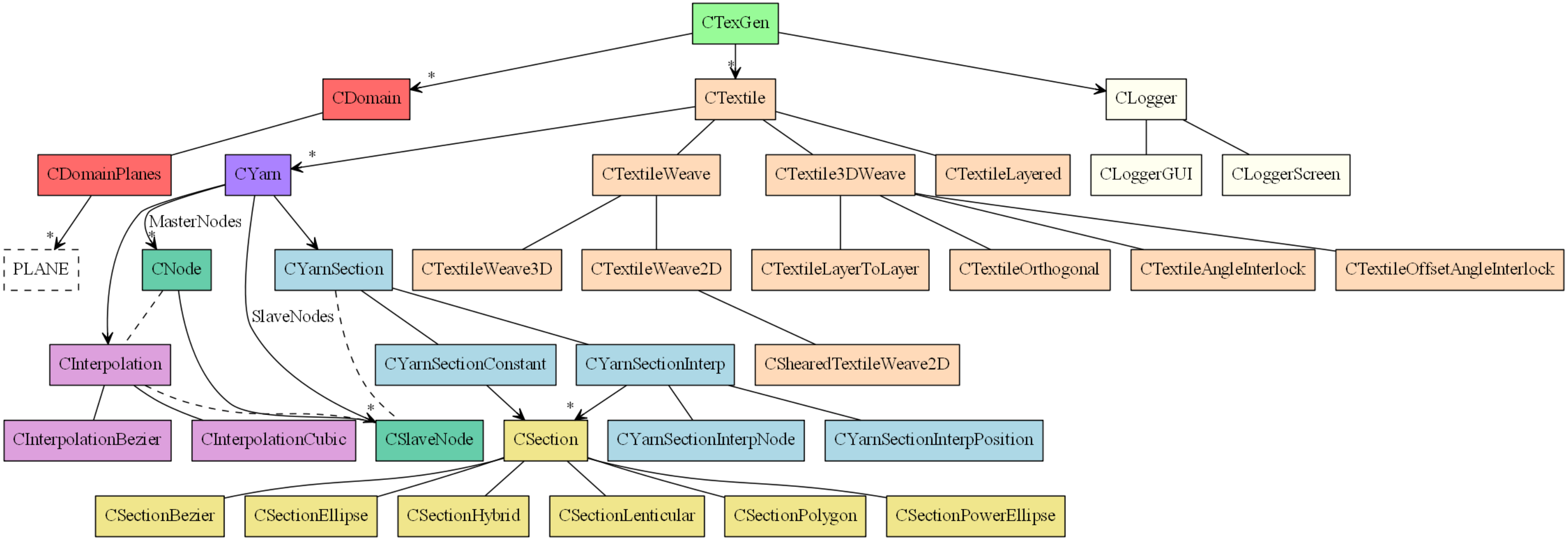
Modular - Core functionality is in the core module, graphics are in a renderer module; if not using visualisation, the renderer doesn't need to be built.

Flexible – Can be used with the GUI, using SWIG generated Python code or used as a library of C++ functions

Platform independent – Can be run on most operating systems supported by the Cmake build system.



TexGen Class Hierarchy



TexGen Use Cases

Advanced Geometry Modelling of 3D Woven Reinforcements in Polymer Composites: Processing and Performance Analysis

X. Zeng, L.P. Brown, A. Endruweit, A.C. Long

X Zeng, L P Brown, A Endruweit, A C Long. "Advanced geometry modeling for 3D woven fabrics in composites processing and performance analysis", Proc. 4th World Conf. on 3D Fabrics & their Applications, Aachen, Germany, Sept 2012.

Geometrical modelling

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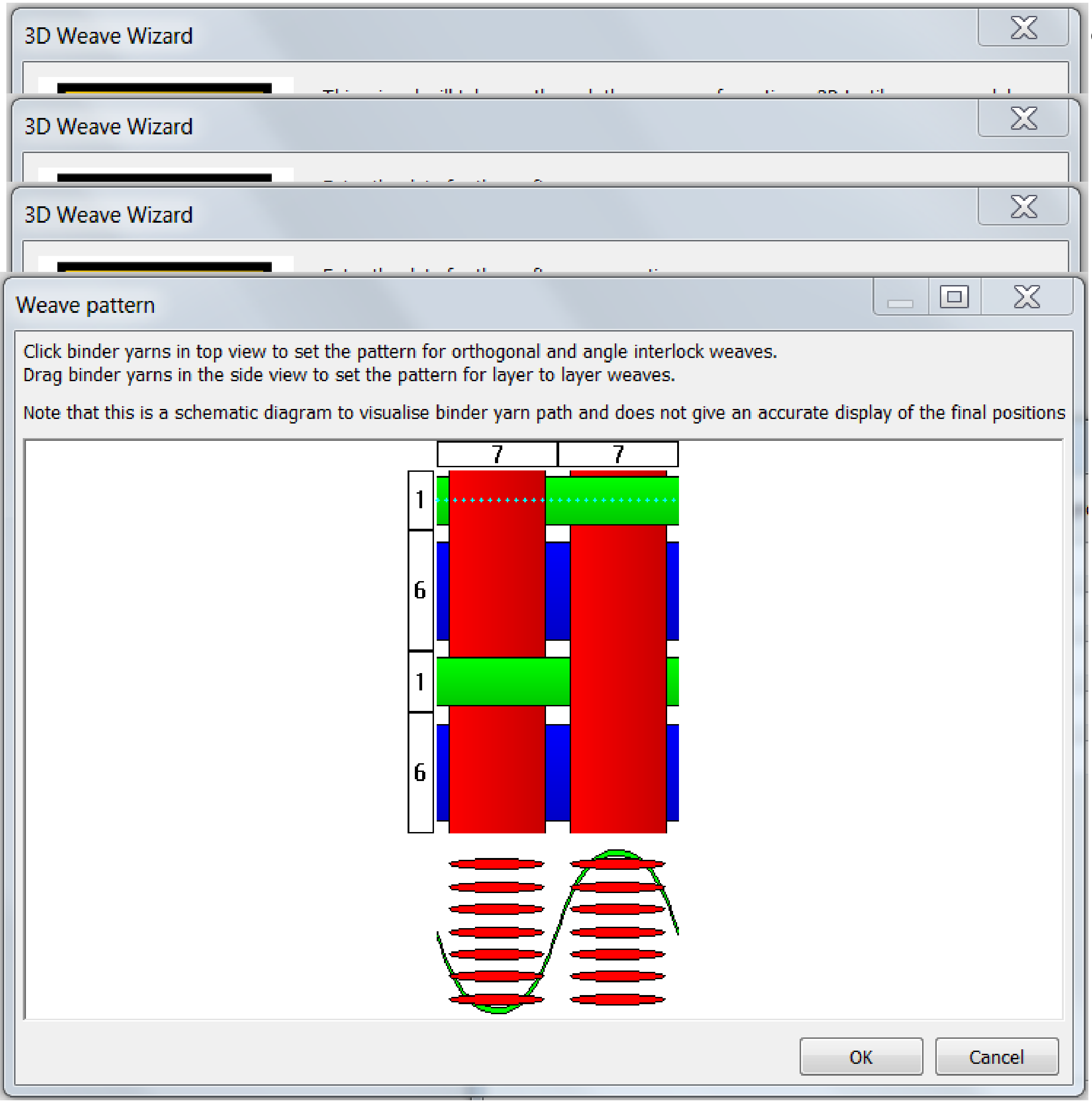
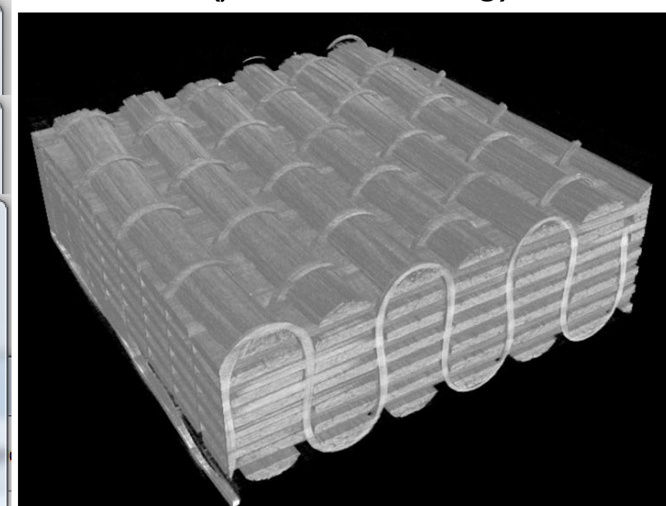
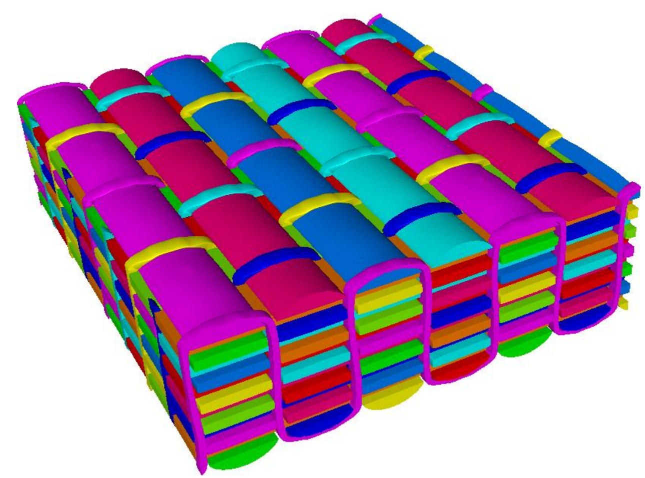


acquisition of detailed geometry data (μ-CT scanning)



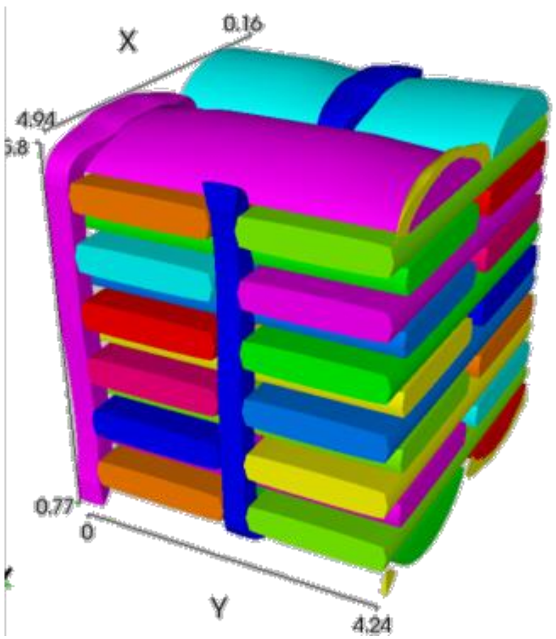
generation of geometrical model in TexGen



Fabric permeability

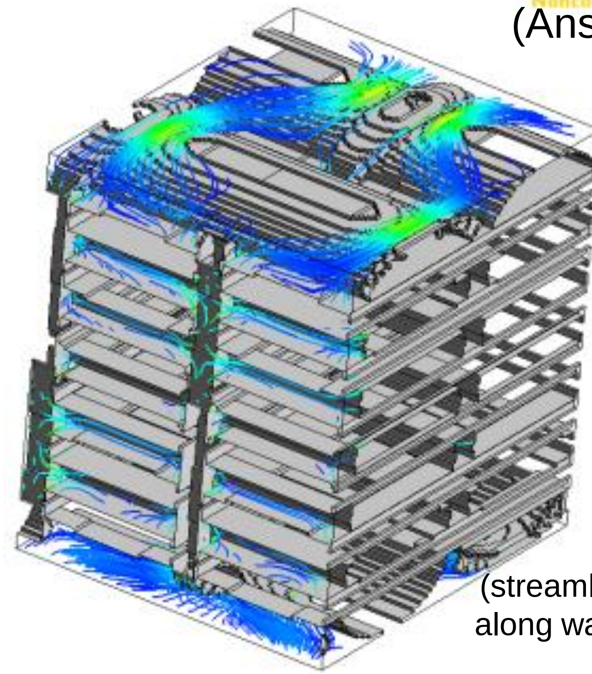
Impregnating resin flow in composites processing is described by homogenisation of local flow through pore spaces in the textile unit cell

TexGen unit cell model



generation of voxel mesh

CFD simulation of steady-state Stokes flow (Ansys CFX)



(streamlines for flow along warp direction)

Determine in-plane and through-thickness permeabilities from prescribed pressure gradients and calculated average flow velocities

Geometry refinement

Increasingly accurate modelling of yarn geometries

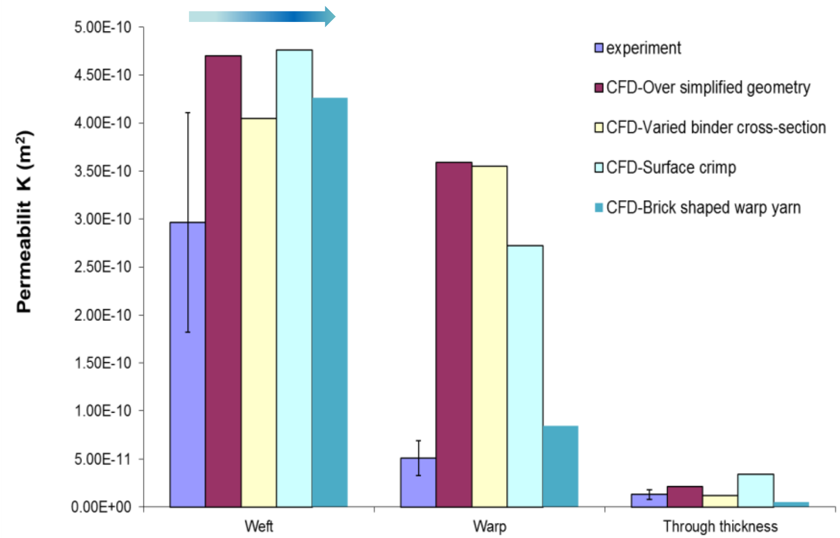
Experimental permeability data

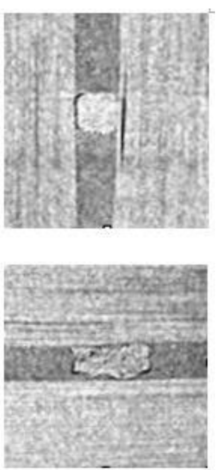
Simulation with straight yarns, constant elliptical cross-section

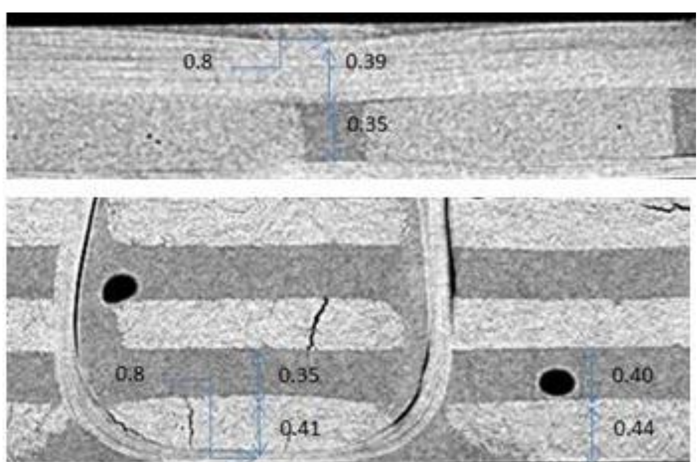
Varying binder cross-section, weft and warp yarns straight, constant cross-section

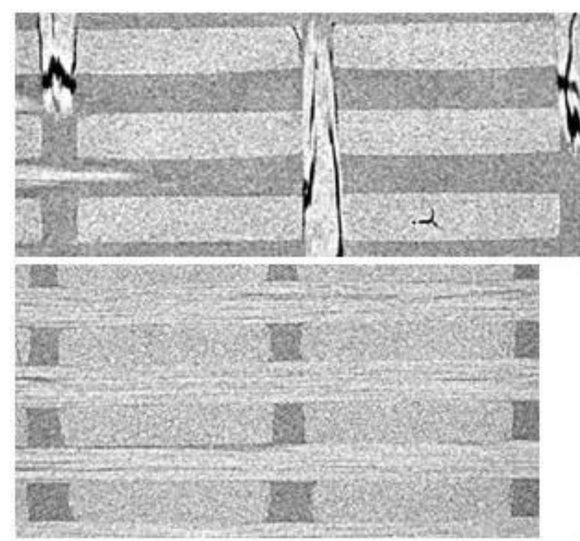
Deformation of weft yarns on fabric surface

Yarn cross-sections ‘more rectangular’ in warp direction than in weft direction



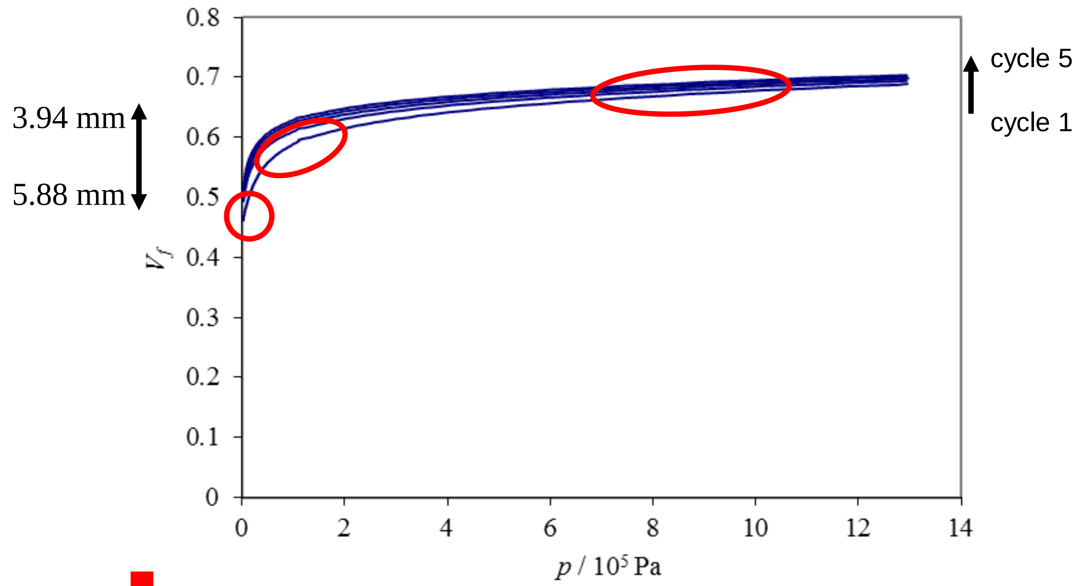


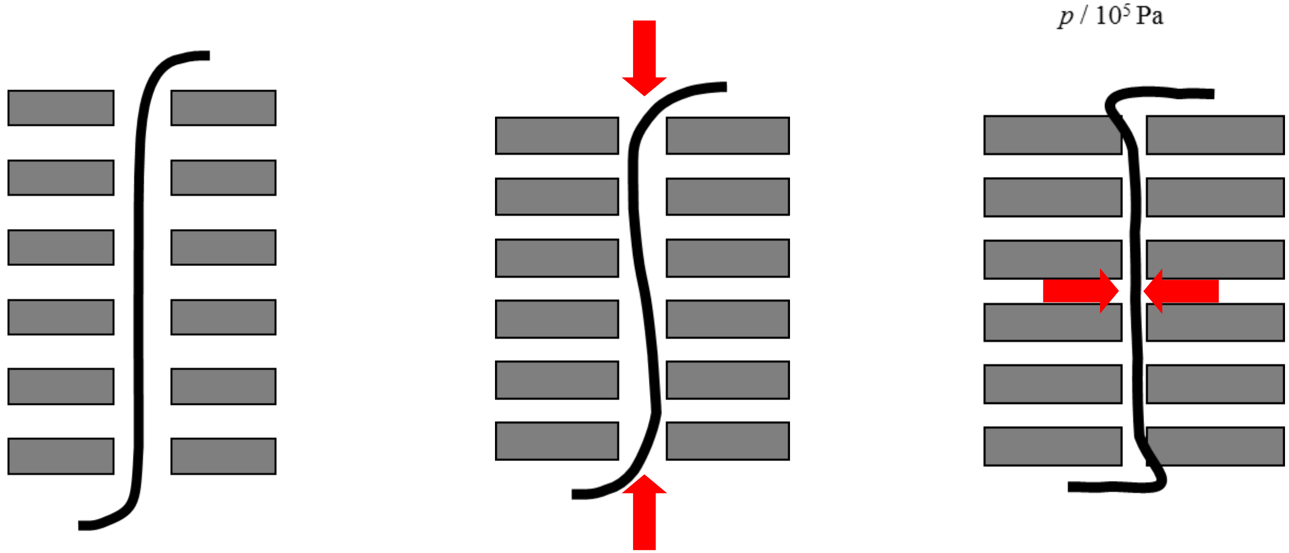




Compression modelling

Quasi-static compression (5 mm/min) between flat parallel plates,
1 fabric layer





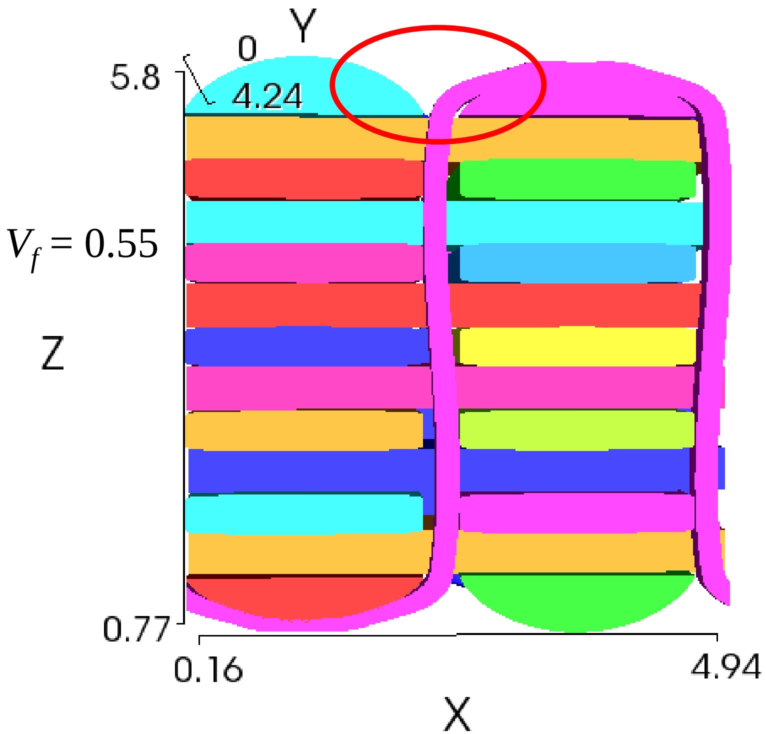
binder “buckling”

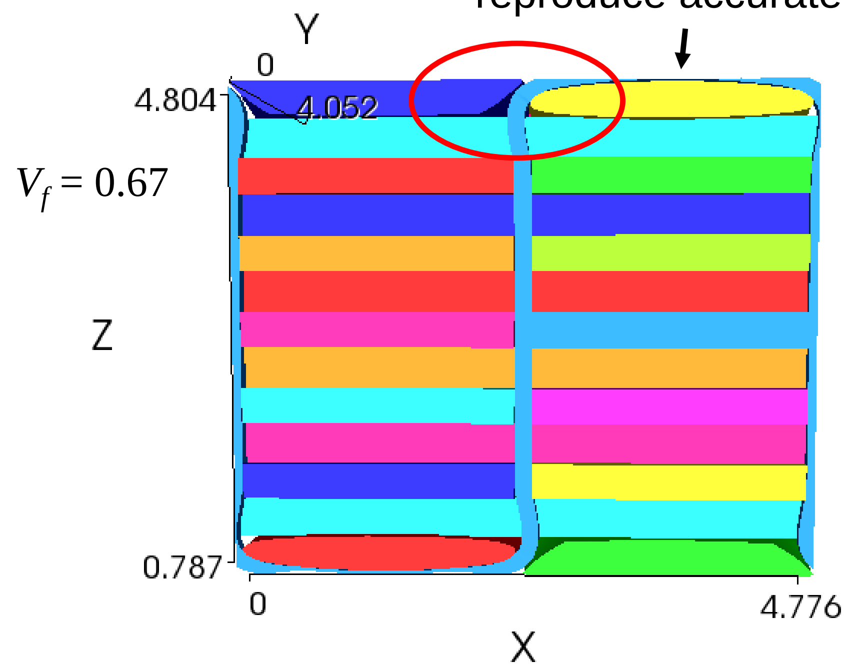
yarn flattening, widening

Compression modelling

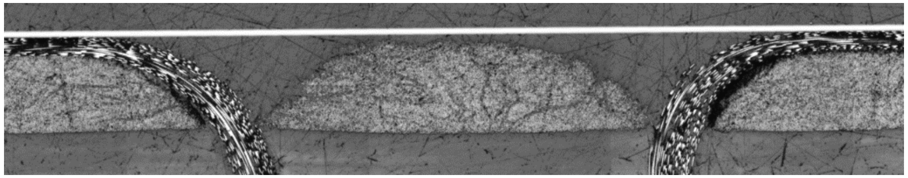
Geometry modelling of fabric at different compaction levels

details of complex deformation difficult to reproduce accurately !

