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Designing, Optimizing and Simulating the Mechanical Properties of Composite Lattice Reinforced Plastics With FEA

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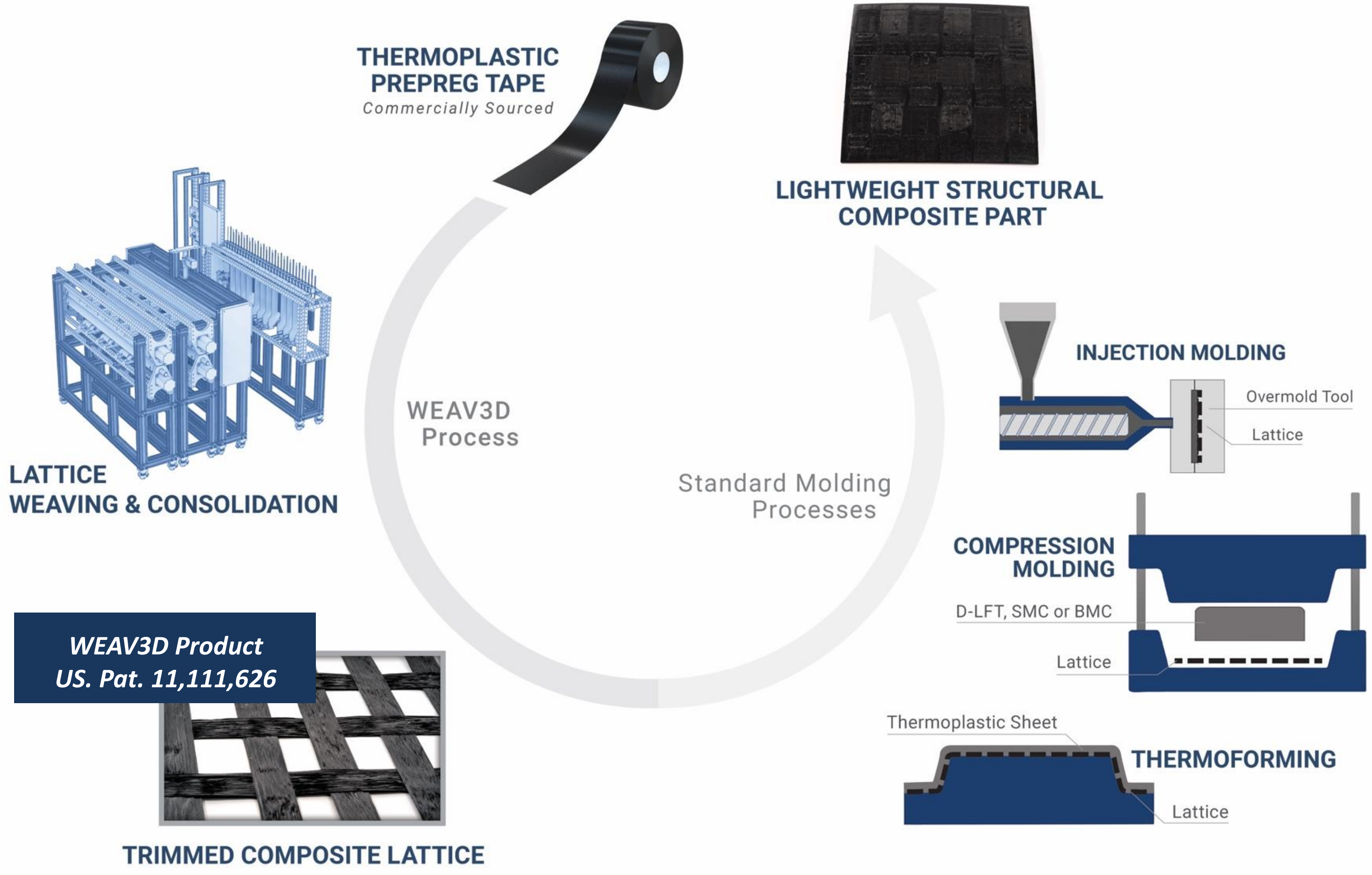
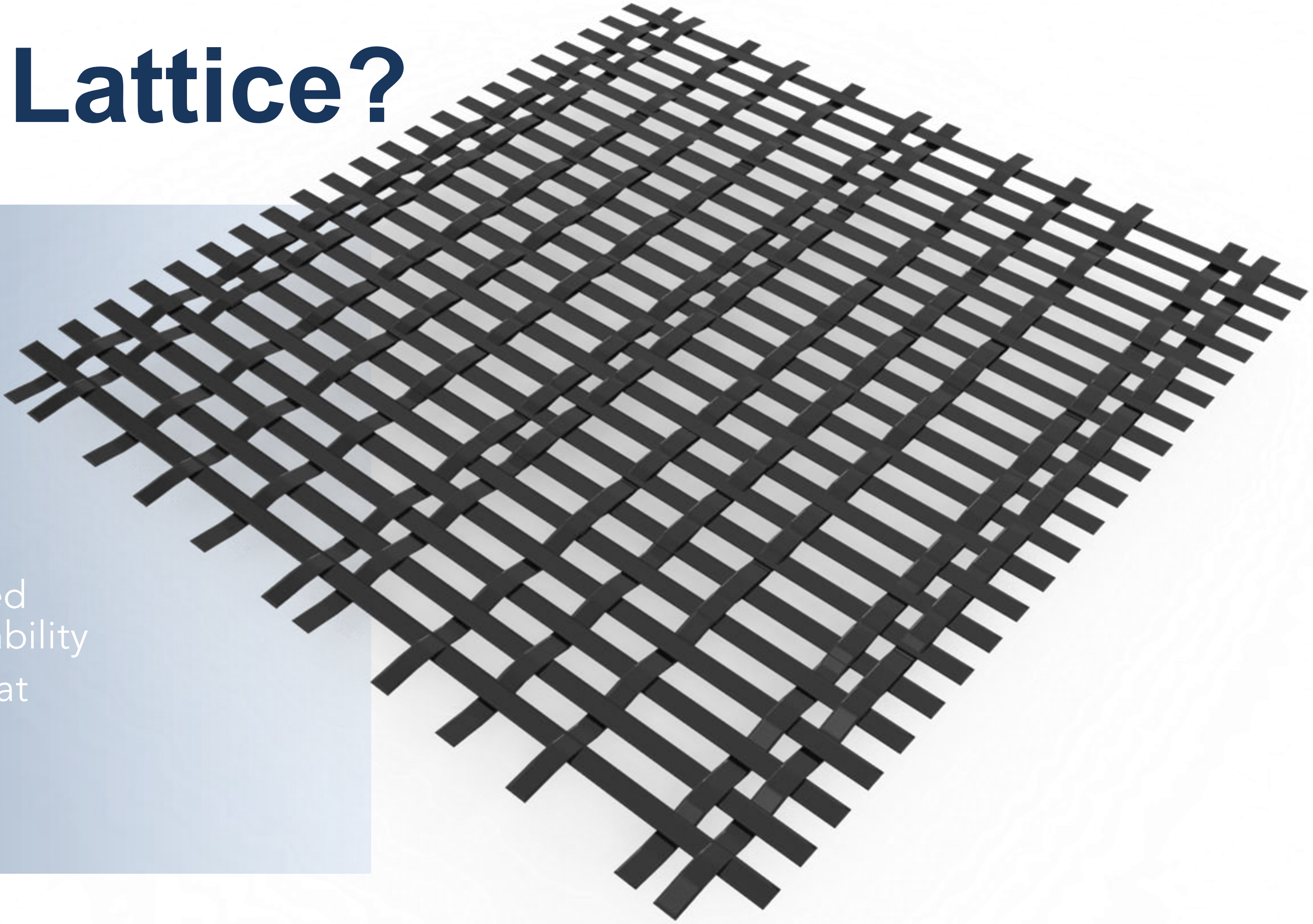
Outline

