Meso-modeling of 3D Woven Composites

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ABSTRACT

• **What are composites?**

Composites are composed of two or more separate materials that, when combined, lead to improved properties over the individual components. They have extraordinary advantage when weight limitation is critical (aeronautics, sports, marine applications).

- **UD or Woven Composites?**

There are 3 types of composites in terms of the alignment of fibrous reinforcement:

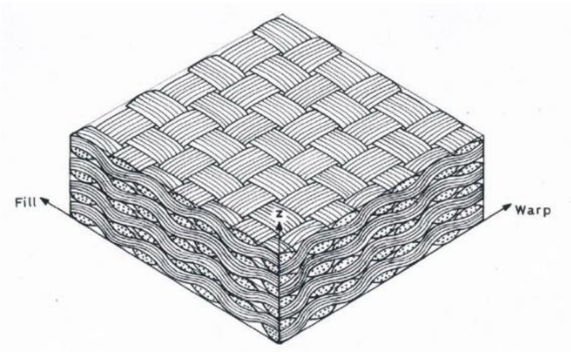
UD: Fibre tows lie in the same direction (x direction)

2D: Fibre tows lie in two orthogonal direction (x-y)

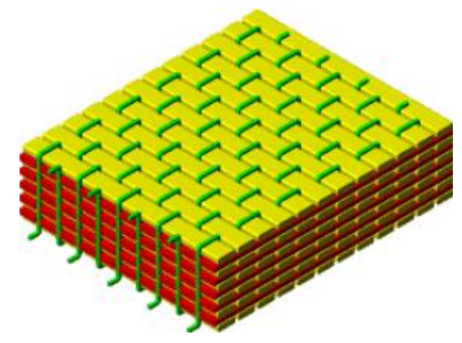
3D: Additional to 2D, there are fibre tows lie in thickness direction (x-y-z directions)

Even though UD can carry more load along its fibers, it is weaker in the other directions hence woven composites (2D and 3D) are more preferable.


UD composite prepreg



2D woven composite unit cell


3D woven composite unit cell

- **Why modeling woven composite materials?**

In material design it is important to know the mechanical properties. To obtain mechanical properties experiments or simulations can be used. Since mechanical tests are costly and destructive, simulations are more feasible and environment-friendly. Simulations primarily require the geometrical data of the structure, which is the most complex for 3D woven composites. Therefore, researchers are still improving the models of these materials.

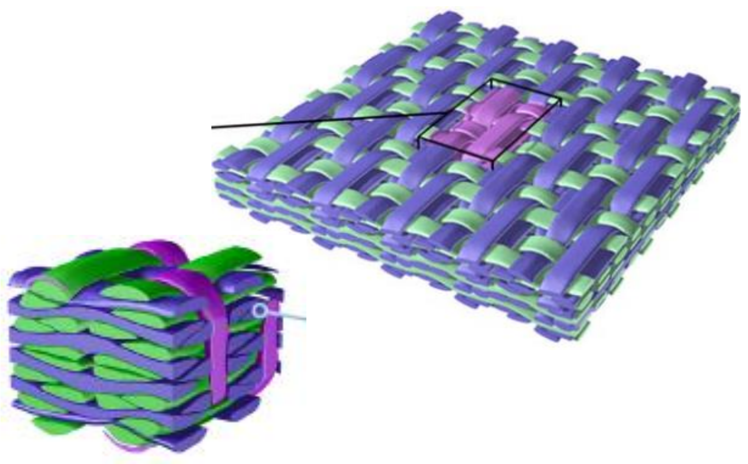
- **Why Modelling in Meso Scale**?

Woven composites include ideally repeating unit cells, so modeling these instead of the whole structure is recommended.

Macro scale (> 5 mm): useful only if the meso-properties of the composite are known

Micro scale (100 nm to 100 µm): modeling fibres one by one is not within the scope of this project.

Meso Scale (0.1 mm to 5 mm): applicable when the elastic properties of fibres and resin are known. The output can be used in macro scale analyses too.