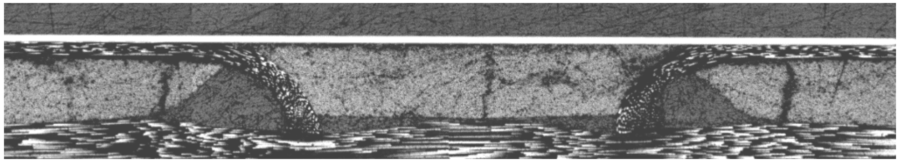




Experimental geometry analysis: top layer of weft yarns on fabric surface

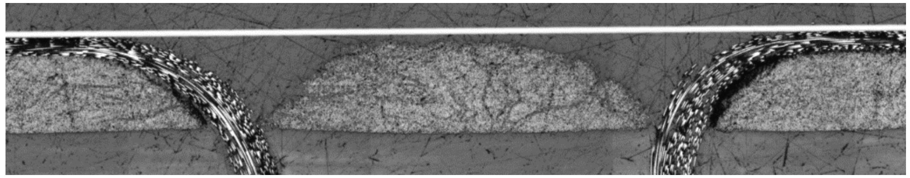


$V_f = 0.55$, $h = 5$ mm



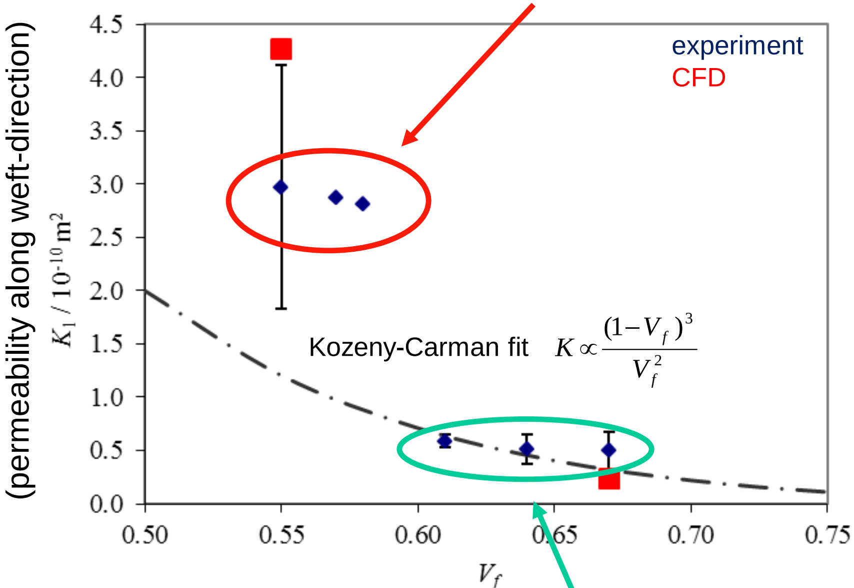
$V_f = 0.65$, $h = 4.2$ mm

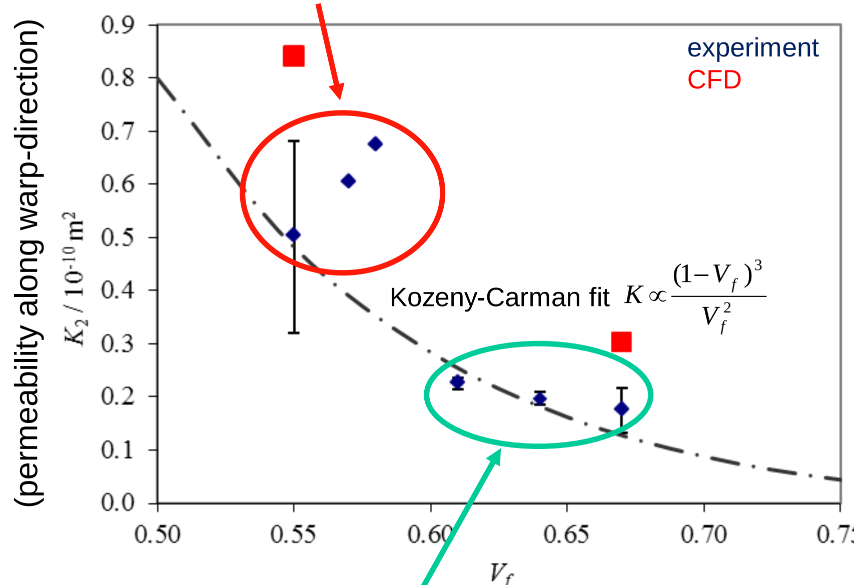
Compressed permeability

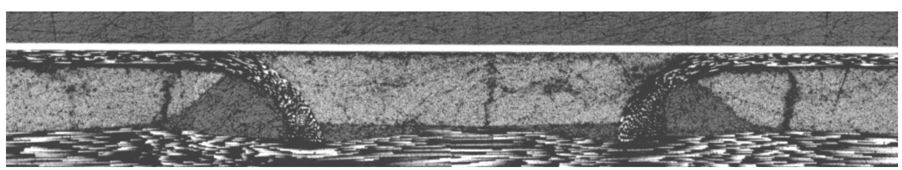


top layer of weft yarns on fabric surface

$V_f = 0.55$







$V_f = 0.65$

Discontinuity in K_1 is related to change in binder configuration on fabric surface; not described by analytical permeability models, requires numerical analysis

Composite mechanical properties

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Moulding of composite plaques by vacuum-driven RTM:

- 1 fabric layer
- Gurit PRIME 20LV epoxy infusion system

h = 5 mm, V_f = 0.55

Tensile testing according to European Standard EN ISO 527-4:1997

composite was tested in warp- and weft-direction

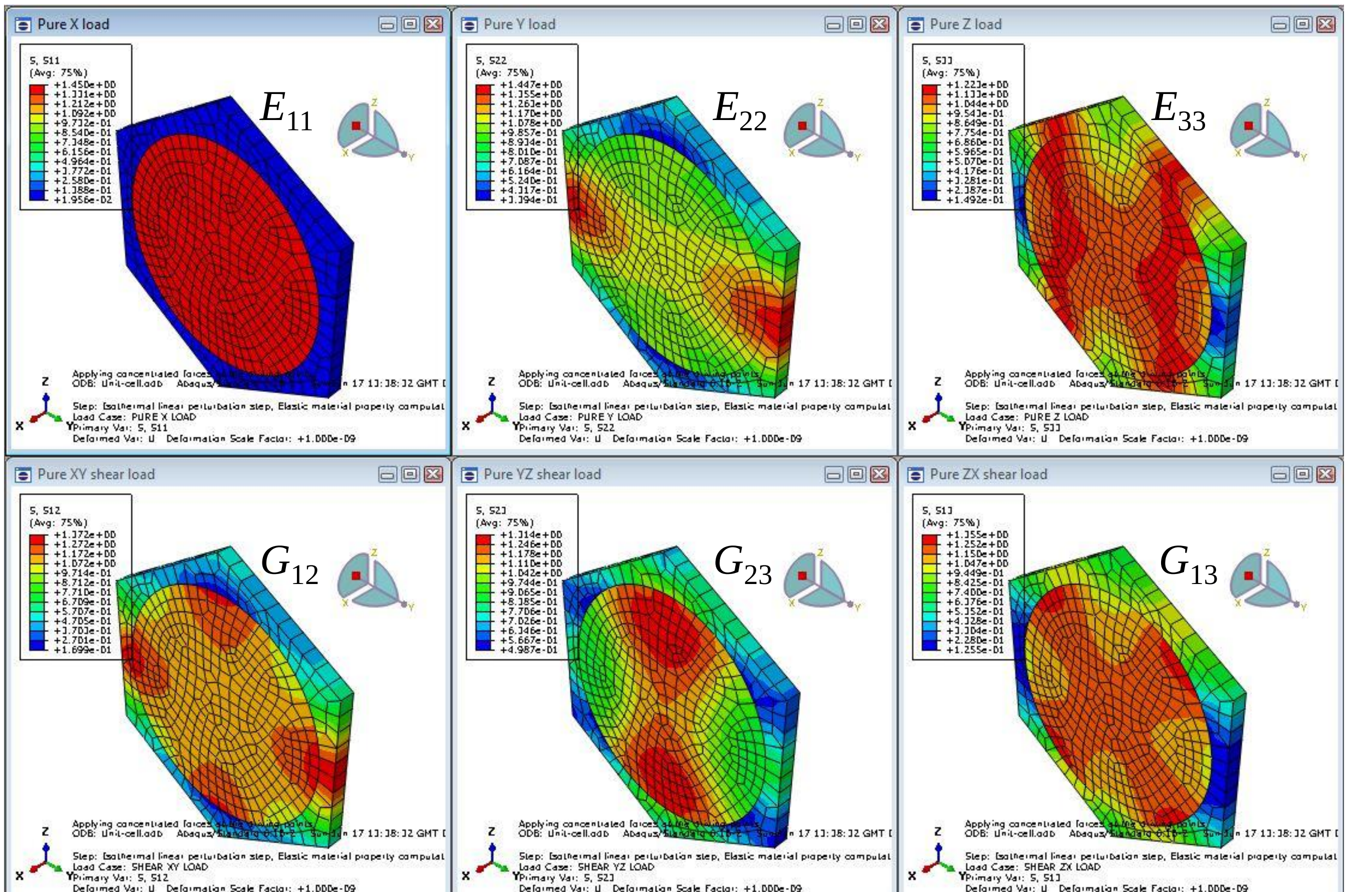
Nominal material data for numerical analysis

	E / GPa	Tensile strength / MPa	Tensile failure strain / %	Interlaminar shear strength / MPa
Cured resin	3.5	73	3.5	47
Fibre: Toray T300	230	3450	1.5	-

Yarn mechanical analysis

Finite element analysis for calculation of elastic properties for composite (impregnated yarns), assuming hexagonal packing of filaments:

six load cases of a single filament (+ resin) unit cell model



(ABAQUS)

alternative: micromechanics equations (Chamis)

Yarn mechanical analysis

Properties of impregnated yarn, derived from FE analysis, fibre Torayca T300

V_f = 0.66 in yarn, corresponding to V_f = 0.55 in unit cell

E_{11}	E_{22}, E_{33}	G_{12}, G_{13}	G_{23}	ν_{12}, ν_{13}	ν_{23}	F_{11}	F_{22}	F_{12}
152.6 GPa	8.15 GPa	3.02 GPa	2.9 GPa	0.3	0.345	2289 MPa	69.6 MPa	47 MPa
						from fibre failure strain	resin tensile strength	ILSS

Failure model (Ruijter): $E = E_0 \max(P, 0.001)$

longitudinal: brittle failure (fibres)

$$P = \begin{cases} 1, & D_1 \le 1 \\ 0.001, & D_1 > 1 \end{cases}$$

transverse, shear:
gradual stiffness reduction (matrix)

$$P = 1 - \frac{1}{\exp(-c_1 D + c_2)}$$

$c_1 = 8$, $c_2 = 13$ (empirical)

longitudinal:
maximum stress

$$D_1 = \max\left(\frac{\sigma_{11}}{F_{11}^t}, -\frac{\sigma_{11}}{F_{11}^c}\right)$$

shear:
partial distortion energy

$$D_2 = \frac{\sqrt{\sigma_{12}^2 + \sigma_{13}^2}}{F_{12}}$$

transverse: $$D_3 = \max\left(\frac{\max(\sigma_{22}, \sigma_{33})}{F_{22}^t}, -\frac{\min(\sigma_{22}, \sigma_{33})}{F_{22}^c}\right)$$

maximum principal stress

Ruijter, W., Analysis of mechanical properties of woven textile composite as functions of textile geometry, PhD dissertation, University of Nottingham, 2008

Unit cell mechanical analysis

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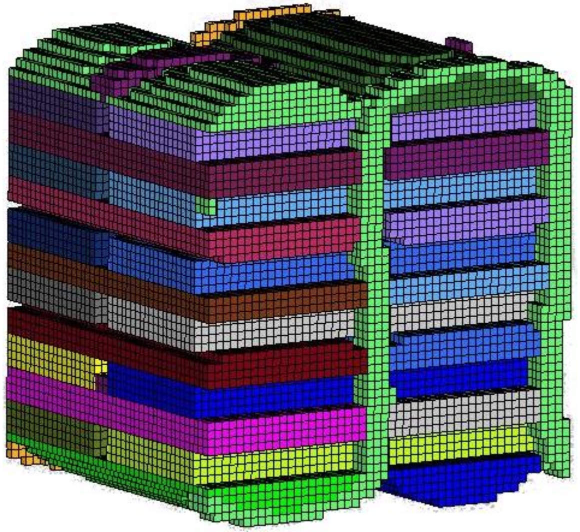
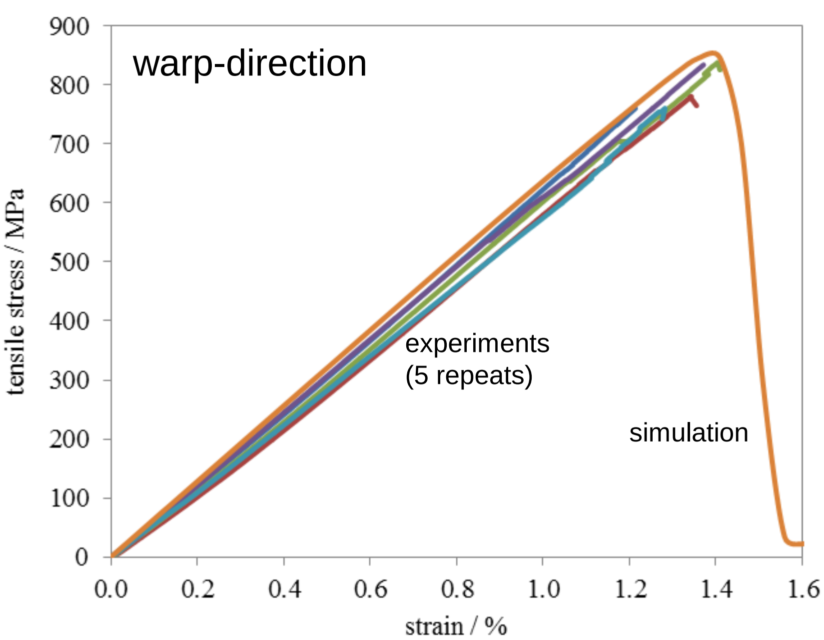
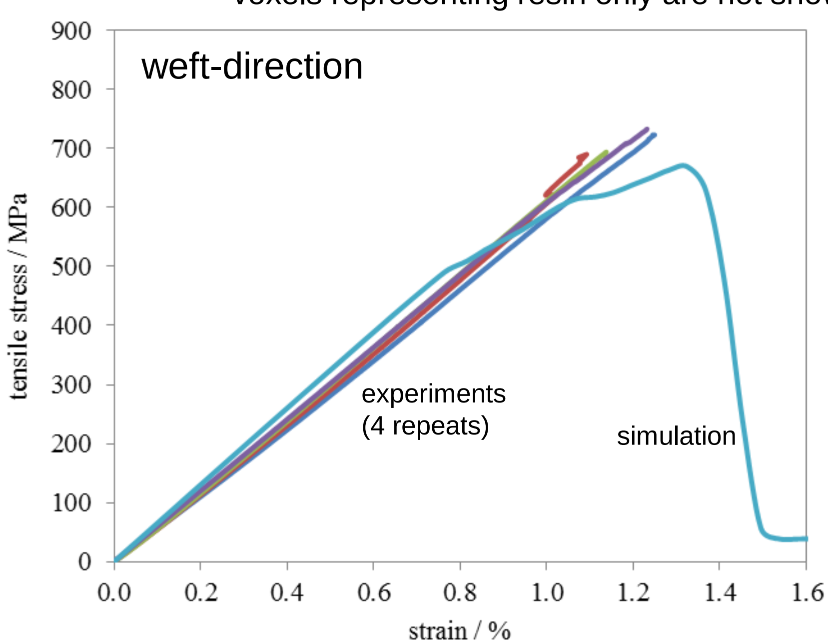
Assignment of local properties + orientations to TexGen voxel mesh of composite unit cell for mechanical FE analysis

	warp		weft	
	F / MPa	*E* / GPa	*F* / MPa	*E* / GPa
simulation	845	64	669	64
experiment	791 ± 38	60 ± 2	710 ± 21	58 ± 3



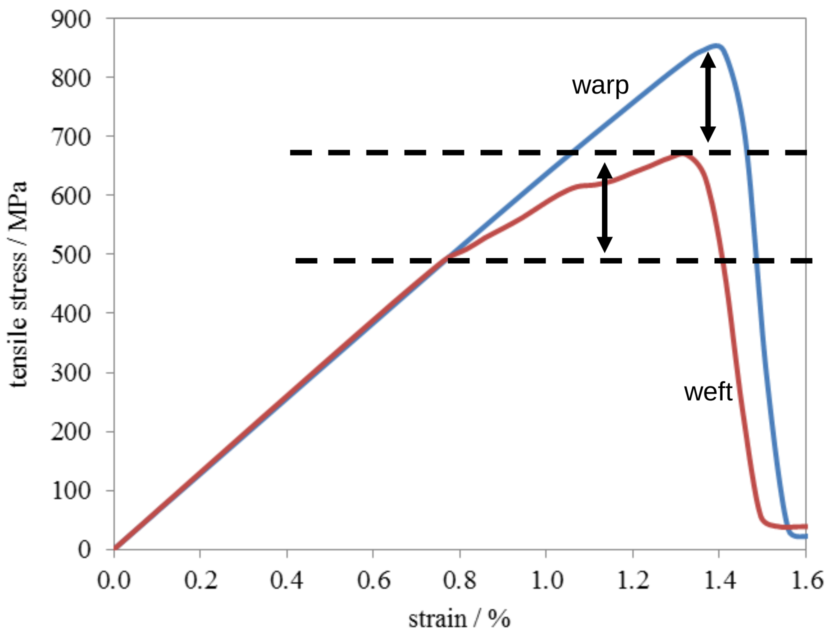
voxels representing resin only are not shown