- Hybrid Overmolding – Rebar for Plastics®
- Key Terminology
- Experiment Design
- FEA Workflow for Hybrid Materials
- Experimental Results
- Conclusions

Rebar for Plastics® — Process Overview



Why Composite Lattice?



TUNABLE

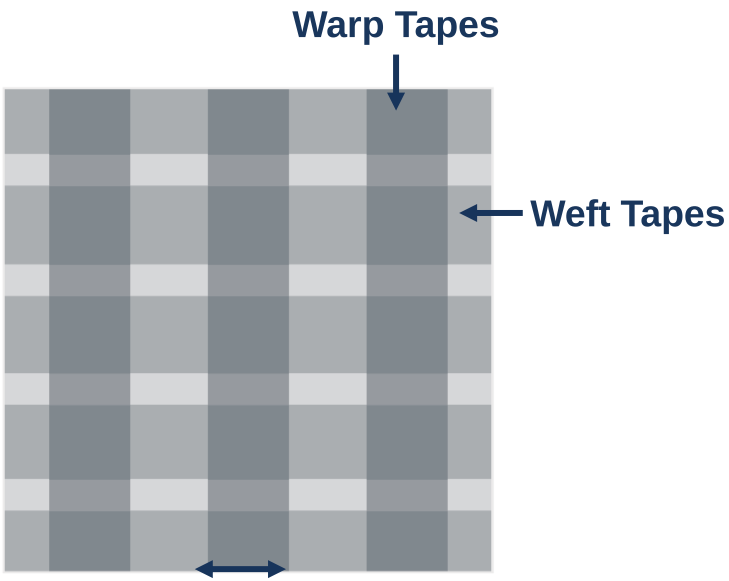
Locally optimized:
- Lattice density
- Tape material