3D Woven Composite Model and its unit cell (Drach A., et al, 2004)

A 3D RUC consists of 3 types of yarns:

Weft fibre tows in x direction (shown in green)

Warp tows in y direction (in purple)

Z Binders tows in z direction (in pink)

OBJECTIVES

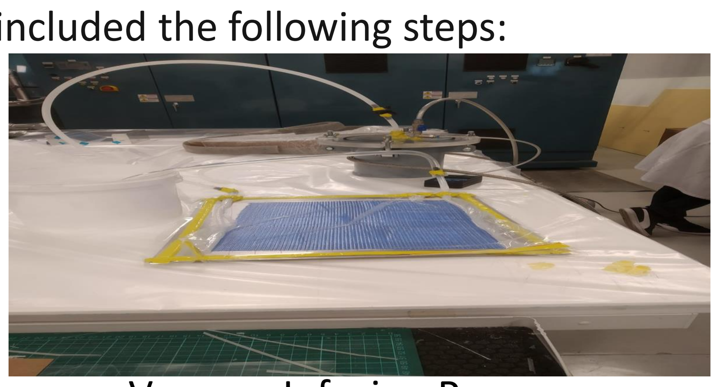
Designing a realistic Meso Model of 3D orthogonal woven composite using CAD software and generating an improved quarter meso model of the ideal RUC so that they will be ready for finite element analysis are the two main objectives of the project.

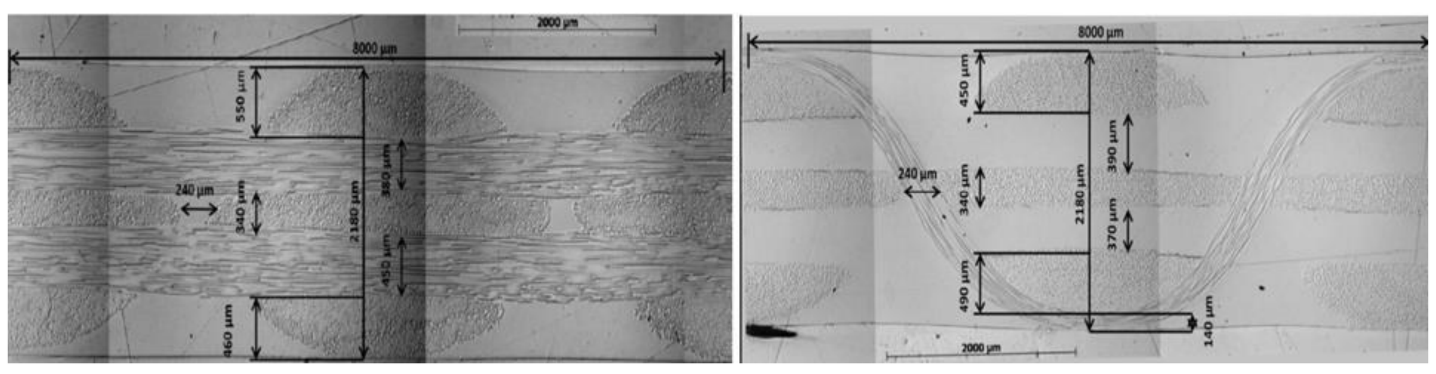
METHODOLOGY

1. Vacuum infusion and Optical Microscopy

In order to understanding geometrical data of the Unit Cell that will be modelled, a composite sample is manufactured with vacuum infusion method. Samples are inspected with Optical Microscope. Vacuum Infusion process included the following steps:

- Preform preparation
- Sealing
- Vacuum application → resin impregnation
- Oven Curing
- Part removal