Unit cell mechanical analysis

Comparison of calculated properties in warp- and weft-direction



failure strain similar in both directions

predicted failure of crimped surface layers

difference in strength is related to ratio of fibre volume in both directions, if surface layers are discounted

$$\frac{F_{weft}}{F_{warp}} = 0.79 \qquad \frac{V_{fweft}(5\ \text{layers})}{V_{fwarp}(6\ \text{layers})} = 0.74$$

crimped surface layers in weft-direction contribute little to strength

Unit cell mechanical analysis

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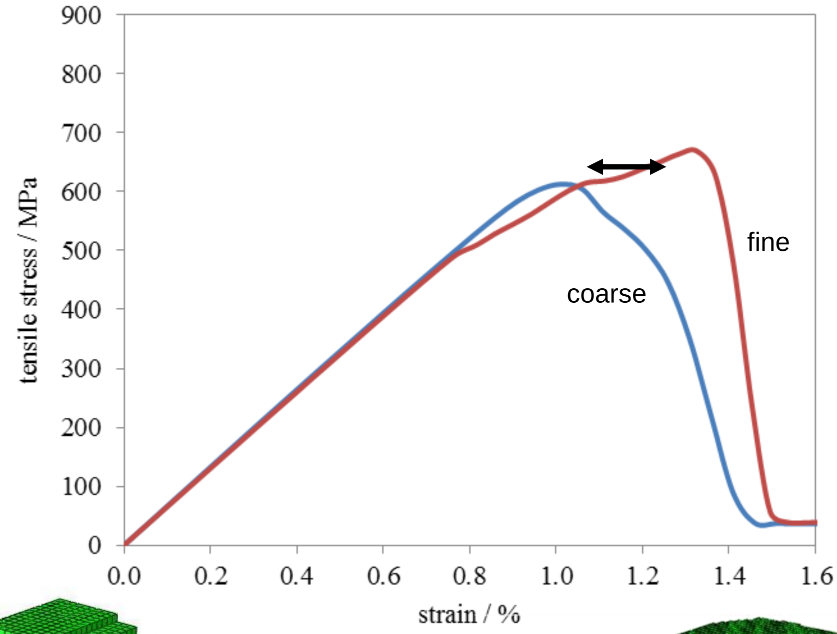
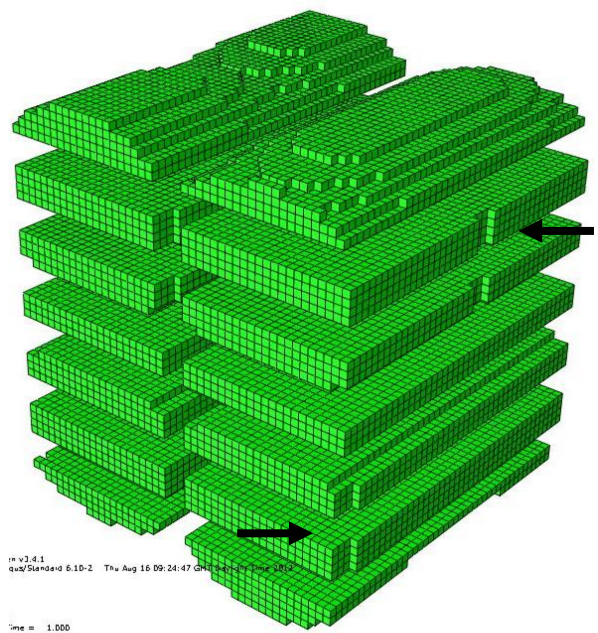
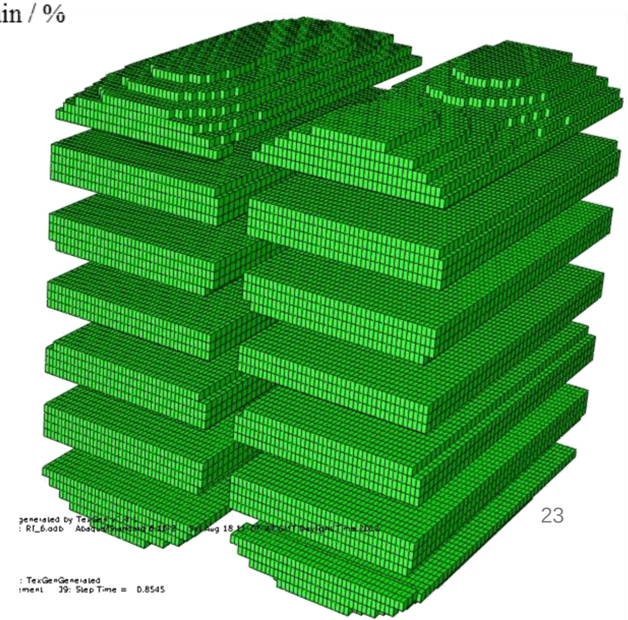
Influence of voxel mesh density, for weft yarns only



significant difference in failure strain

artefacts in geometry meshing affect simulation results





Conclusions

For a 3D orthogonal weave, the architecture was characterised in detail by analysis of μ-CT images of composites.

Geometrical unit cell models were generated in TexGen in a semi-automated manner.

Fabric permeability predictions based on simulations of impregnating flow
- improved significantly in accuracy with increasing level of detail in geometrical modelling
- indicated that binder configuration on fabric surface has significant effect on weft permeability

Composite strength predictions based on static mechanical analyses
- showed good quantitative agreement with experimental results
- indicated reduced strength in weft-direction, mainly due to crimp in surface layers

Acknowledgement

This work was supported by the Engineering and Physical Sciences Research Council [grant number: EP/IO33513/1], through the EPSRC Centre for Innovative Manufacturing in Composites.

3D woven fabric was supplied by Airbus UK.

Predicting the Coefficient of Thermal Expansion for Textile Composites Based on a Unit Cell Approach

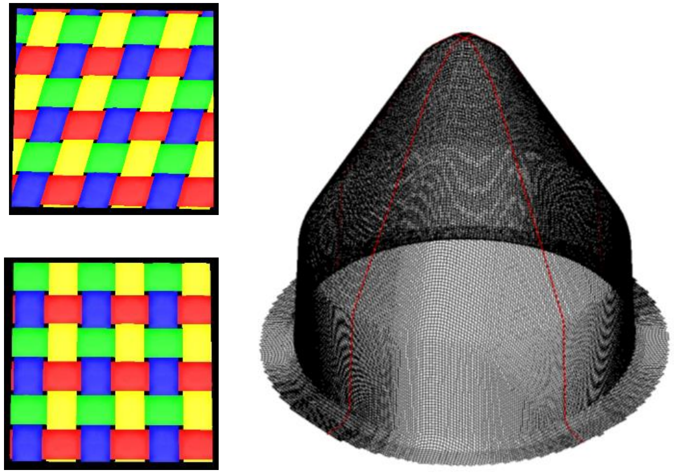
Louise P. Brown, Xuesen Zeng, Andrew C. Long, Richard Brooks, I. Arthur Jones

L P Brown, X Zeng, A C Long, R Brooks, I A Jones. “Predicting the coefficient of expansion for textile composites based on a unit cell approach”, Proc. 11th Int. Conf. on Textile Composites (TexComp-11), Leuven, Sept 2013.

Objectives

To predict coefficients of thermal expansion (CTEs) for sheared woven fabric laminates, which have been characterised through experiments.

To improve the quality of prediction by automated creation of realistic geometries in TexGen

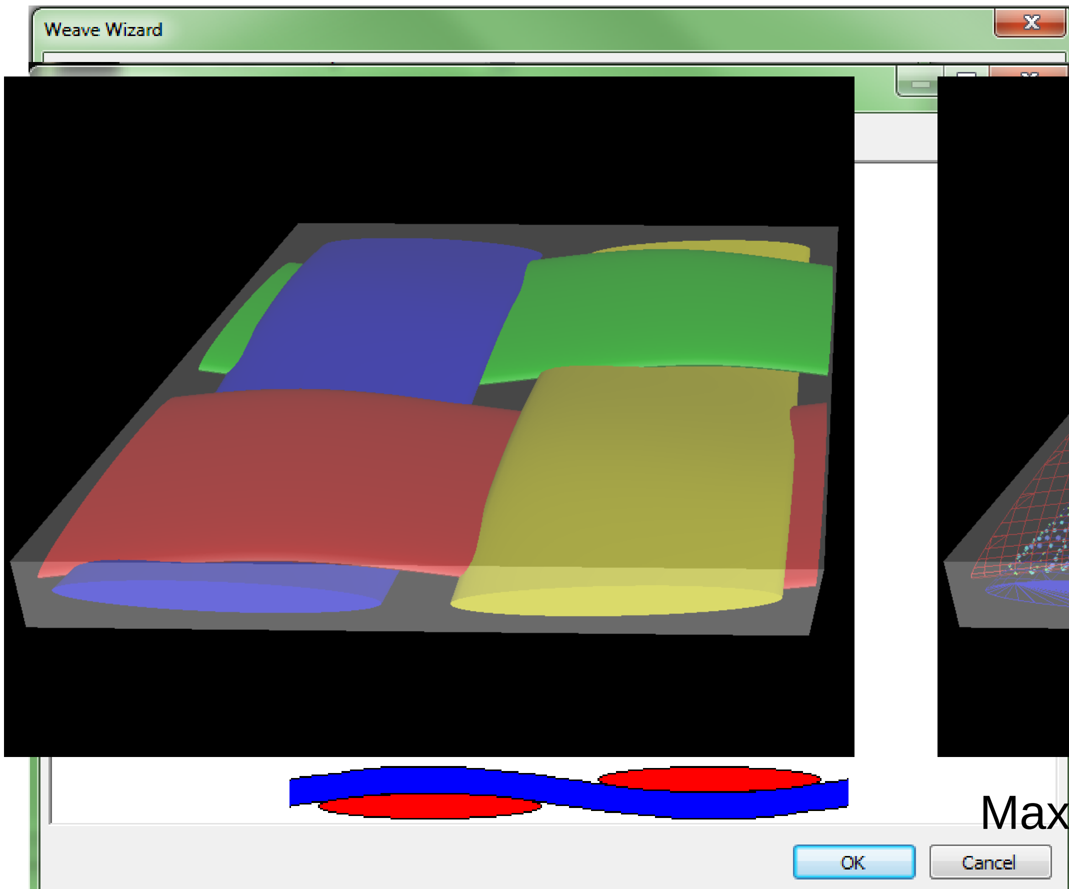


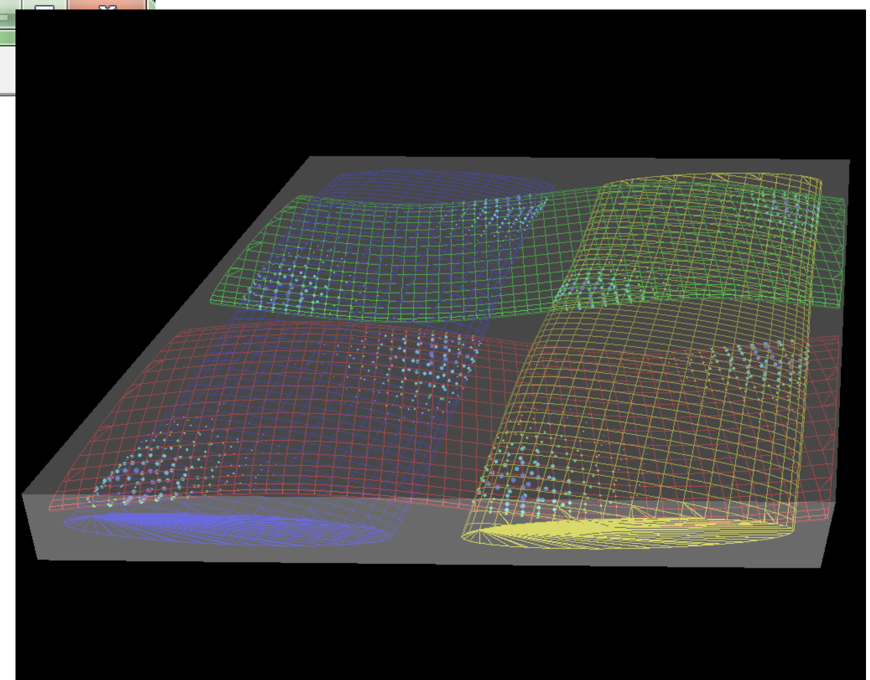
Sources of shear deformation

- Fabric forming
- Manufacturing defects caused by material handling

Sheared Textile Modelling

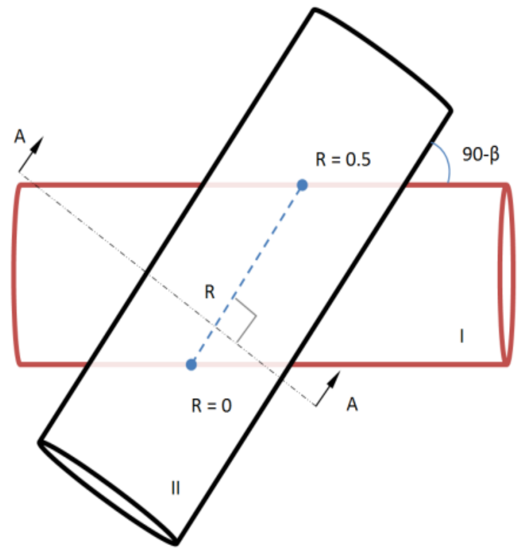
Extension to existing 2D weave wizard
- Input shear angle
- Optional sheared domain

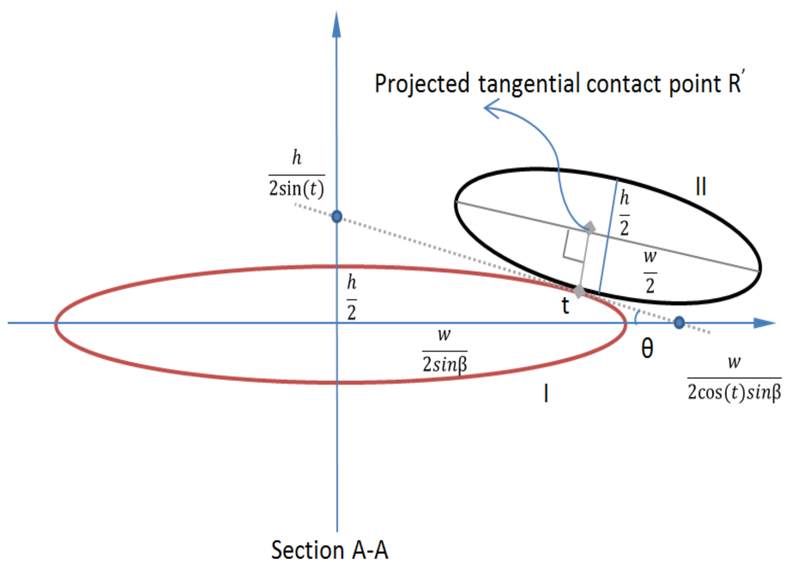




Max intersection depth = 0.034mm

Sheared Yarn Rotation Angle

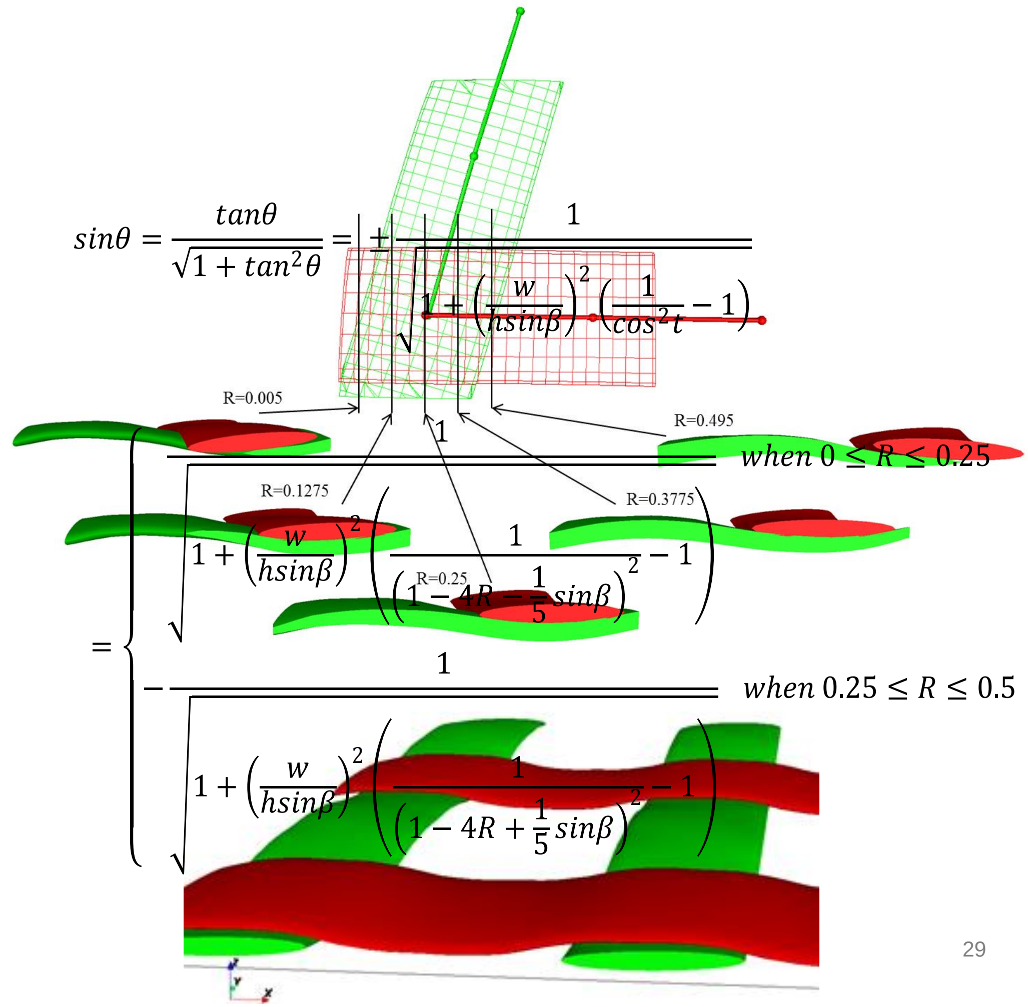




Calculation of rotational angle at yarn crossover to avoid intersections

$$sin\theta = \frac{tan\theta}{\sqrt{1+tan^2\theta}} = \pm\frac{1}{\sqrt{1+\left(\frac{w}{hsin\beta}\right)^2\left(\frac{1}{cos^2t}-1\right)}}$$

$$= \begin{cases} \dfrac{1}{\sqrt{1+\left(\frac{w}{hsin\beta}\right)^2\left(\frac{1}{\left(1-4R-\frac{1}{5}sin\beta\right)^2}-1\right)}} & when\ 0 \le R \le 0.25 \\ -\dfrac{1}{\sqrt{1+\left(\frac{w}{hsin\beta}\right)^2\left(\frac{1}{\left(1-4R+\frac{1}{5}sin\beta\right)^2}-1\right)}} & when\ 0.25 \le R \le 0.5 \end{cases}$$

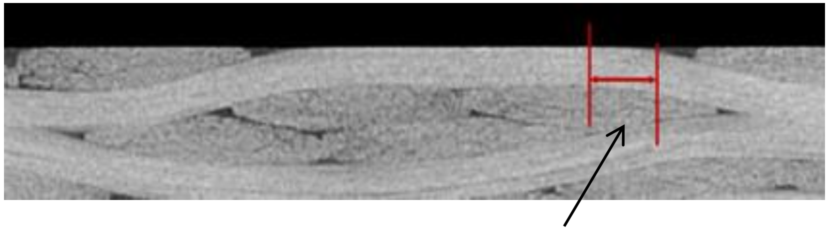


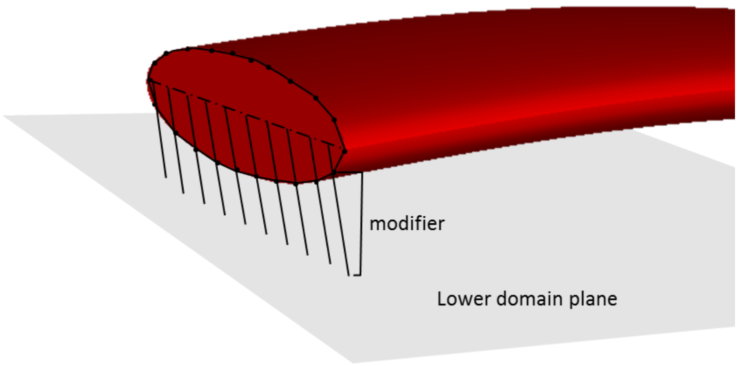
Cross-section adjustment

Intersection correction

- Algorithm already implemented for non-sheared 2D weaves
- Creates polygon cross-sections
- Results in loss of yarn volume

Cross section adjustment





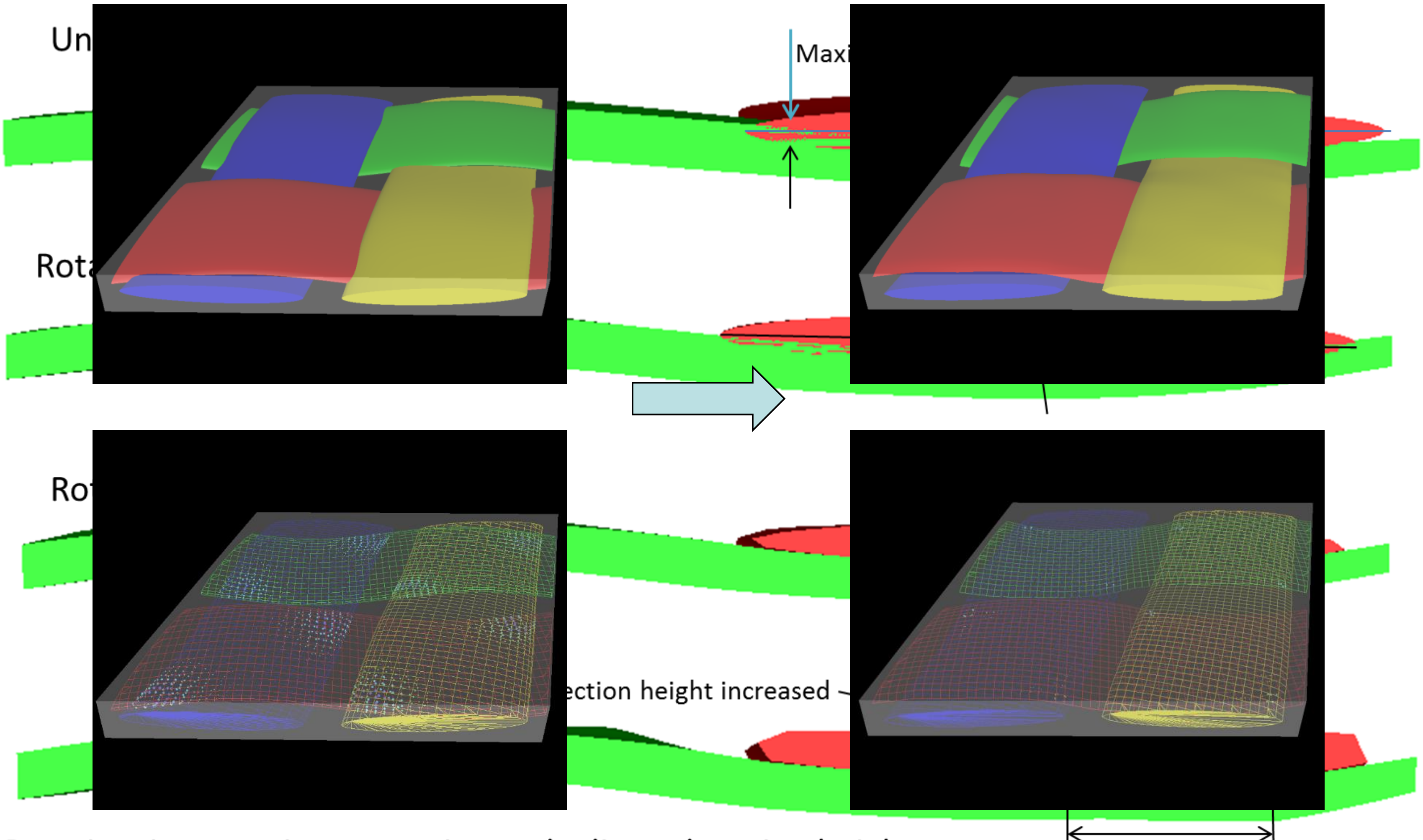
Modifier = 1: Cross-section point is on domain plane