HANDLEABLE

- Woven and welded at interlace for stability
- Sheet or roll format

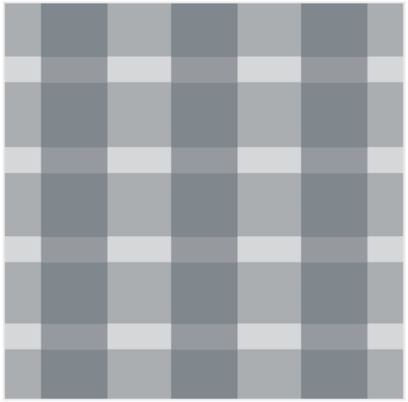
Strategic use of UD tapes in lattice provides a cost-effective and adaptable solution

Key Terminology

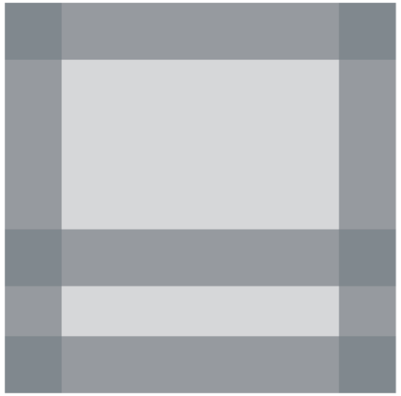


Standard tape width: 25.4mm (1 in)

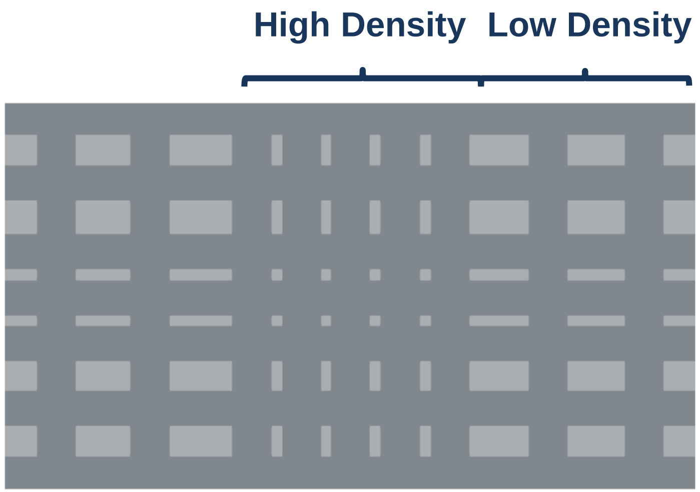
- **UD Tape:** a unidirectional fiber reinforced polymer tape
- **Warp Tape:** a UD tape that runs in the machine direction (Y-axis)
- **Weft Tape:** a UD tape that runs in the cross-machine direction (X-axis)
- **Homogenous lattice** : Centre to Centre tape (C-to-C) spacing between tapes and tape materials are constant throughout the part geometry
- **Heterogenous lattice** : Centre to Centre tape (C-to-C) spacing between tapes and/or tape materials varies throughout the part geometry
- **Weave Density:** relative C-to-C spacing within lattice