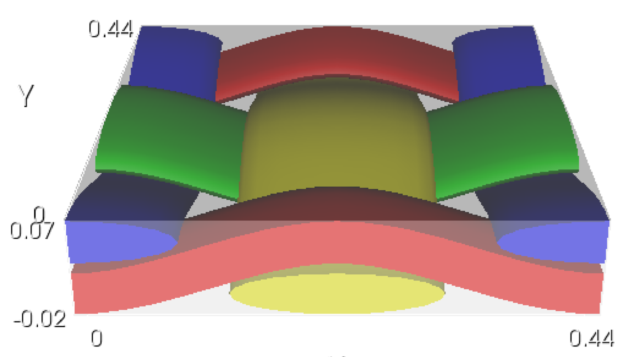

Vacuum Infusion Process


Microscope images of an E-glass/epoxy 3D orthogonal woven composite specimen

2. Using Textile Generators

- Provides 2D and 3D weave preforms
- Best for understanding the fabric structure

TexGen generates unit cells with parameters such as: Number of weft/warp/z binder, distances among yarns, yarn thickness, height of yarns…

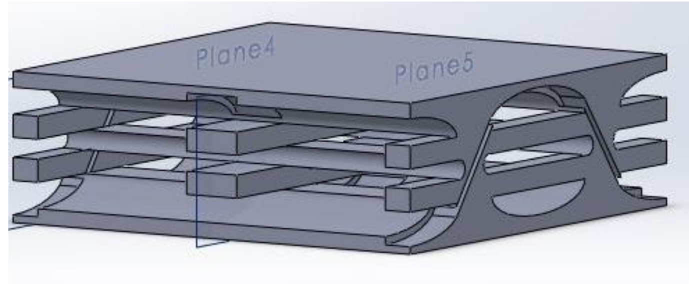

2D Unit Cell Generated by TexGen

TexGen files can be exported to ANSYS in various file types. However, not every FEA program can accurately import these files for analysis. Also with TexGen, geometrical shape of the model is not realistic hence, using TexGen model in simulations is not beneficial for the scope of the project.

3. CAD-Generated Unit Cell Model

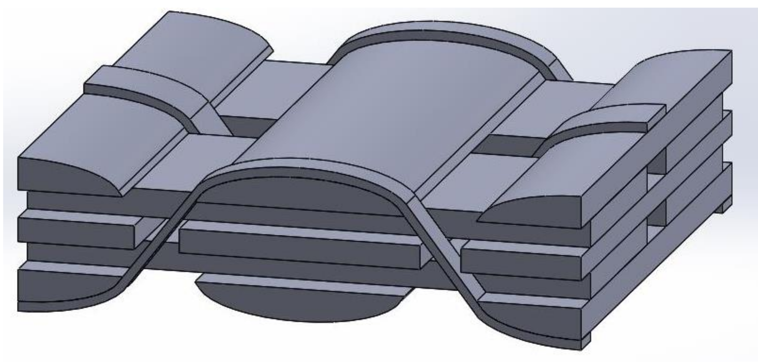
CAD model includes:

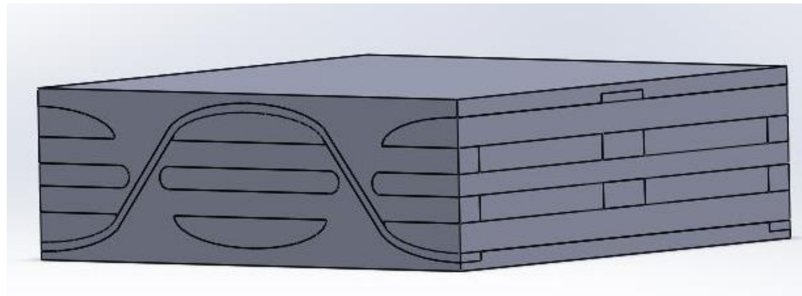
- Realistic z-yarn shapes as seen under microscopy
- Warp volumes: Increased by sacrificing weft thicknesses
- Weft volumes: Decreased to increase warp volumes


1st CAD Model for Resin

Solidworks modeling steps:

1. 2D FrontView Sketch and Extrusion (RUC)
2. Merging yarns with each other
3. 2D FrontView Sketch and Extrusion (Resin Structure)
4. Subtracting the yarn assembly from Resin part
5. Obtaining resin and yarns as separate solid parts for analysis