Modifier < 1: Intersection with plane lies inside yarn volume. Modifier applied. Iterative method used to adjust cross-section points to restore original cross-sectional area

Modifier > 1: Shown in figure. No adjustment required

Refined Sheared Textile

Unrefined, 15° | Refined, 15 °

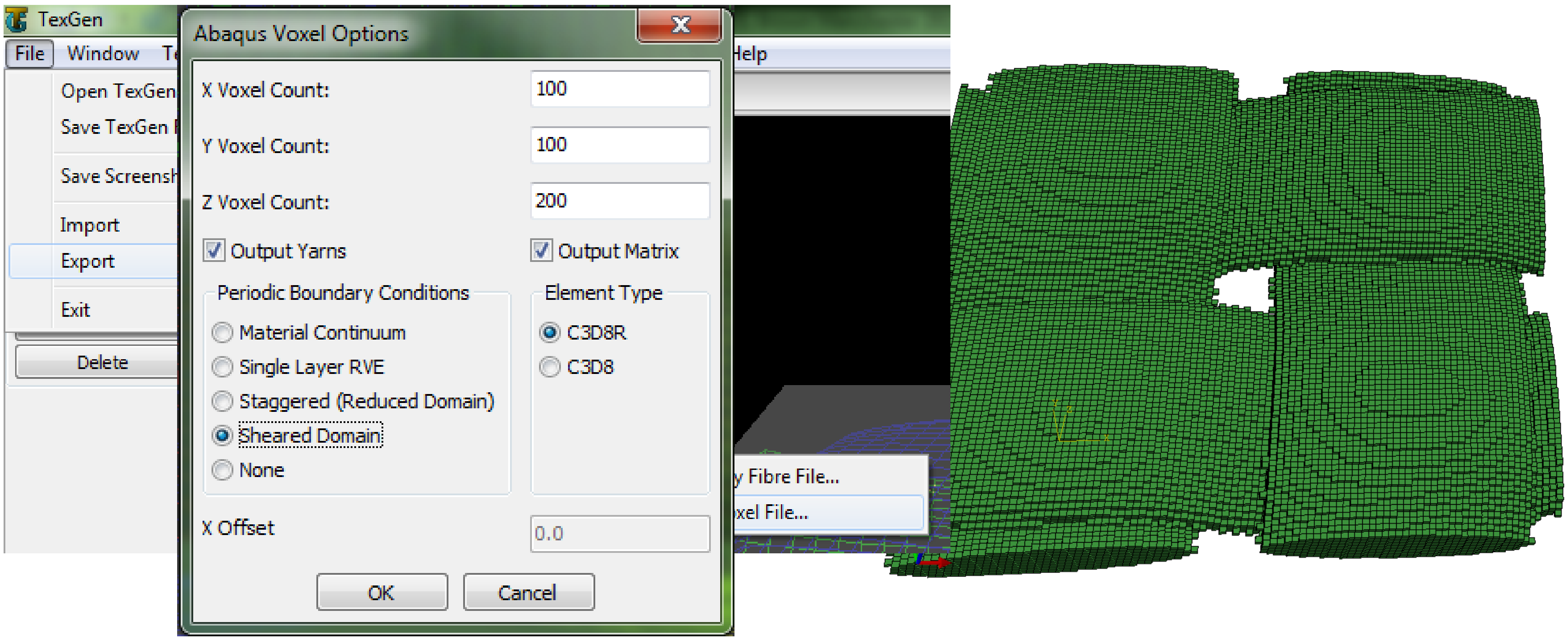


Max intersection depth = 0.034mm

Max intersection depth = 0.0015mm

CTE Prediction of Sheared Laminates

Abaqus input file is generated automatically within the TexGen GUI
Compatible voxelised mesh is created with periodic boundary conditions



Shear domain periodic boundary conditions

Face A & B relative displacement

$$-u\Big|_B + u\Big|_A - S_1\,\varepsilon_x^0 = 0$$

$$-v\Big|_B + v\Big|_A = 0$$

$$-w\Big|_B + w\Big|_A = 0$$

Edges:

$$\vec{U}_2 - \vec{U}_1 = F_{AB}$$

$$\vec{U}_4 - \vec{U}_1 = F_{CD}$$

$$\vec{U}_3 - \vec{U}_1 = F_{AB} + F_{CD}$$

$$\vec{U}_6 - \vec{U}_5 = F_{AB}$$

$$\vec{U}_8 - \vec{U}_5 = F_{EF}$$

$$\vec{U}_7 - \vec{U}_5 = F_{AB} + F_{EF}$$

$$\vec{U}_{10} - \vec{U}_9 = F_{CD}$$

$$\vec{U}_{12} - \vec{U}_9 = F_{EF}$$

$$\vec{U}_{11} - \vec{U}_9 = F_{CD} + F_{EF}$$

Face C and D:

$$-u\Big|_D + u\Big|_C - S_1\,(\varepsilon_x^0 \sin\beta + \gamma_{xy}^0 \cos\beta) = 0$$

$$-v\Big|_D + v\Big|_C - S_1\,\varepsilon_y^0 \cos\beta = 0$$

$$-w\Big|_D + w\Big|_C = 0$$

Vertices:

$$\vec{U}_{N2} - \vec{U}_{N1} = F_{AB}$$

$$\vec{U}_{N4} - \vec{U}_{N1} = F_{CD}$$

$$\vec{U}_{N3} - \vec{U}_{N1} = F_{AB} + F_{CD}$$

$$\vec{U}_{N5} - \vec{U}_{N1} = F_{EF}$$

$$\vec{U}_{N6} - \vec{U}_{N1} = F_{EF} + F_{AB}$$

$$\vec{U}_{N7} - \vec{U}_{N1} = F_{AB} + F_{EF} + F_{CD}$$

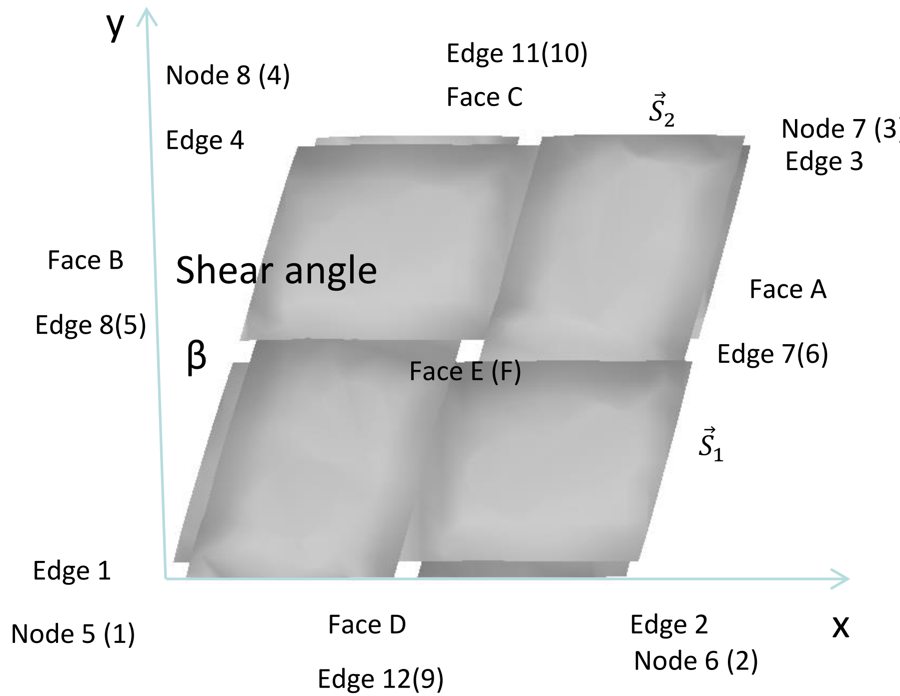
$$\vec{U}_{N8} - \vec{U}_{N1} = F_{CD} + F_{EF}$$

Faces E and F orthogonal to Z (Thickness *C*)

$$-u\Big|_E + u\Big|_F - C\gamma_{xz}^0 = 0$$

$$-v\Big|_E + v\Big|_F - C\gamma_{yz}^0 = 0$$

$$-w\Big|_E + w\Big|_F - C\varepsilon_z^0 = 0$$



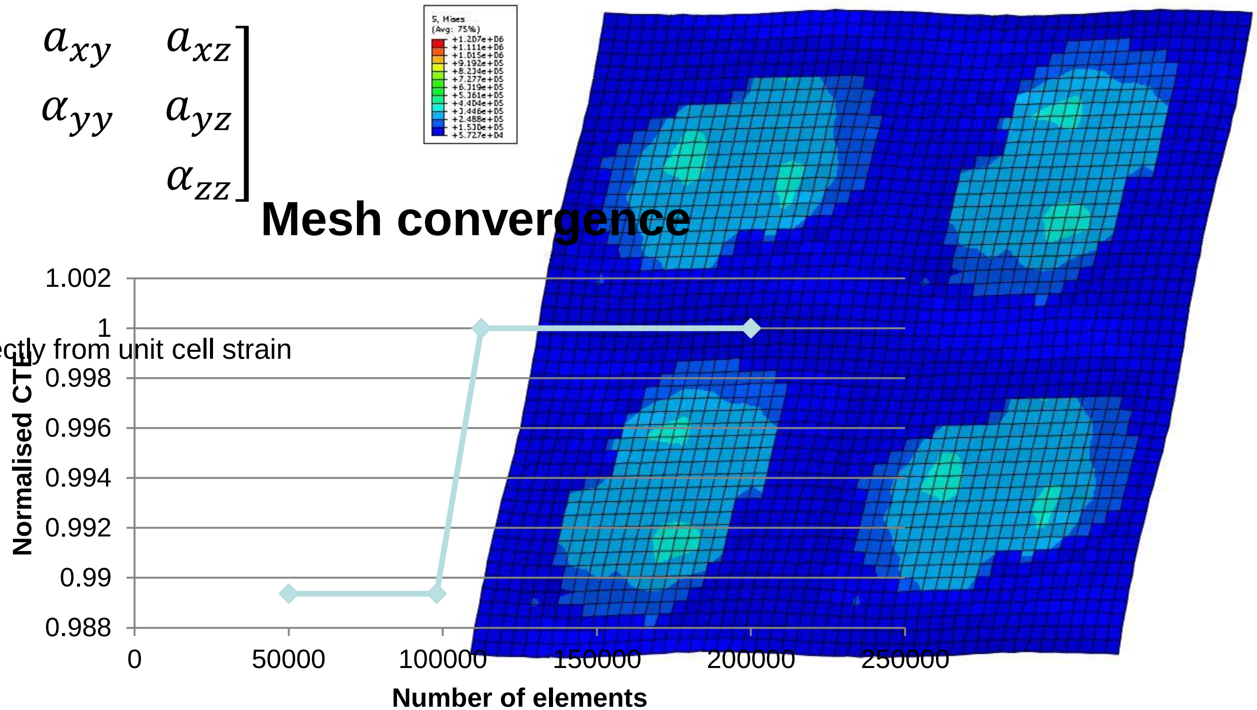
Li, S., C.V. Singh, and R. Talreja, *A representative volume element based on translational symmetries for FE analysis of cracked laminates with two arrays of cracks.* International Journal of Solids and Structures, 2009. **46**(7–8): p. 1793-1804.

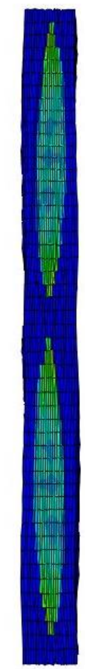
Thermal mechanical analysis

$$\alpha = \begin{bmatrix} \alpha_{xx} & a_{xy} & a_{xz} \\ & \alpha_{yy} & a_{yz} \\ & & \alpha_{zz} \end{bmatrix}$$

CTEs are recovered directly from unit cell strain tensor:

$$\alpha_{xx} = \varepsilon_x$$
$$\alpha_{yy} = \varepsilon_y$$
$$\alpha_{zz} = \varepsilon_z$$
$$\alpha_{xy} = \gamma_{xy}$$
$$\alpha_{xz} = \gamma_{xz}$$
$$\alpha_{yz} = \gamma_{yz}$$





ABAQUS static analysis, perturbation

Temperature change $\Delta T = 1\,^{o}C$

Validation case study

Material:

Plain weave, CF0504, (3K HTA 5131 carbon fibres, 200 gsm, 5 ends per cm)

10-ply laminates, created by resin film stacking :

(1) un-sheared (V_f =47.5%), (2) sheared at 16 degrees & (3) 20 degrees

Yarn width	Yarn height	Yarn in-plane spacing	Laminate thickness
1.76mm	0.16mm	2.03mm	2.4mm

Fibre properties

E_{11} =235GPa, E_{22} = E_{33} =15GPa, v_{12} =0.3, v_{23} =0.3, G_{12}=15, a_L = -0.4x10^{-6}/K, a_T = 10x10^{-6}/K

Consolidation:
Autoclave at pressure of 6 bar

5 hours initial cure at 80° C
Ramp rate 2° C/min

After cooling below 60° C and release of pressure, free standing post-cure for 1 hour at 120° C

Matrix:
MTM46 from CYTEC (previously ACG or UMECO

Matrix properties

E=2.7GPa

v=0.4

a = 40x10^{-6} /K after the full thermal cycle

Hobbiebrunken, T., M. Hojo, K.K. Jin, and S.K. Ha, *Influence of non-uniform fiber arrangement on microscopic stress and failure initiation in thermally and transversely loaded CF/epoxy laminated composites.* Composites Science and Technology, 2008. **68**(15–16): p. 3107-3113.

Fiedler, B., M. Hojo, S. Ochiai, K. Schulte, and M. Ochi, *Finite-element modeling of initial matrix failure in CFRP under static transverse tensile load.* Composites Science and Technology, 2001. **61**(1): p. 95-105.

Pradere, C. and C. Sauder, *Transverse and longitudinal coefficient of thermal expansion of carbon fibers at high temperatures (300–2500 K).* Carbon, 2008. **46**(14): p. 1874-1884.

Thermal expansion measurement

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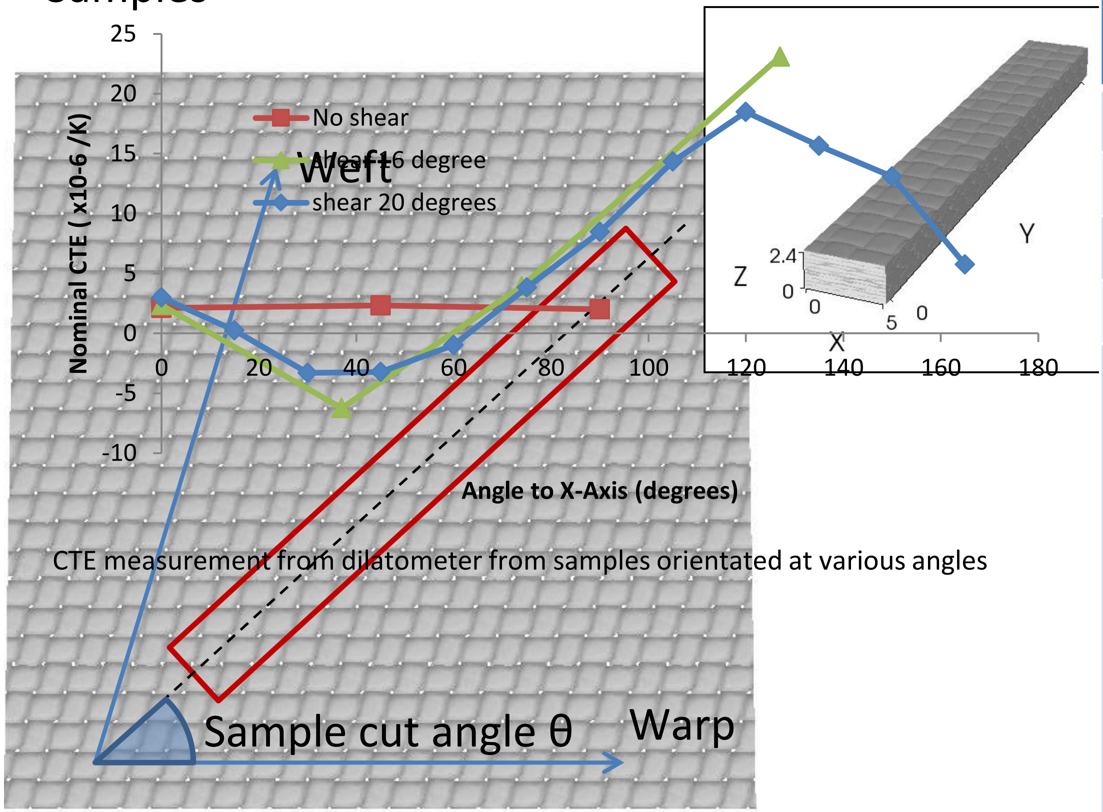
Table of CTEs ($x10^{-6}/K$)

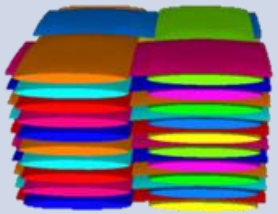
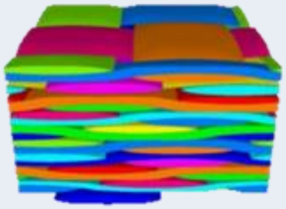
Shear 0º	Shear 16º	Shear 20º
0	0	0
45	37	15
90	74	30
	127	45
		60
		75
		90
		105
		120
		135
		150
		165

Samples



CTE measurement from dilatometer from samples orientated at various angles

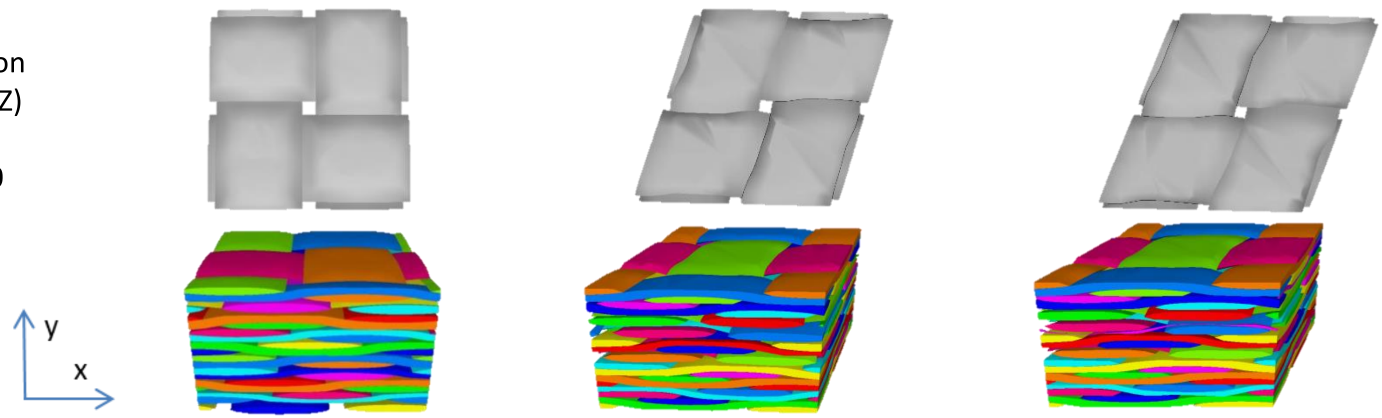
FE predictions- Shear 0º

Model	CTE prediction in warp ($\times 10^{-6}$/K)	
Experiment	2.12	
Infinite size in in-plane and thickness, zero nesting, represented by single layer with periodic boundary conditions	3.20	
Ten layers, no nesting, pbc in-plane	2.51	
Ten layers, random nesting, pbc in-plane (3 laminate models)	2.17±0.01	

FE Predictions – Shear 0°,16° & 20°

Converged mesh using 2 million elements - 100x100x200 (X Y Z)

HPC: 32CPUs, 69GB RAM, 130 minutes



CTE ($\times 10^{-6}$ /K)	Non-shear	16° shear	20° shear	
α_{xx}	2.170	1.422	1.240	
α_{yy}	2.160	4.960	6.420	
α_{xy}	0.0071	12.40	14.240	
Correlated prediction[1]	2.171 in x	2.97 in x	3.02 in x	8.20 in y
Experiment	2.12	2.63	2.99	8.46
Error (%)	2.4	12.9	1.0	-3.1

[1] $\alpha_{dilatometer} = \frac{\Delta L}{L_o} = \varepsilon_x + \frac{W_o}{L_o}|\gamma_{xy}| = \alpha_{xx} + \frac{W_o}{L_o}\alpha_{xy}$

Conclusions

Basic principles and assumptions have been used to refine fabric geometry to simulate realistic shear deformation.

The refinement process has been automated in TexGen and used to generate sheared unit cell models . These features are included in the latest TexGen release, version 3.6.0, www.texgen.sourceforge.net

CTE predictions based on FE thermo mechanical analysis showed good correlation with experimental results.

Laminate thickness and nesting were found to be significant geometric factors prediction of CTE in textile laminates.

Future work

Automation of laminate nesting in TexGen.

To predict manufacturing induced shape distortion by coupling unit cell and composite structural models.