Homogenous Lattice



Heterogenous Lattice



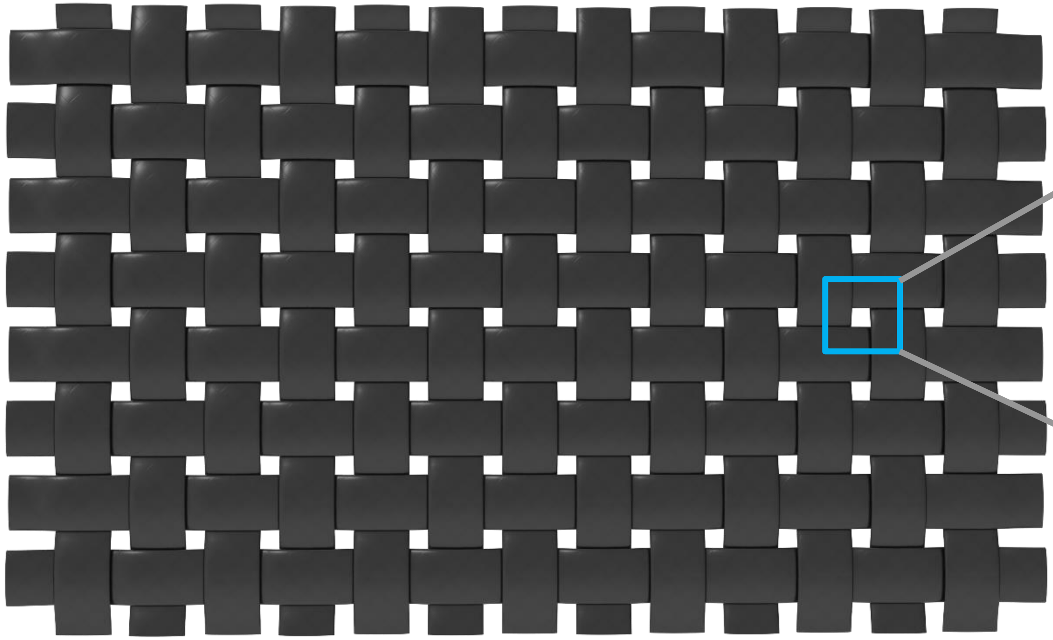
Previous Approach and Challenges

- Most commercially available FEA models are designed for ply-based composites, with fiber type, orientation, volume fraction, and weave type defined on a "per-ply" basis

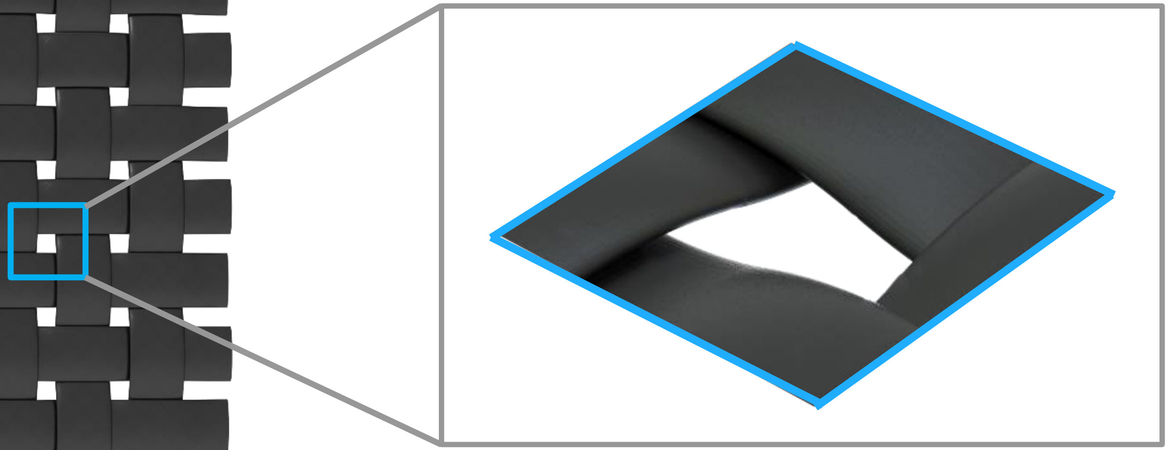
- Hybrid structures, particularly lattice-reinforced hybrid structures, have additional degrees of freedom that cannot be fully captured within traditional ply-based models

- Prior work at Georgia Tech leveraged MATLAB 2017a to create a hybrid analytical/finite element model

What is a Representative Volume Element?