2nd CAD Model for RUC

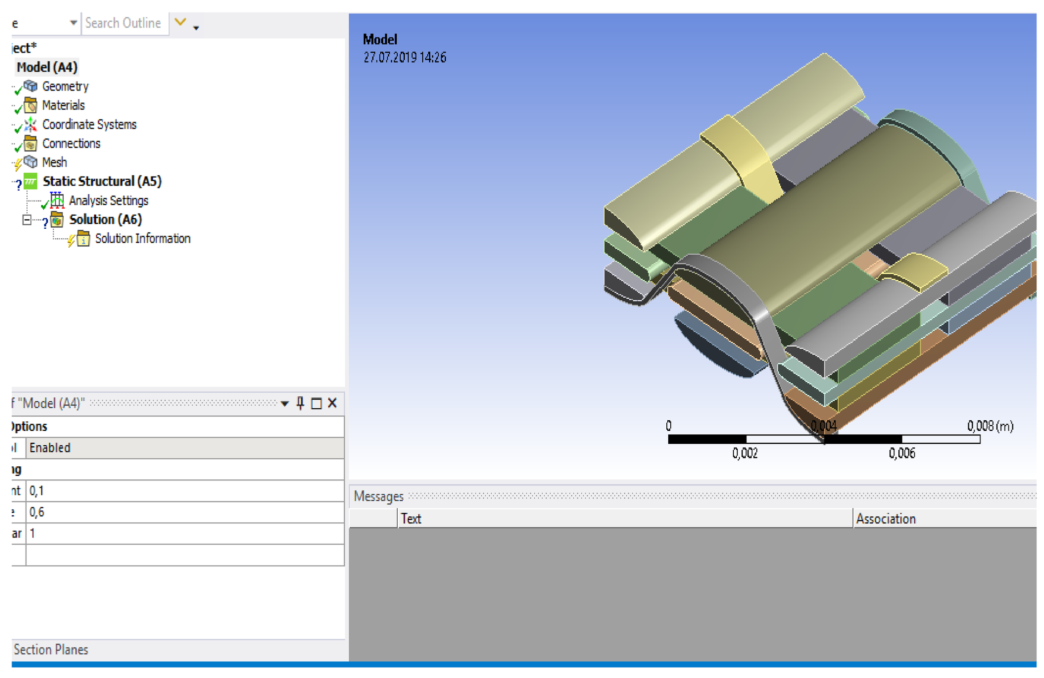

Assembled parts of 1st model

4. Steps For Finite Element Analysis

- Imported as a STEP file from the Solidworks program in ANSYS static structural section.
- Yarn and resin material elastic properties were assigned to the model (carbon fibre properties to yarns, E-glass epoxy properties to resin).
- Material orientation is defined by using local coordinate systems.
- Meshing of the yarns and the resin piece (hexagonal mesh is preferred).
- In the model "fabric-resin contact surface pairs" were automatically given by the program, however they are checked if there is any missing contact region.

$E = 2$ GPa	$E_x = 46$ GPa	$G_{xy} = 5$ GPa	$\nu_{xy} = 0.3$
$\rho = 1.16$ g/cm^3	$E_y = 13$ GPa	$G_{xy} = 5$ GPa	$\nu_{xz} = 0.3$
$\nu = 0.4$	$E_z = 13$ GPa	$G_{xy} = 4.6$ GPa	$\nu_{yz} = 0.42$

Material properties of the isotropic Bisphenol-A epoxy resin and resin impregnated E-glass yarns


RUC of the 3D woven composite that is exported from Solidworks into ANSYS

CONCLUSION & FUTURE WORK

Two different ideal RUCs are modelled using SolidWorks. First model allows finite element analysis, yet geometrical shape of the resin is not suitable to meshing, requiring improvement. In the second model the error-causing shape of the weft yarns were corrected, however the resin cutting operation could not be completed. Two options can be selected: using the first model and meshing the resin randomly (sacrificing hexahedral mesh) while this can still cause problems in contact pair formation thus converging a solution; or drawing the weft yarns accordingly to obtain a resin that can be meshed structurally. Completing the mesh, the FEA will be executed and overall elastic modulus, deformation and critical stress regions in the model can be obtained.

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