Acknowledgement

This work was supported by the Engineering and Physical Sciences Research Council [grant number: EP/IO33513/1], through the EPSRC Centre for Innovative Manufacturing in Composites.

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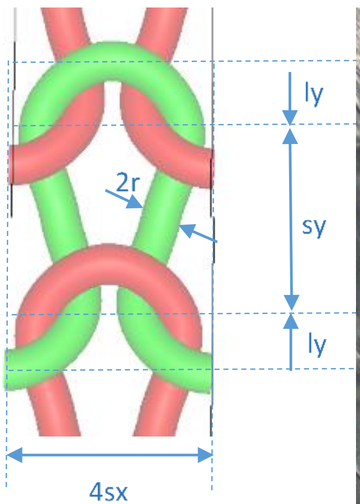
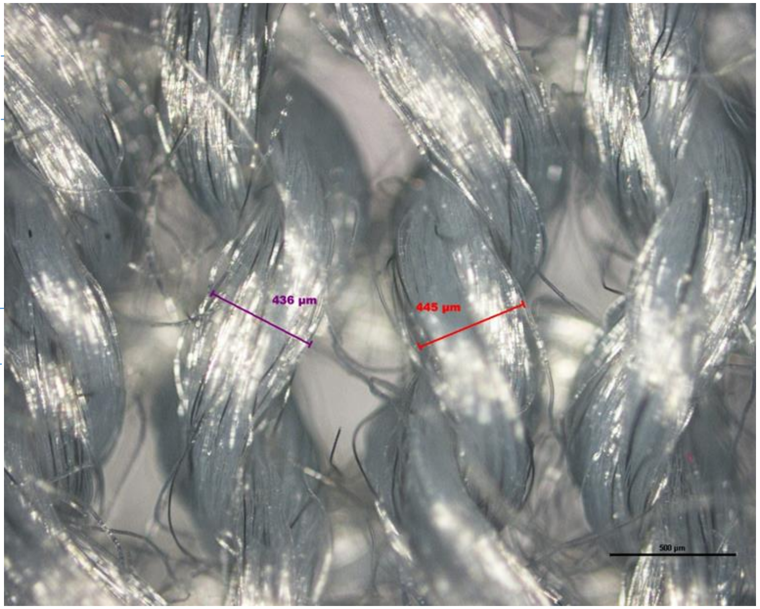
Modelling Deformation in Knitted Fabrics

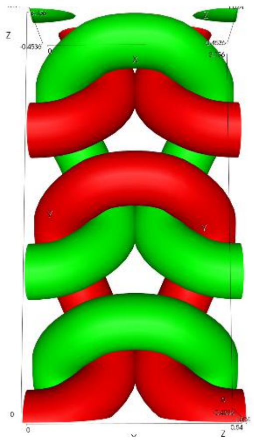
Material measurements used to create parameterised model





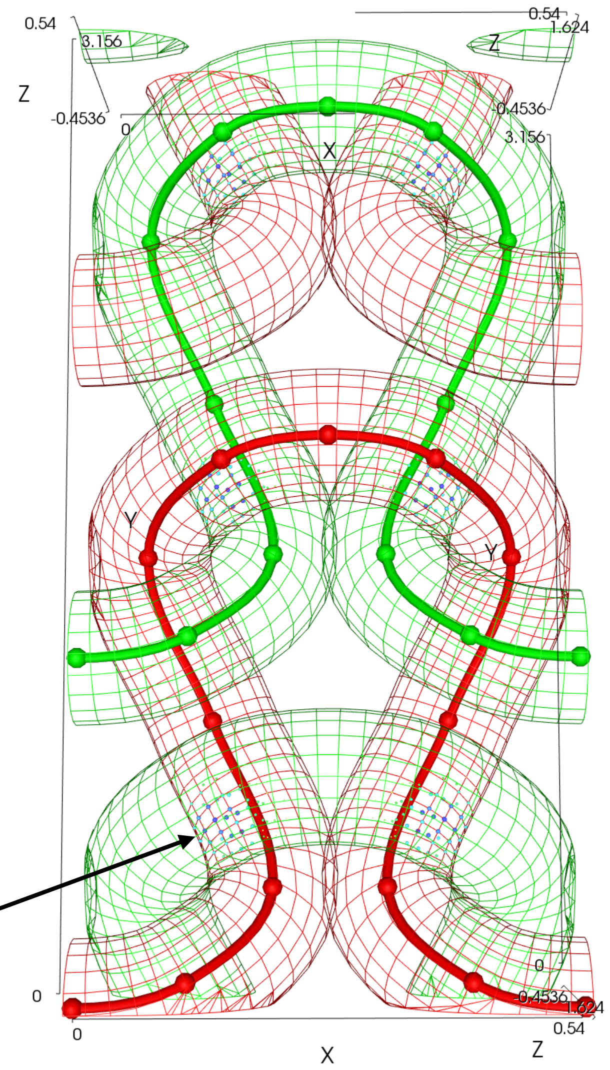
Parameter	Measurement /µm
Radius, r	216
Height, ly	363
Height, sy	1107
Width, sx	406

Initial Idealised Model

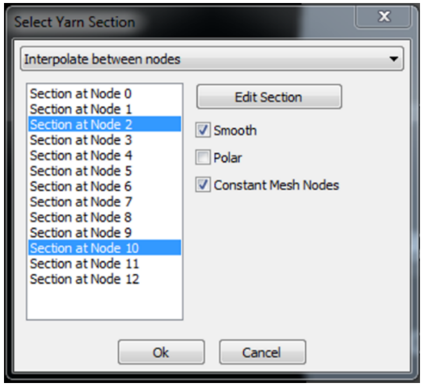


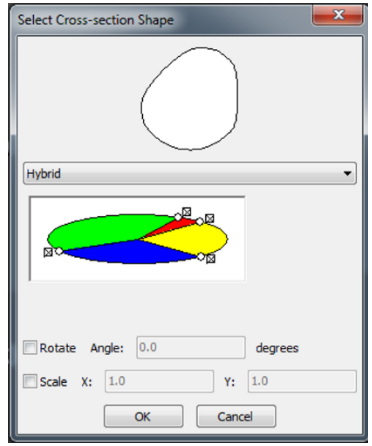
Model created using actual textile measurements with constant, circular cross-sections

Intersections

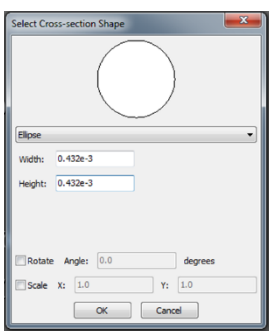


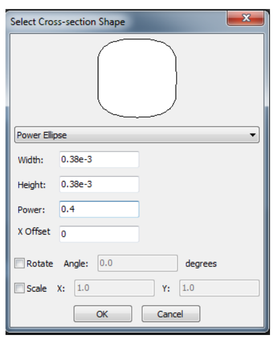
Modification of Cross-Sections

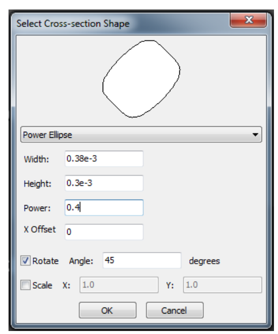


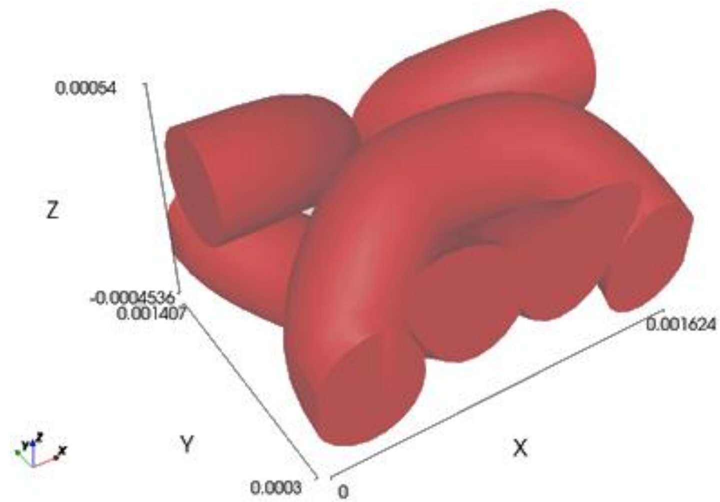


Hybrid cross-sections defined and assigned to specific nodes



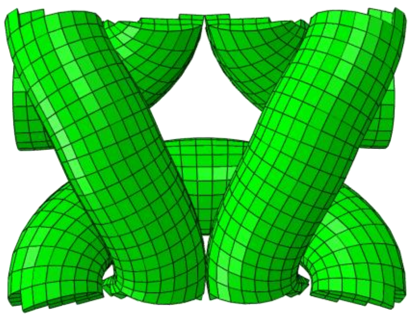


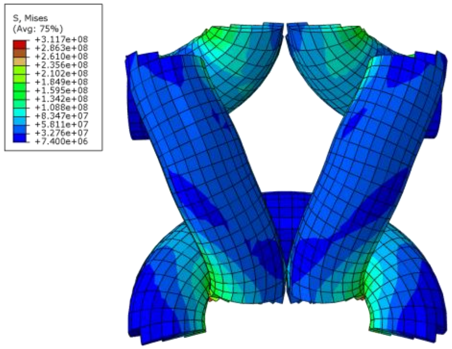




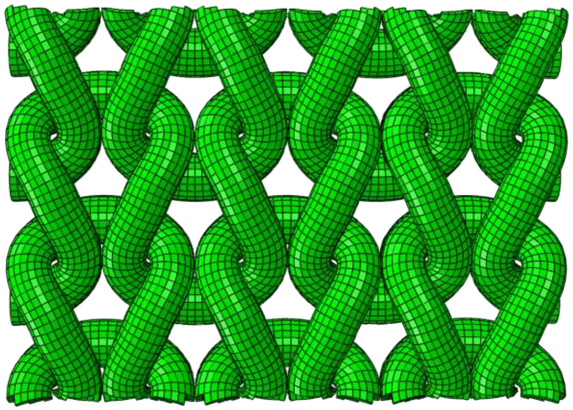
Deformation Simulation

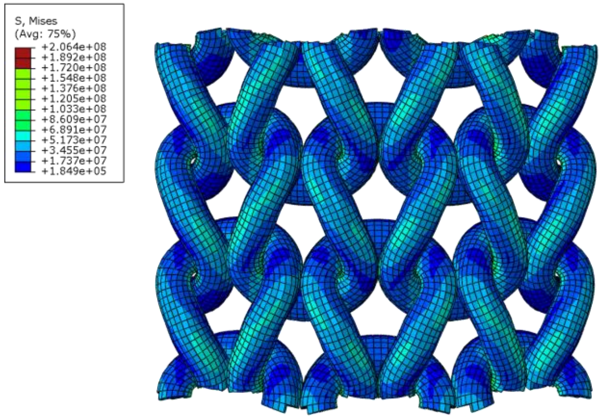
- TexGen dry fibre export generates conformal mesh and .inp for ABAQUS/Explicit simulation
- Used ABAQUS General Contact algorithm





Unit cell with periodic boundary conditions





3x3 unit cell, unconstrained in x direction

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TexGen Modelling Theory

Generating a Textile

Steps combined and performed automatically in 2D and 3D wizards

1 - Create Textile

2 - Add yarns

3 - Specify domain

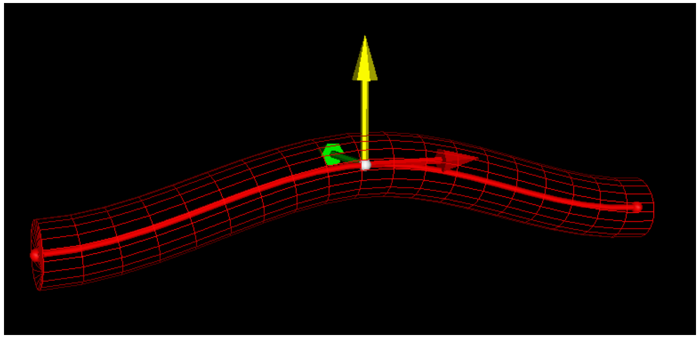
4 - Output data

Create yarn path
Assign sections
Select interpolation
Assign repeats
Assign fibre properties

Each step individually using either GUI, Python script or C++ API functions

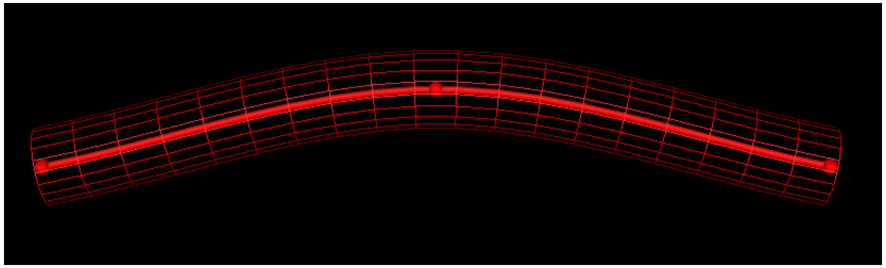
Yarn Specification

Yarns are denotes by a set of Master Nodes

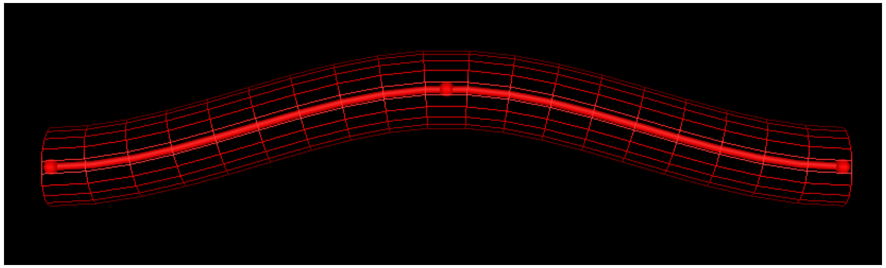


A path is generated between the master nodes by an interpolation function

- Bezier spline
- Natural cubic spline
- Linear spline



Periodic to maintain continuity across yarn repeats



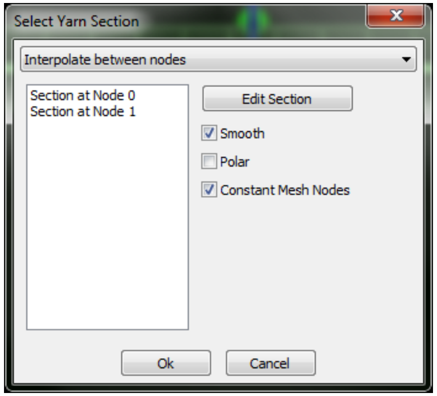
Yarn Cross-Sections - Interpolation

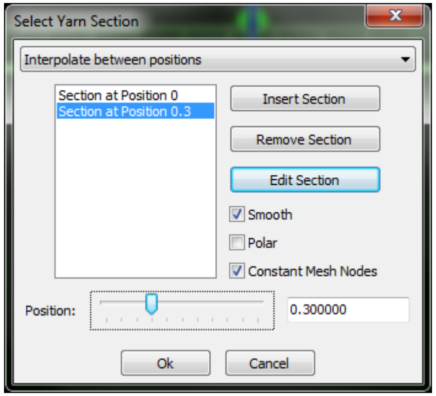
Yarn cross-sections are specified as 2D sections perpendicular to the yarn tangent

By default the cross-section is constant along the length of the yarn or an interpolation method can be chosen

GUI: Select *Modeller -> Assign Section*

- Select interpolation
  - Constant
  - Interpolate between nodes
  - Interpolate between positions



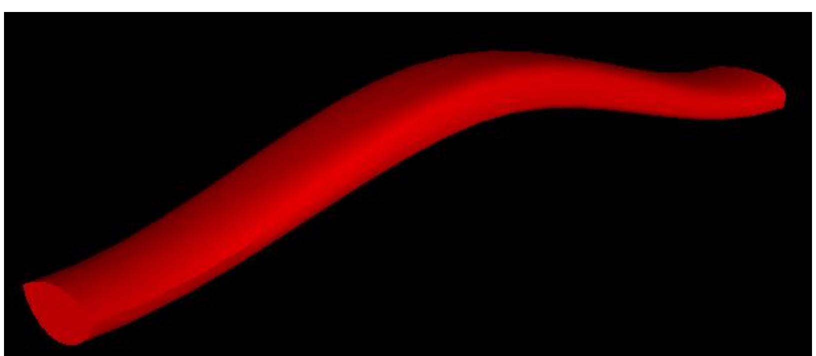


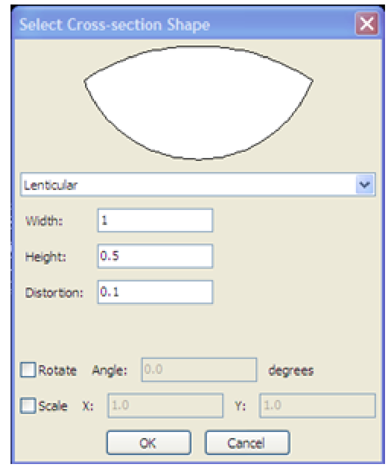
Yarn Cross-Sections – Section Specification

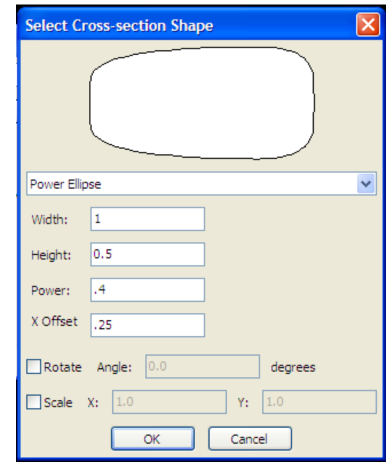
Cross-sections are specified at the locations given by the section interpolation

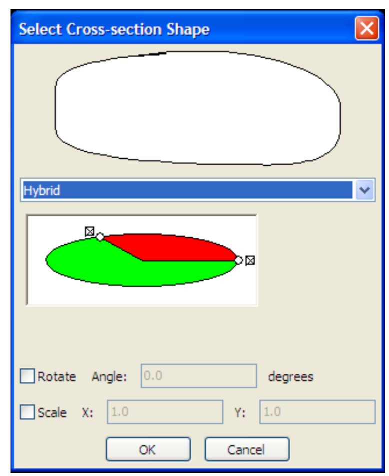
Available cross-sections:

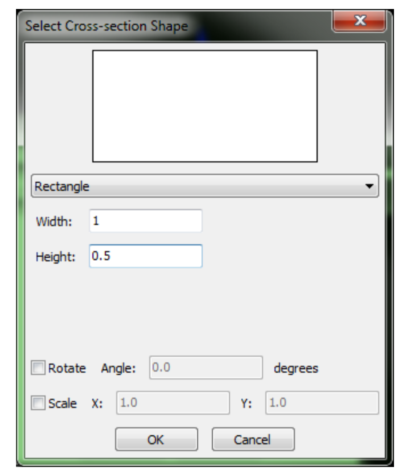
- Ellipse
- Lenticular
- Power ellipse
- Hybrid
- Rectangle
    - Use rather than power ellipse with power = 0 to generate uniform section meshes
- Polygon
    - Only by scripting









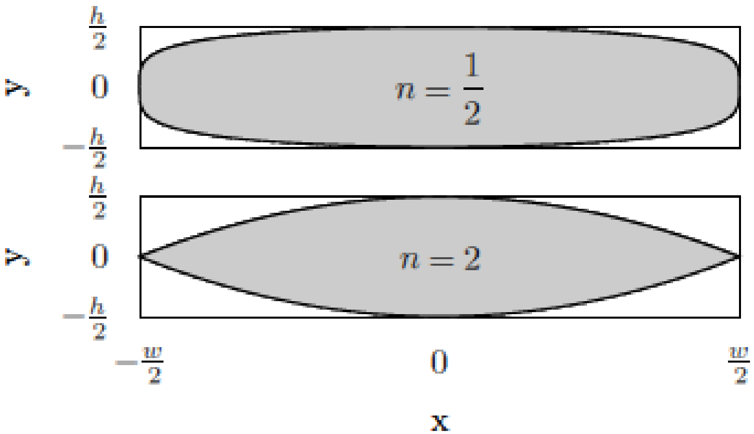


Power Ellipse Cross-Section

Specialisation of the Superellipse discovered by Gabriel Lame*

$$C(t)_x = \frac{w}{2}\cos 2\pi t \qquad 0 \le t \le 1$$

$$C(t)_y = \begin{cases} \frac{h}{2}(\sin(2\pi t))^n & if\ 0 \le t \le 0.5 \\ -\frac{h}{2}(\sin(2\pi t))^n & if\ 0.5 \le t \le 1 \end{cases}$$

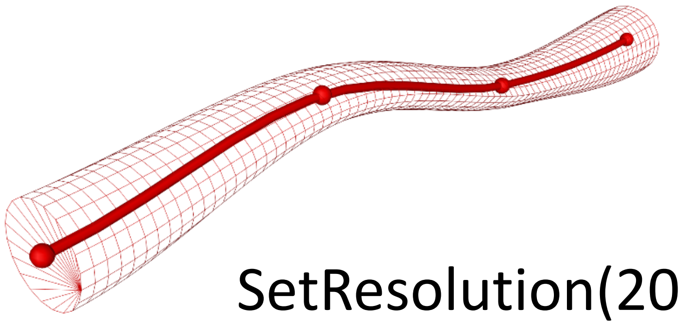


*M. Gardner, editor.Mathmatical Carnival. Vintage, 1977

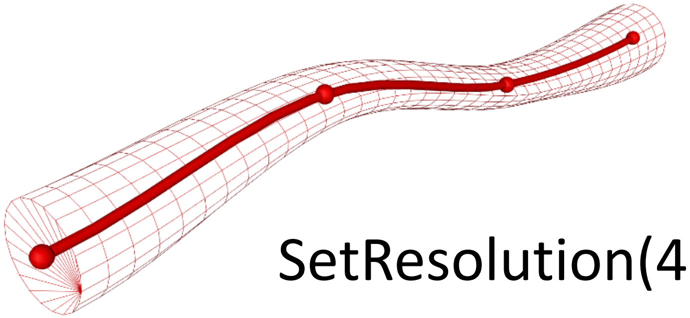
Building Yarns

1. Generates yarn path using specified interpolation function
   - Creates a set of slave nodes along the interpolated path at the specified resolution
2. Generates cross-sections for each slave node, interpolating between specified cross-sections where necessary
3. Generates surface by joining points on adjacent cross-section

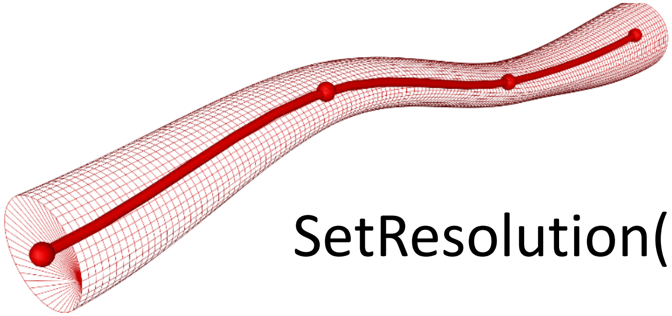
Yarn.SetResolution function assigns number of section points and, optionally, number of slave nodes



SetResolution(20)



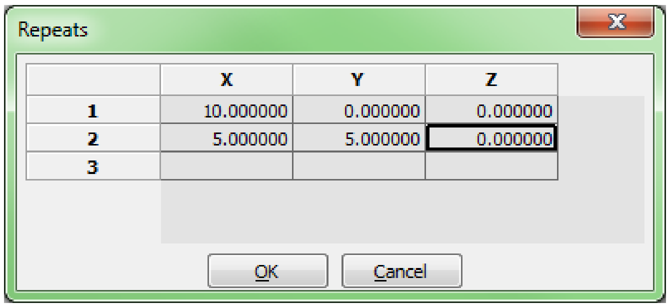
SetResolution(40,20)



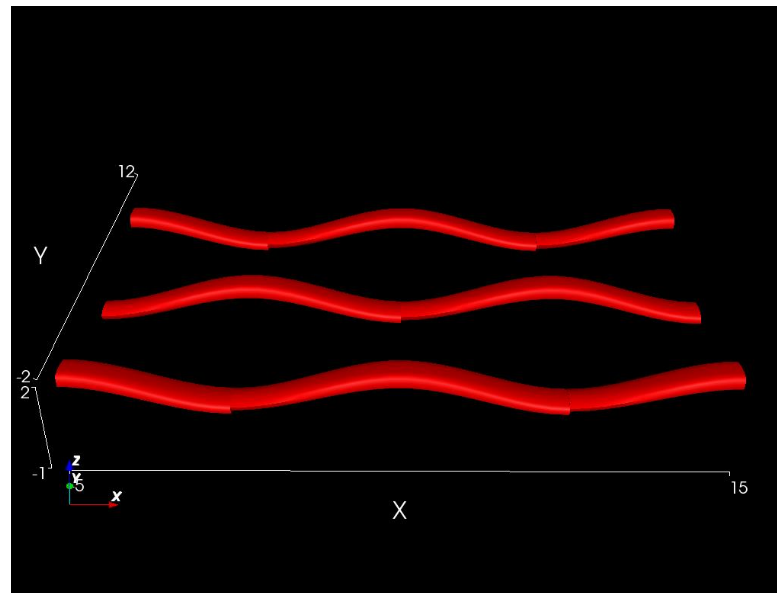
SetResolution(40)

Yarn Repeats and Domain

Yarn repeats allow a given yarn section to be repeated as specified by a set of vectors (in theory, allowing an infinite textile)



	X	Y	Z
1	10.000000	0.000000	0.000000
2	5.000000	5.000000	0.000000
3			

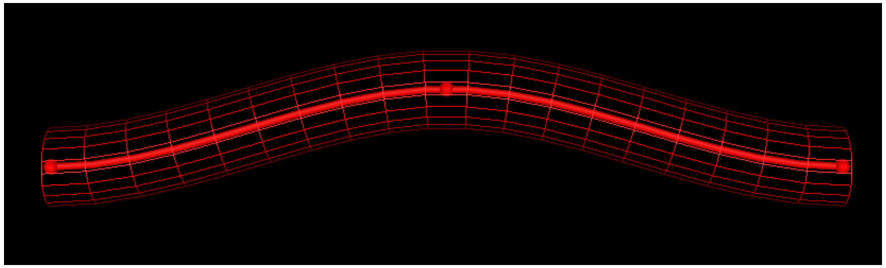


The domain restricts the model to a specific region

- Specified by a set of convex planes
- Typically, but not always, the unit cell

TexGen File Format

- tg3 file – basically a renamed xml file
  - Three versions containing different levels of data
    - Minimal – textile data only (generated by the weave classes)
    - Standard – textile and yarn data
    - Full – textile, yarn and mesh data



TexGen as a Pre-processor for Generating Textile Models

Workflow for finite element elastic analysis

Material properties for yarn fibres and matrix (manufacturer data)

Micro-scale simulation for yarn material properties

TexGen geometry model (.TG3) file

TexGen export of Abaqus input (.INP) file

Customisation of .INP file

Abaqus simulations
* Elastic
* Thermo-mechanical
* (Damage)

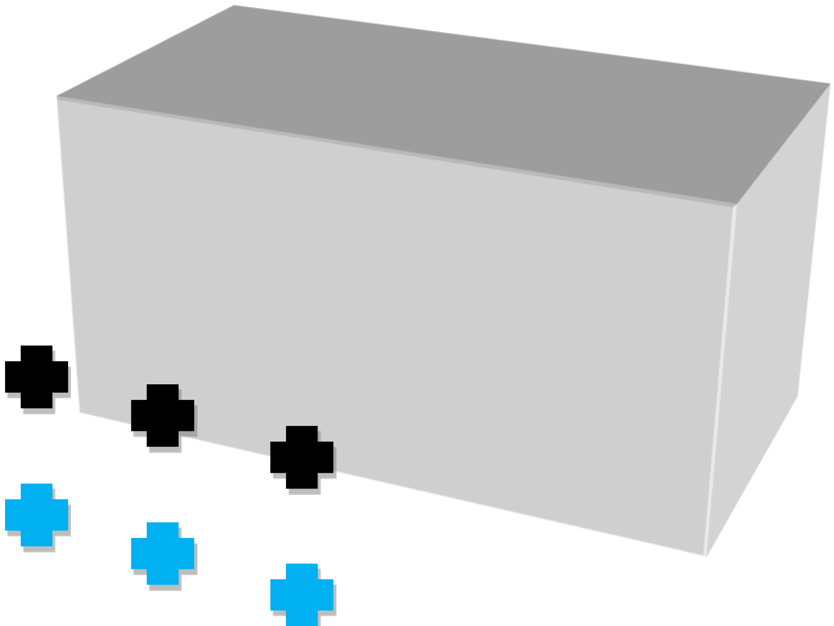
Abaqus script for result file (.ODB) exploitation.

RVE material properties

Reporting of results:
* Material properties
* Stress fields
* Strain fields

Material continuum assumption

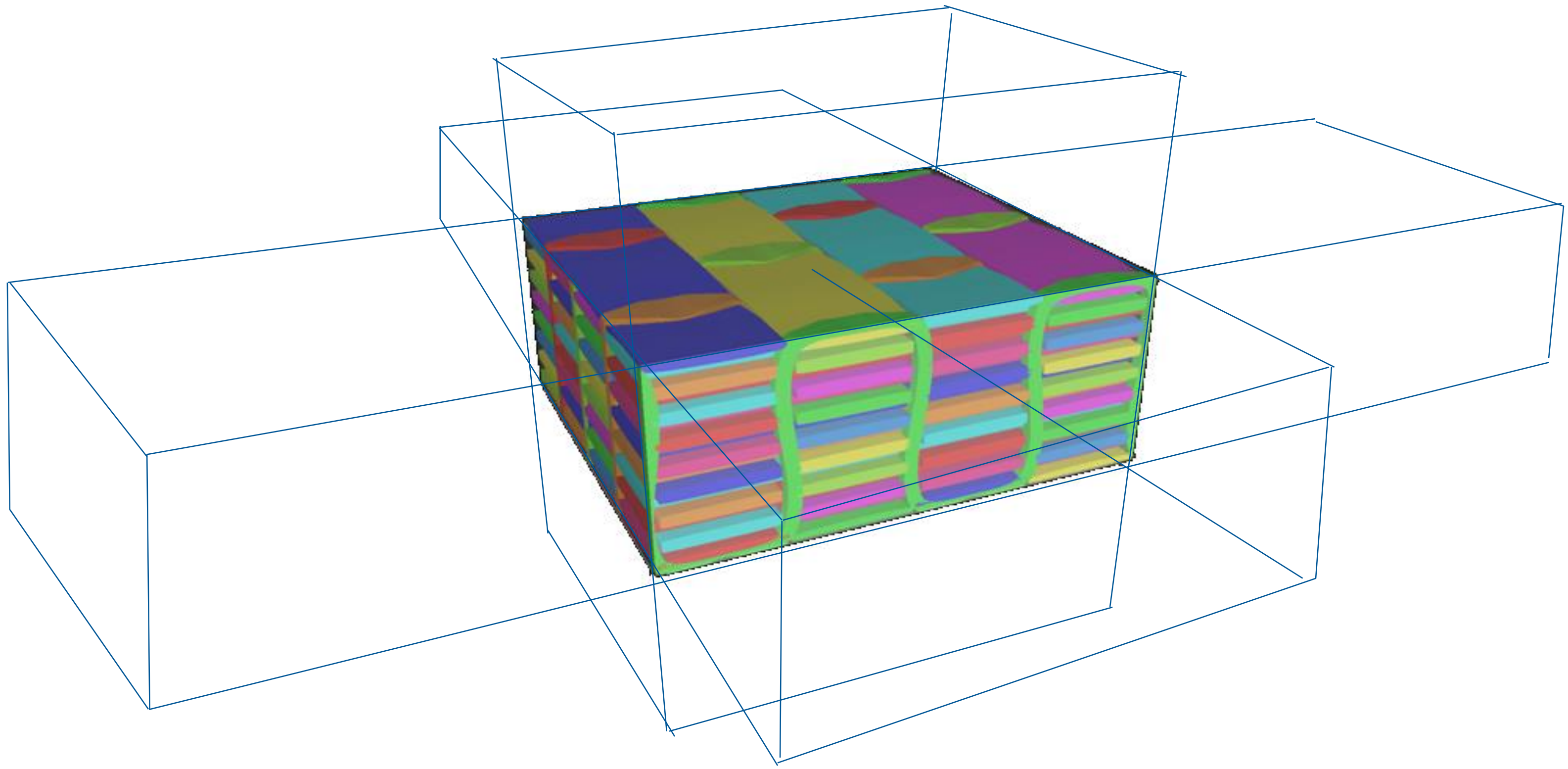
- Displacement field under overall macroscopic strains:
  - 3 direct strains
  - 3 shear strains



- “Correct” BC approach: equivalent continuum, tie to 6 “driver points”
- Recover relationship between stresses and strains (elastic props)

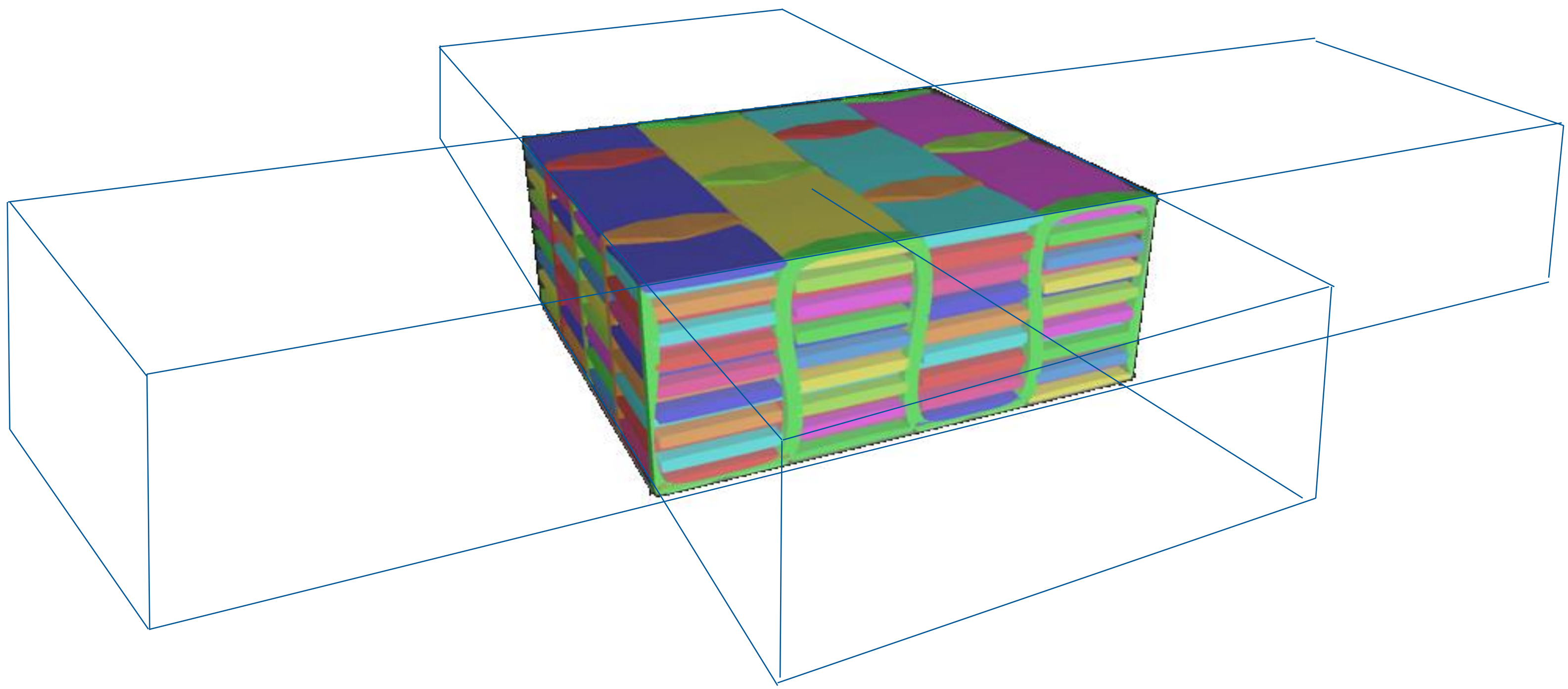
Periodic BCs: 3D and "untied"

- "Correct" BC approach of Li and Wongsto
- Full 3D boundary conditions: infinitely repeating 3D continuum
- Not true for tests!



Periodic BCs: 3D and "untied"

- Also tried "untying" the through-thickness constraints
- Represents repeating units only in-plane, free surfaces top and bottom
- Differences in results actually insignificant



Evaluation of yarn component properties

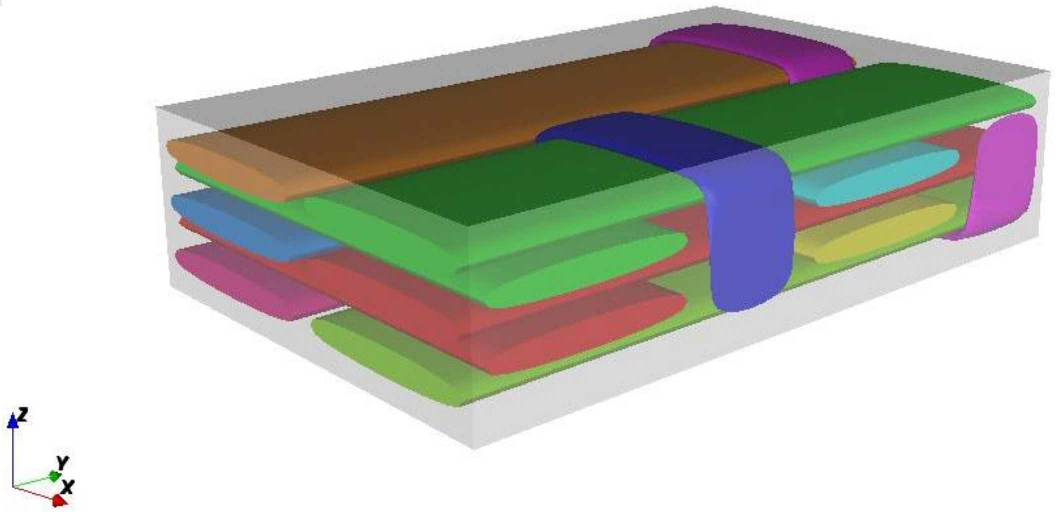
Fibre properties (HTS40 F13)

	E_x	ν
Fibre	238.6	0.20
Resin	3.1	0.35

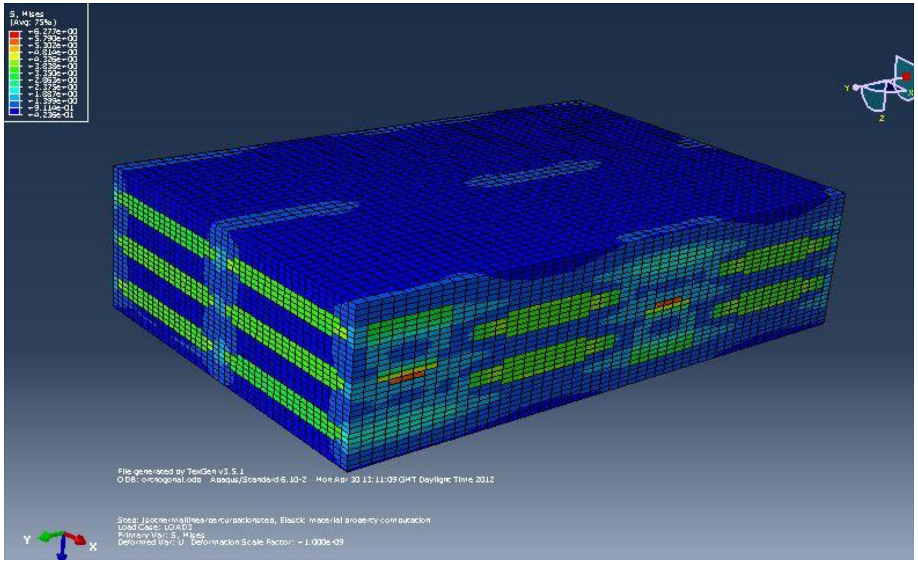
Input yarn material properties:

7micron fibre at 76% vol.
UD hexagonal packing

E_1	E_2	E_3	v_{13}	v_{12}	v_{32}	G_{12}	G_{23}	G_{31}
183.1	9.67	9.67	0.23	0.23	0.43	5.66	3.37	5.66



FE prediction



Mesh size	E_1	E_2	v_{12}	v_{21}	G_{12}
40-50-30	34	64	0.03	0.05	3.06

$$E = \frac{\sigma}{\varepsilon} = \frac{F}{V\varepsilon} = \frac{1}{\varepsilon} \qquad v_{xy} = \frac{\varepsilon_y}{\varepsilon_x}$$

Step 1: export ABAQUS .inp file

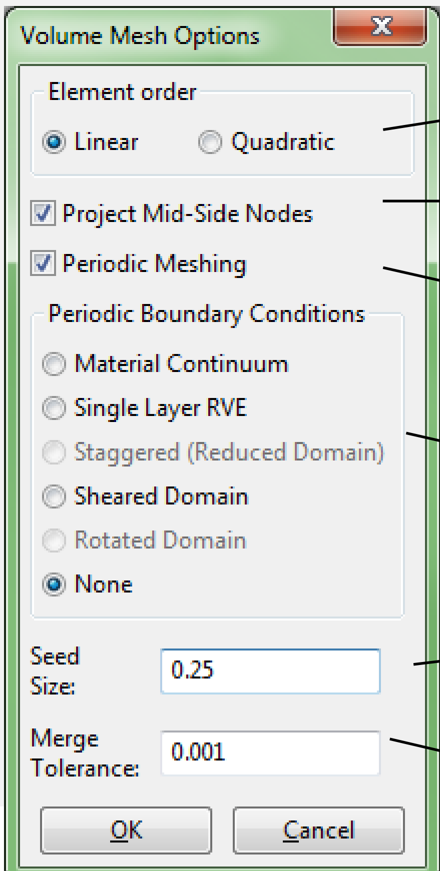
Step 2: lauch ABAQUS Solver with command line:
ABAQUS job=Filename

Step 3: extract material properties from .odb file:
Use the dataHandling.py and effectiveMatPropRVE.py files supplied with TexGen to calculate the material properties
http://texgen.sourceforge.net/index.php/Extraction_of_Material_Properties_using_Voxel_Meshing_and_Abaqus

Tutorial - Flow simulation using TexGen and CFX

1. Exporting volume mesh from TexGen

Open a TexGen model ready in TexGen window. Click "File -> Export -> Volume Mesh…", a dialog window appears as below. Once the parameters are set and click ok, a volume mesh file is created, either in .vtk or .inp format.



1.a This controls the number of element nodes. Linear results in 4 noded tetrahedrons while Quadratic results in 10 noded tetrahedrons.

1.b Option for Quadratic meshing only.

1.c Create the matching meshes on opposite faces to ensure periodic interface.

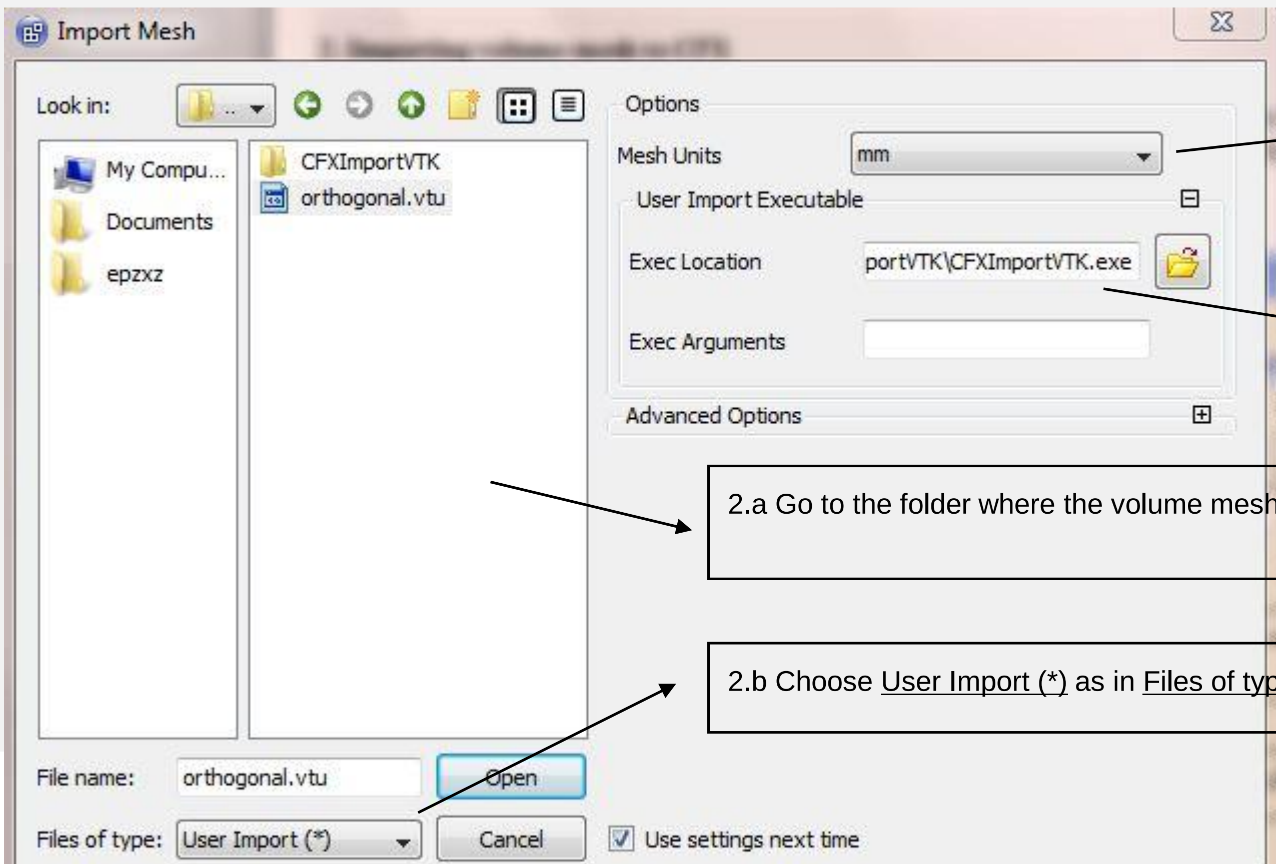
1.d Sets up periodic boundary conditions. Select None.

1.e Controls the mesh density and it approximates the edge length of elements.

1.f Any gap between yarns smaller than this tolerance will be merged to avoid bad quality elements.

2. Importing volume mesh to CFX

Launch ANSYS CFX -> CFX Pre 13.0. Go to File and then New Case, choose General as Simulation Type and click OK. Go to File -> Import -> Mesh, an Import Mesh window comes up. After the steps 2.a-d, click Open. The mesh is now imported.



2.c Choose mm as mesh unit

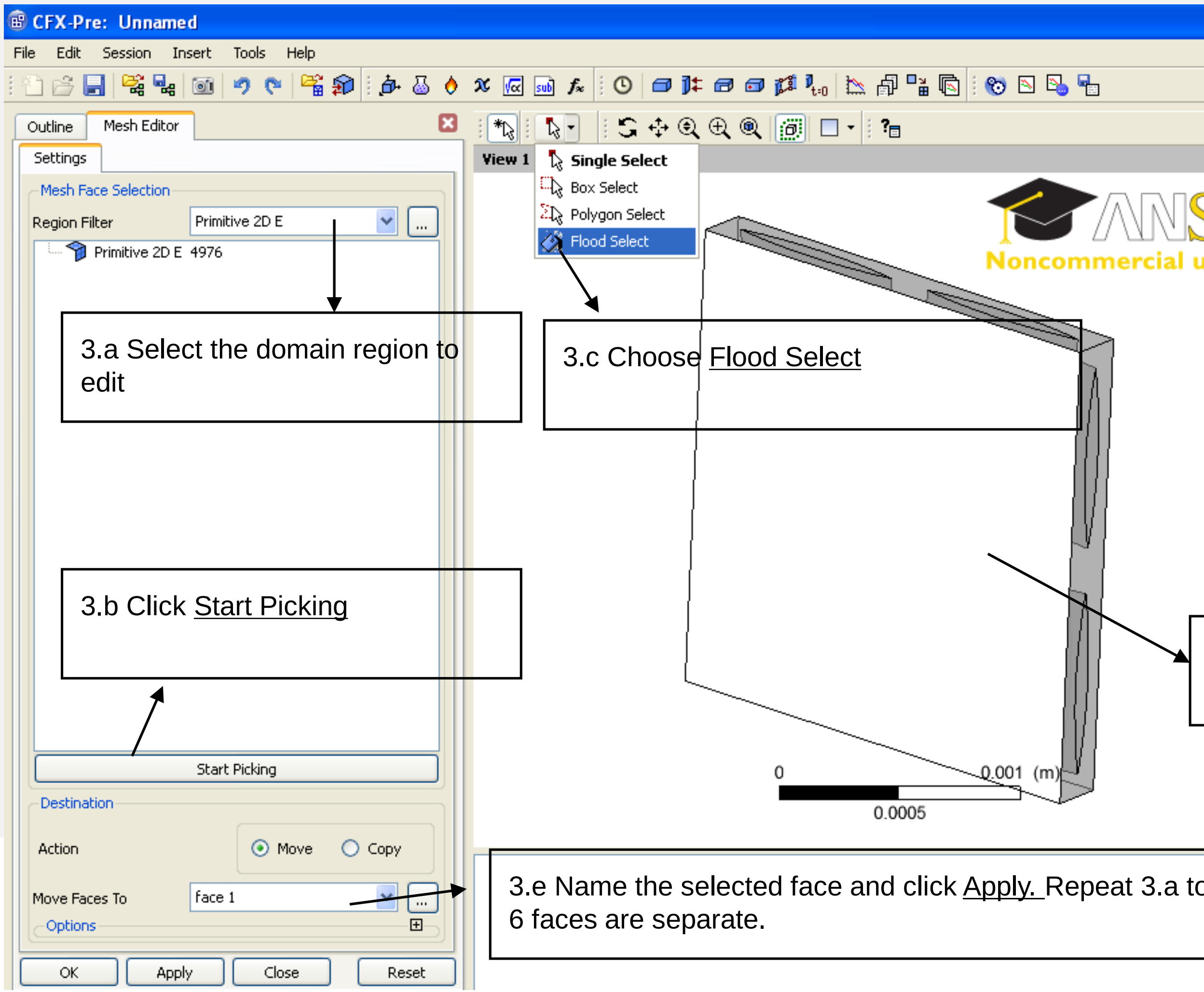
2.d If importing .vtk file choose CFXImportVTK.exe which is available on Sourceforge.

2.a Go to the folder where the volume mesh .vtu file is allocated

2.b Choose User Import (*) as in Files of type

3. Editing mesh in CFX

To organise the domain surfaces mesh into 6 separate regions which will be used for defining boundary conditions.



3.a Select the domain region to edit

3.b Click Start Picking

3.c Choose Flood Select

3.d Click on the face to be moved

3.e Name the selected face and click Apply. Repeat 3.a to 3.e till all 6 faces are separate.

4. Defining domains in CFX

To define the **fluid domain** for the gaps between yarns only.

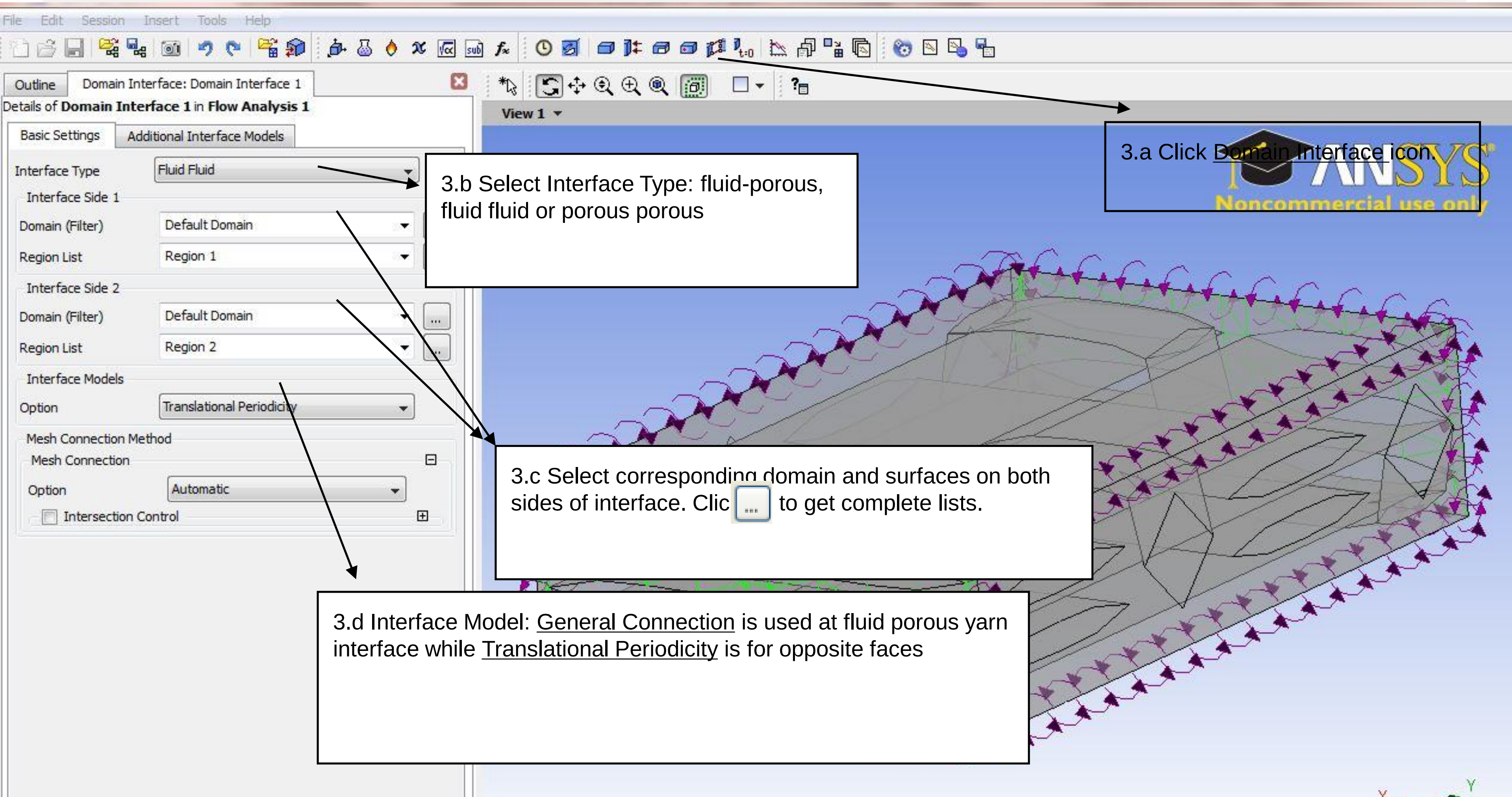
New domains are created by selecting **Insert** > **Domain** or clicking the *Domains* icon. Note that creation of domains from the menu bar or toolbar may subsequently require selection of the appropriate analysis type. Domains can also be created by right-clicking the appropriate analysis type in the **Outline** view.

For the fluid domain, the default setting is recommend in the **Basic Settings Tab**, and in **Fluid Models Tab** a **None (Laminar)** option is chosen for Turbulence Model.

Click OK/Apply

5. Domain interface

2 sets of interfaces is to be defined. 2 sets of **fluid fluid** interface with translational periodicity at opposite faces of the domain;



6. Boundary conditions

To define pressure drop on two faces along Z direction. Click Boundary icon 

In **Basic Settings Tab**, Boundary Type is chosen as Opening. Since the boundary surface is very close to fabric, Opening option allows the fluid to cross the boundary surface in either direction. Choose the appropriate region for Location.

In **Boundary Details Tab,** set the relative pressure in Pa.

7. Initialisation

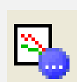
Click the global initialisation icon  to assign all the unspecified solution field values (an Initial Guess).

8. Solver Control

Right click Solver Control in **Outline,** select Edit.

In **Basic Settings Tab, Convergence control,** set the maximum iteration to 1000. **Convergence Criteria:** Set **Residual Type** as **RMS, Residual Target** to 1E-5.

9. Run Solver and Monitor

To start the analysis by clicking 

The simulation will terminate once the convergence criteria is satisfied or it reaches the maximum iterations.

10. CFD results

In CFX-Solver Monitor Window, when the simulation terminates normally, check Post-Process Results and click OK or launch CFD-Post by click Icon 

How to calculate fabric permeability?

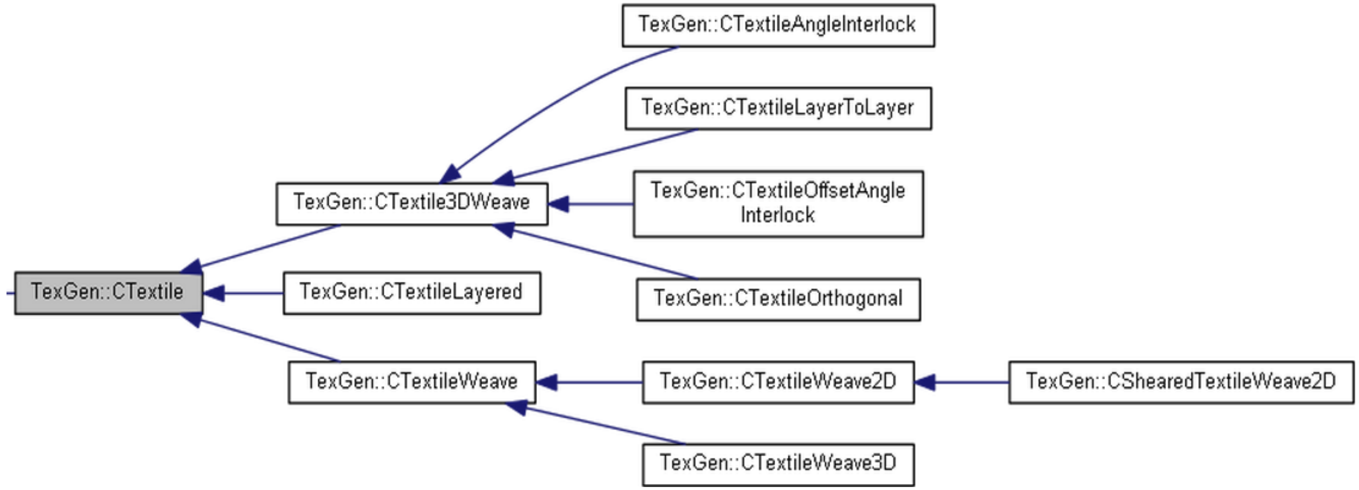
Go to **Calculator Tab,** choose **Function Calculator.** To obtain the values of flow cross-section area (*A*), areaAve pressure at the inlet (*P1*) and at the outlet (*P2*), mass flow rate at either inlet or outlet (m’). Given the air at 25c, its density (ρ) is 1.185kg/m^3, and its dynamic viscosity (μ) is 1.831E-5 Pa s. L is the unit cell thickness. Fabric permeability (*k*) follows Darcy’s law

$$\frac{m'}{\rho} = \frac{kA}{\mu} \frac{P_1 - P_2}{L}$$

Automatic Generation of Weaves

Automatically Generated Textiles

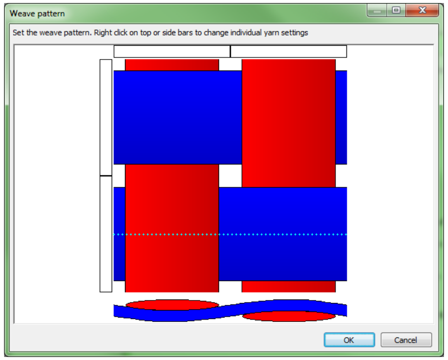
Predefined weave patterns are generated using classes which use Ctextile as a base class. They are used to input weave pattern information which then automatically generate the yarns.

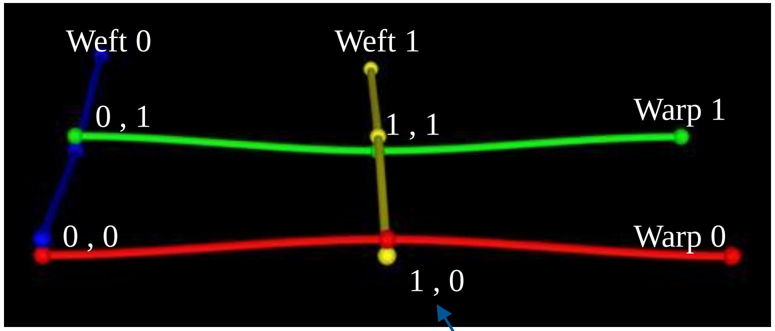


CTextileWeave2D

The 2D wizard in the TexGen GUI creates weaves using the CTextileWeave2D class

Whether the warp and weft are up or down is stored for each x,y position



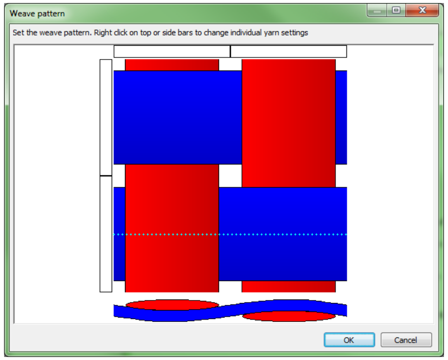


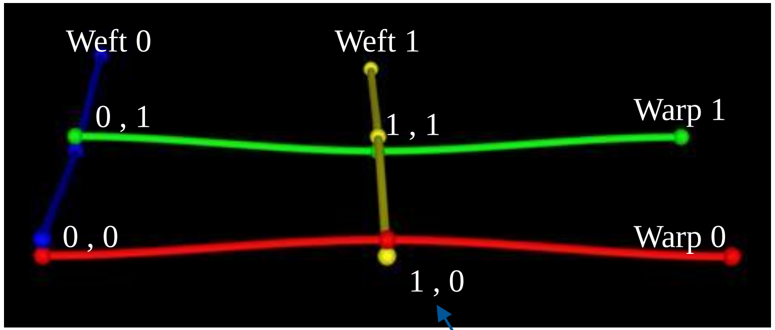
x, y position
Values stored: 0, 1
(Weft down, warp up)

CTextileWeave2D

The 2D wizard in the TexGen GUI creates weaves using the CTextileWeave2D class

Whether the warp and weft are up or down is stored for each x,y position





GUI: Set using Weave Pattern dialog

Python:

```
weave = CTextileWeave2D( numWefts,…
numWarps,spacing, thickness )
weave.SwapPosition(0, 0)
weave.SwapPosition(1, 1)
```

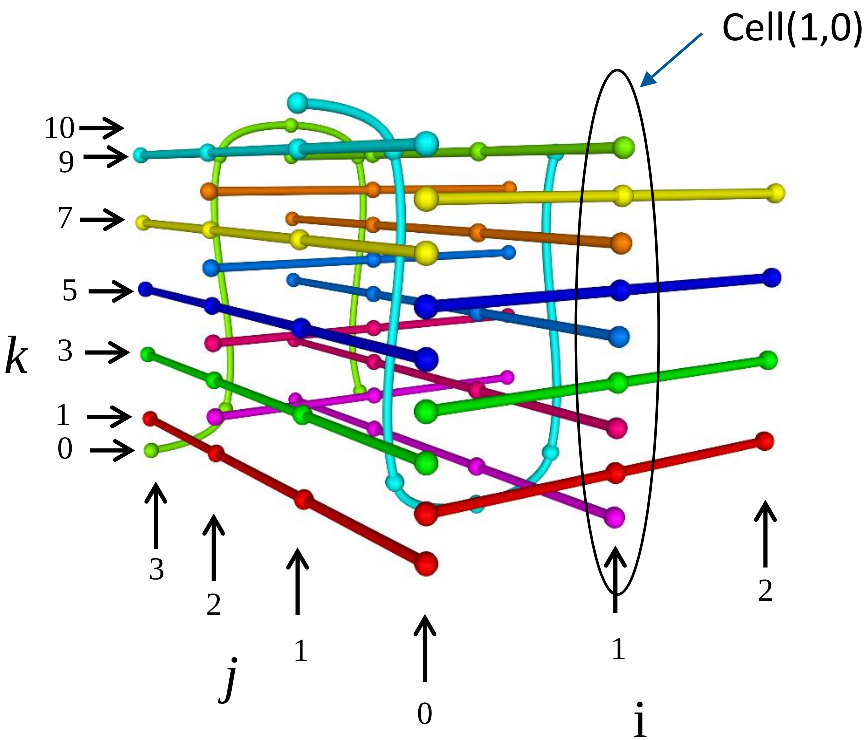
x, y position

Values stored: 0, 1

(Weft down, warp up)

These all use the CTextile3DWeave base class

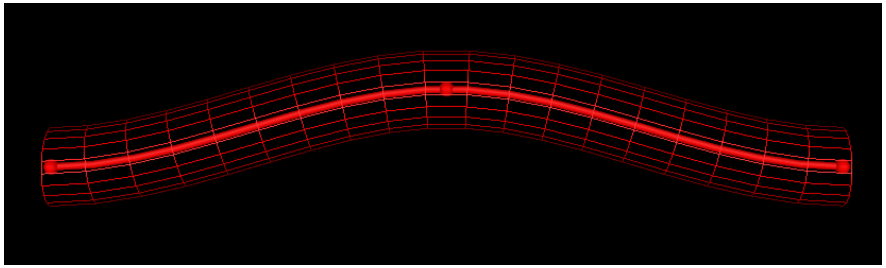
- Creates a grid of points at the yarn crossovers, specified in the GUI by the Weave Pattern dialog
- Each point may be warp, weft or no yarn
- The derived classes then automatically generate the yarn paths from this data
- Textiles using the base class can be created using a Python script



Saving and Export

Save File Format

- tg3 file – basically a renamed xml file
  - Three versions containing different levels of data
    - Minimal – textile data only (generated by the weave classes)
    - Standard – textile and yarn data
    - Full – textile, yarn and mesh data



Saving Images

Outputting images

- File -> Save Screenshot
- Saves as .png file
- Increase magnification to export with higher resolution
- Use Render->Change Background Colour to change to white (or desired) background

Yarn Properties

To export element volume fractions set up yarn properties, either for whole textile (all yarns same) or individual yarns

Modeller -> Assign Yarn Properties

Requires

Total fibre area

Or

Fibre density and yarn linear density

Or

Fibre diameter and number of fibres per yarn

Mechanical properties

Select required yarns then *Modeller -> Assign Yarn Properties*

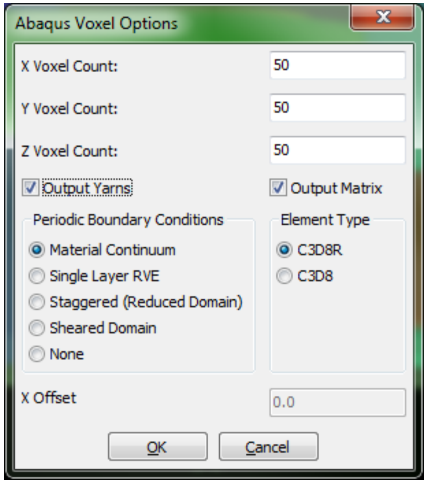
to set Young's modulus, Shear modulus, Poisson's ratio and coefficient of thermal expansion

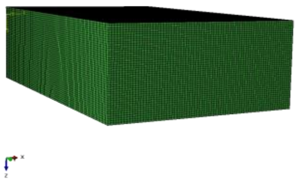
Select *Modeller -> Assign Matrix Properties* to set matrix properties

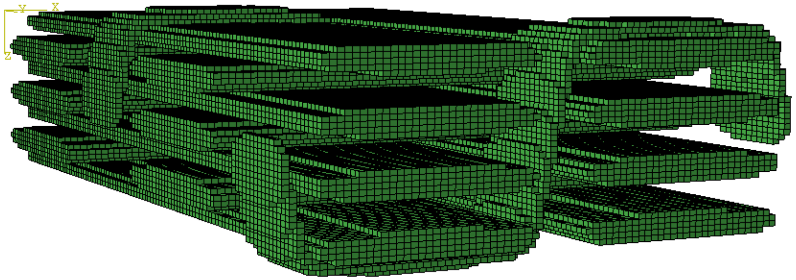
ABAQUS Voxel Export

GUI: Select *File -> Export -> ABAQUS File -> ABAQUS Voxel File*

- Hex elements
- Periodic boundary conditions and steps for extraction of material properties
- http://texgen.sourceforge.net/index.php/Extraction_of_Material_Properties_using_Voxel_Meshing_and_Abaqus





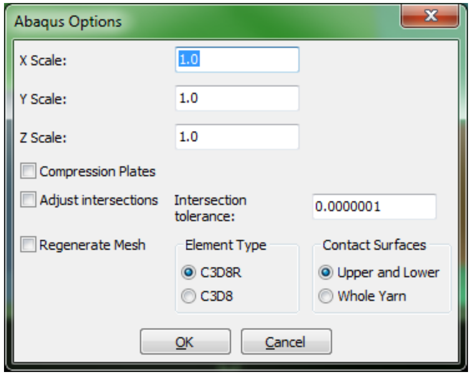


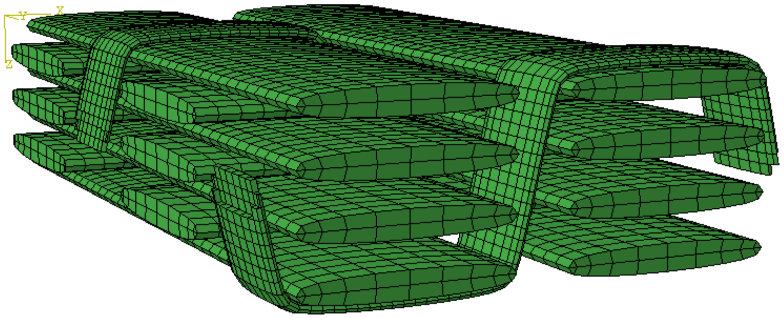
All ABAQUS exports include additional .ori and .eld files containing element orientation, fibre volume fraction and yarn information.

ABAQUS Dry Fibre Export

GUI: Select *File -> Export -> ABAQUS File -> ABAQUS Dry FibreFile*

- Conformal mesh using hex and wedge elements
- Uses weave pattern information to generate contact surfaces
- Correction for small intersections



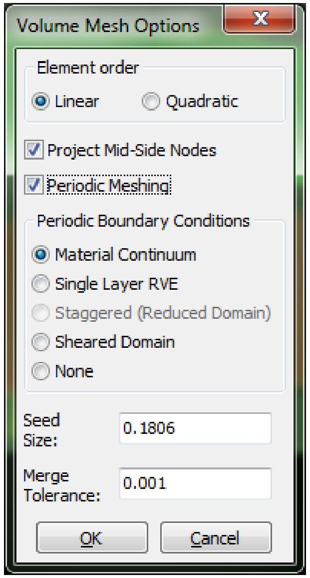


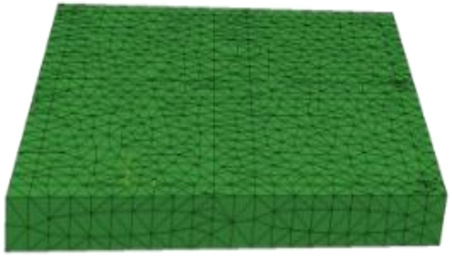
Conformal Mesh

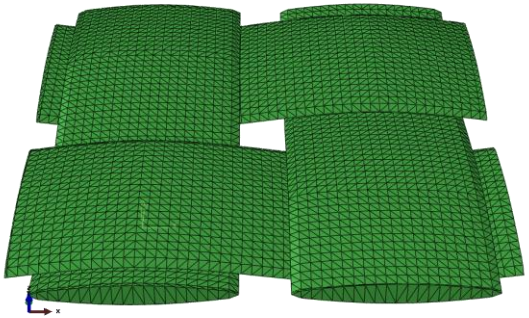
Volume Mesh

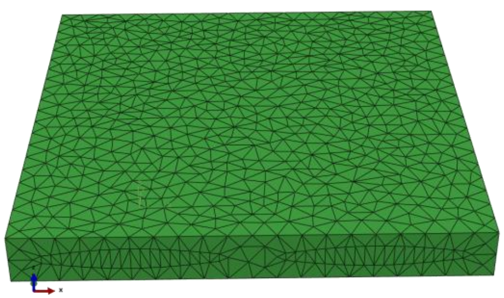
GUI: Select *File -> Export -> Volume Mesh*

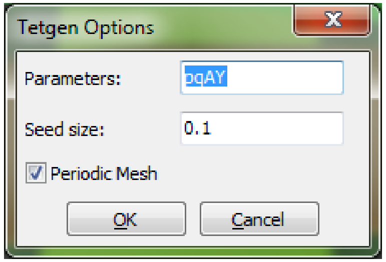
- Tetrahedral elements
- Save as ABAQUS .inp file or .vtu
- Works best for 2D weaves











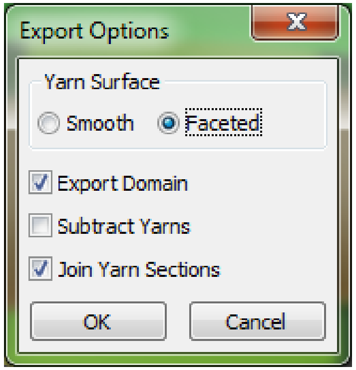
Tetgen Export

GUI: Select *File -> Export -> Tetgen Mesh*

- Tetrahedral elements
- Save as ABAQUS .inp file
- May need to introduce gap between yarns for export to be successful
- Uses Tetgen library: http://wias-berlin.de/software/index.jsp?id=TetGen&lang=1

Geometry Export

The geometry alone can be exported in IGES, STEP or stl format. No orientations, volume fractions or properties are exported.



GUI: Select *File -> Export -> IGES File*
or -> STEP File

- This option uses the OpenCASCADE library.
- The ‘Smooth’ option may be unsuccessful for more complex geometries
- ‘Join Yarn Sections’ will remove joins at repeat boundaries but is <u>much</u> slower

GUI: Select *File -> Export -> Surface Mesh*

- Exports the surface mesh as displayed by *Rendering -> X-Ray*
- Saves in .vtu or .stl format

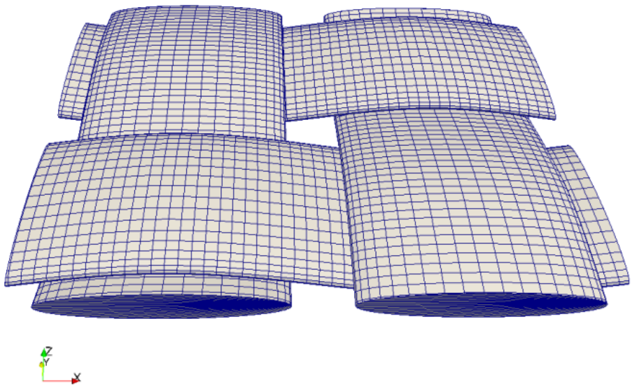
Geometry Export

IGES and STEP export

- Uses OpenCASCADE package to generate these
- Exports only the geometry
- Lose any orientation and volume fraction information

Surface Mesh exportExports the surface mesh as shown by the Rendering -> X-Ray option

- Surface mesh as shown by the Rendering -> X-Ray option
- Export with or without the domain
- VTK unstructured grid file (.vtu)
- ASCII or binary STL file (.stl or .stlb)
- SCIRun file (.pts)



.vtu surface mesh displayed in Paraview

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Manually creating textiles

Documentation

- User Guide for the TexGen GUI:
  - http://texgen.sourceforge.net/index.php/User_Guide
- API Reference Guide:
  - http://texgen.sourceforge.net/api/
- Scripting Guide with sample scripts:
  - https://github.com/louisepb/TexGenScriptingGuide

Create Textile

Each textile is created in a Ctextile object

GUI: Select *Textiles -> Create Empty* (Step 1)

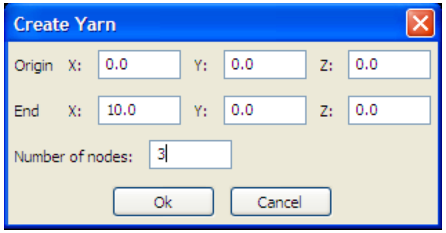
Python:

```
Textile = CTextile()
```

Create Yarns

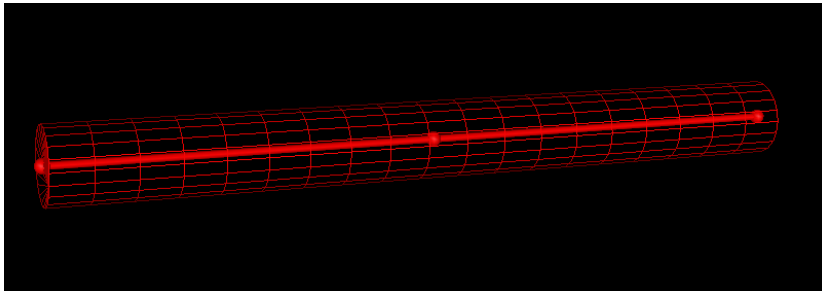
Yarns are denotes by a set of Master Nodes

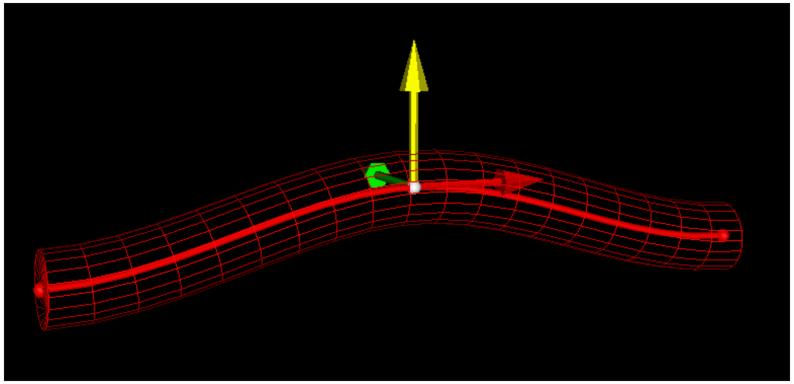
GUI: Select *Modeller->Create Yarn* (Step 2)



Python:

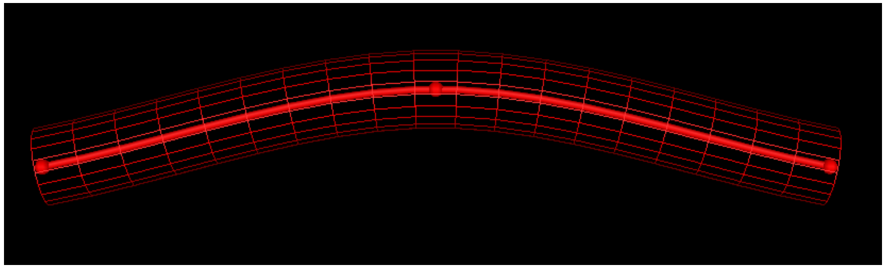
```
Yarn = CYarn()
Yarn.AddNode(CNode(XYZ(0,0,0)))
Yarn.AddNode(CNode(XYZ(5,0,1)))
Yarn.AddNode(CNode(XYZ(10,0,0)))
```





Interpolation Between Nodes

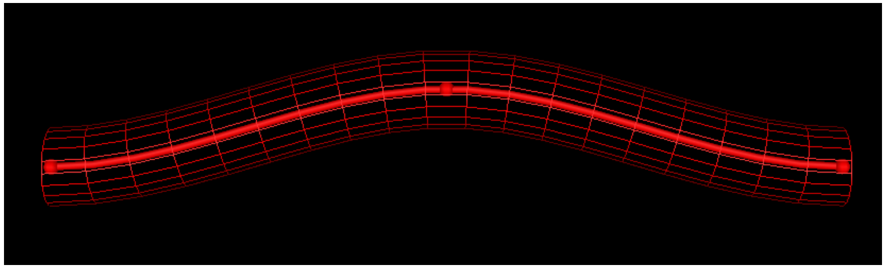
A path is generated between the master nodes by an interpolation function



GUI: Select *Modeller -> Interpolation*

- Bezier spline
- Natural cubic spline
- Linear spline

- Periodic – select to maintain continuity across yarn repeats



Python:

```
Yarn.AssignInterpolation(CInterpolationCubic())
```

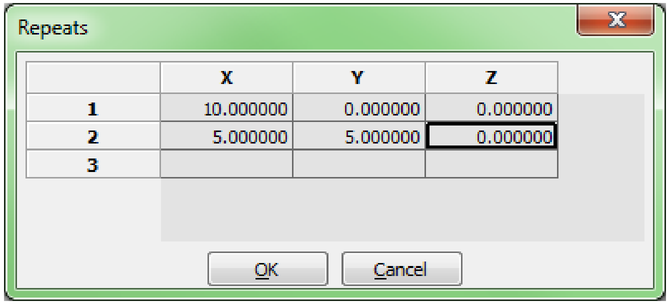
Defaults to periodic, send False as parameter to CInterpolationCubic() for non-periodic interpolation

Yarn Repeats

Yarn repeats allow a given yarn section to be repeated as specified by a set of vectors (in theory, allowing an infinite textile)

GUI: Select *Modeller -> Assign Repeats*

- Specify a set of repeat vectors



Python:

```
Yarn.AddRepeat(XYZ(10,0,0))
Yarn.AddRepeat(XYZ(5,5,0))

Textile.AddYarn(Yarn)
```

Domain

The domain restricts the model to a specific region

- Specified by a set of convex planes
- Typically, but not always, the unit cell

GUI:

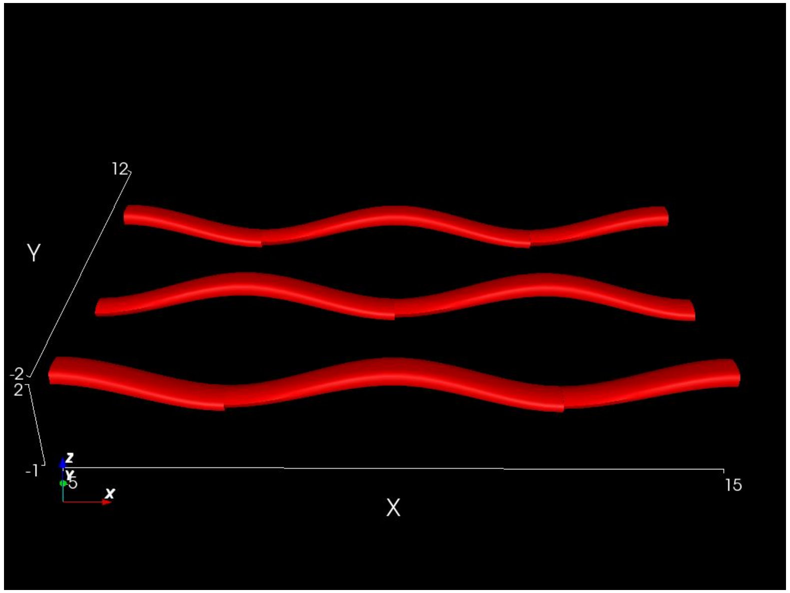
Select *Domain -> Create Box*

- Input minimum and maximum x,y,z values for bounding box

Or

Select *Domain -> Create Planes*

- Input required number of planes specified by the unit normal to the plane and its distance from the origin



Python:

```
Textile.AssignDomain(CDomainPlanes(XYZ(-5,-2,-1),XYZ(15,12,2)))
AddTextile("Workshop", Textile)
```

or:

```
Planes = PlaneVector
Planes.push_back(PLANE( XYZ(1,0,0), 0)) #Repeat for set of planes
Textile.AssignDomain(CDomainPlanes( Planes ))
AddTextile("Workshop", Textile)
```

Creating Sections

Cross-sections are created and assigned to an object derived from the CYarnSection base class which is then assigned to a yarn

Syntax for creating different shaped sections:

```
Shape = CSectionEllipse( width, height)
```

```
Shape = CSectionLenticular( width, height, distortion)
```

```
Shape = CSectionPowerEllipse( width, height, power, xoffset)
```

```
Shape = CSectionRectangle( width, height)
```

```
Shape = CSectionEllipse( width, height)
```

Polygon Sections

Set up a vector of xy points and then use this to create the polygon section:

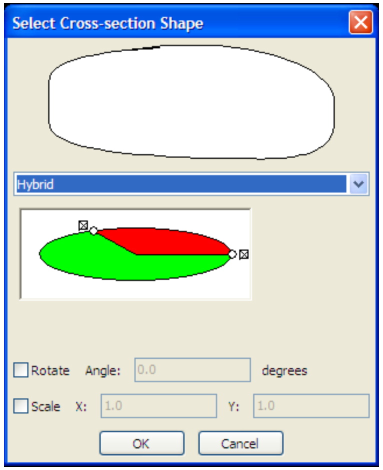
```
Points = XYVector()

Points.push_back(XY(1.47887, -0.080294))
Points.push_back(XY( 1.1267, 0.0421169))
       :
       :
Points.push_back(XY( 1.10991, -0.133933))

Shape = CSectionPolygon(Points)
```

Hybrid Sections

Hybrid sections are generated by combining several different sections

GUI: Select *Hybrid* in the Select Cross-section Shape dialog

- Click on 2 or more points outside the shape in the lower window to specify the divisions for the shapes to be assigned.
- Click within each section in turn to specify the shape to be used.



Hybrid Sections

Python:

```
# Specify two sections with a horizontal division
Top = CSectionEllipse( 1.0, 0.4 )
Bottom = CSectionPowerEllipse( 1.0, 0.4, 0.4, 0.25 )
Hybrid = CSectionHybrid( Top, Bottom )
```

```
# Specify four sections in quadrants
Hybrid = CSectionHybrid( TopRight, TopLeft, …
                              BottomLeft, BottomRight )
```

```
# Specify individual parts
HybridSection = CSectionHybrid()
# Add as many divisions as required
Hybrid.AddDivision(0)
Hybrid.AddDivision(0.3)
# Specify section for each division
Hybrid.AssignSection(0, CSectionLenticular(1.0,0.4))
Hybrid.AssignSection(1, CSectionEllipse(1.0,0.4))
```

Rotated Sections

Sections can be rotated. Create the required section and then rotate

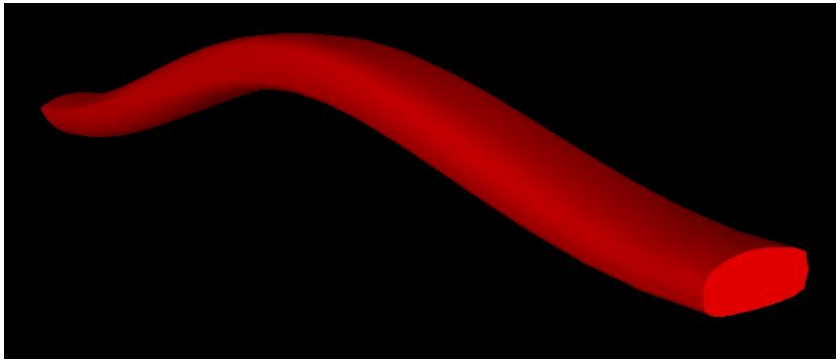
Python:

```
CSectionRotated(CSectionEllipse(1, 0.1), math.radians(45))
```

Yarn Cross-Sections – Python Implementation

Python:

```
YarnSections = CYarnSectionInterpNode()
YarnSections.AddSection( CSectionLenticular(1.0,0.5,0.1) )
YarnSections.AddSection( CSectionPowerEllipse(1.0,0.5,0.4,0.25) )

# Hybrid Section
Top = CSectionEllipse( 1.0, 0.4 )
Bottom = CSectionPowerEllipse( 1.0, 0.4, 0.4, 0.25 )
YarnSections.AddSection( CSectionHybrid( Top, Bottom ) )

Yarn.AssignSection( YarnSections )
```



Resources

User Guide:
http://texgen.sourceforge.net/index.php/User_Guide

Scripting Guide:
https://github.com/louisepb/TexGenScriptingGuide

TexGen source code:
https://github.com/louisepb/TexGen

Workshop materials:
https://github.com/louisepb/ICMAC2018-Workshop