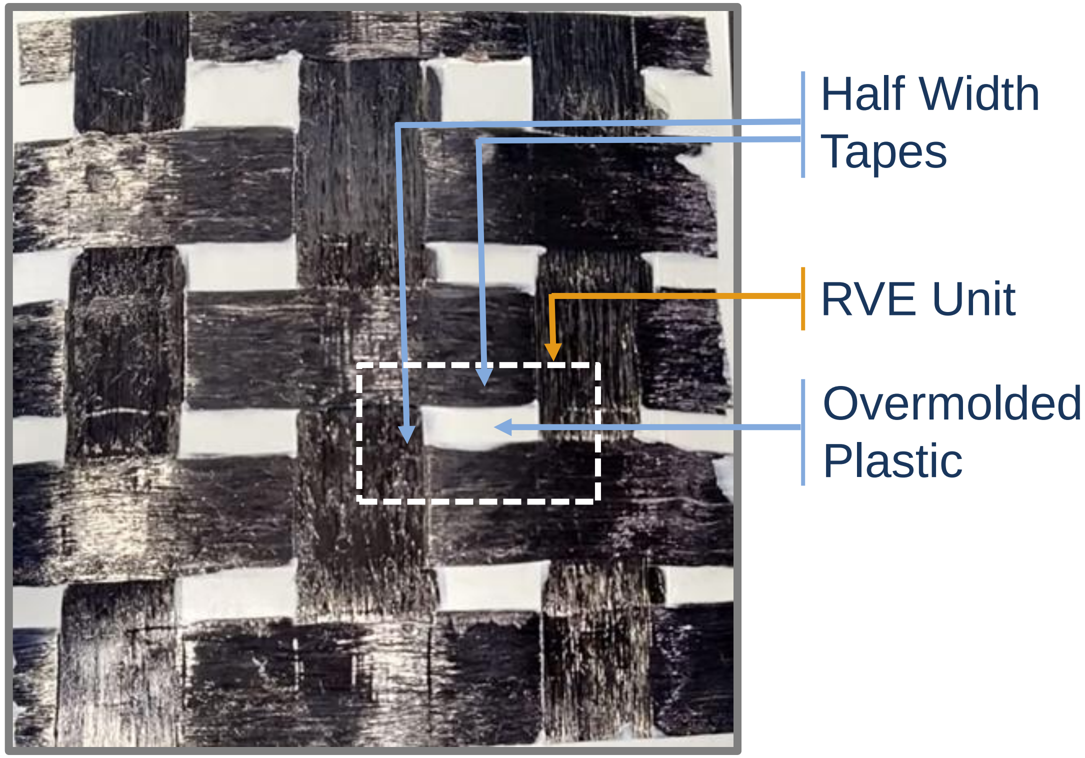
Lattice Structure

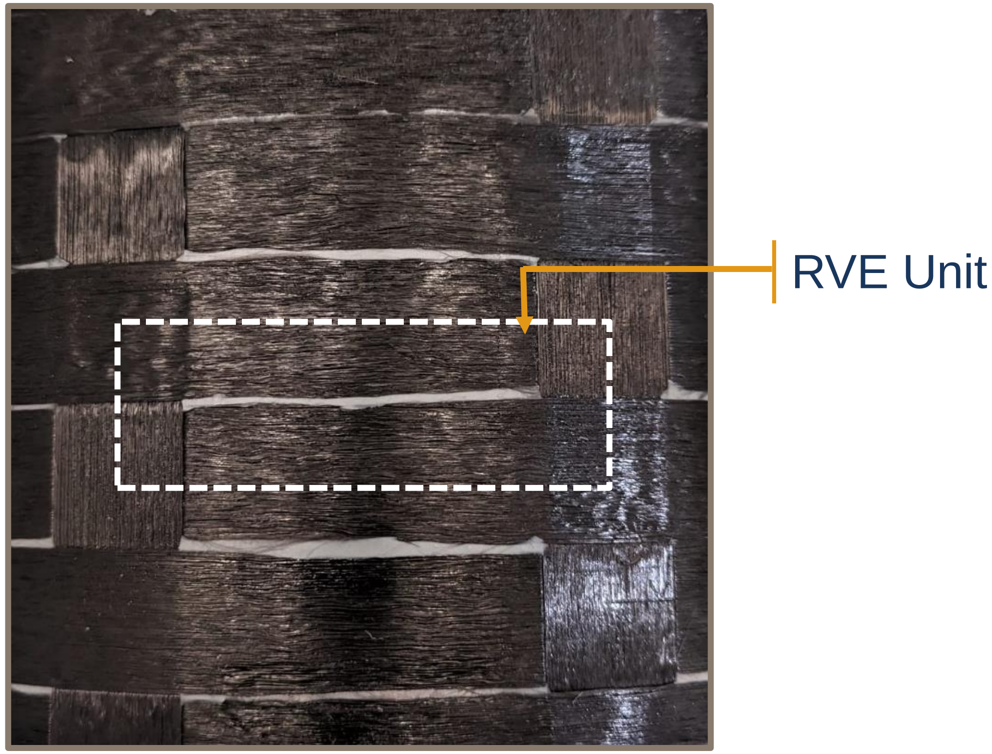


RVE of the Lattice Structure

RVE is uniformly repeated over the domain of a given region and the effective constitutive properties of the unit cell characterize the entire domain as well.

Representative Volume Elements (RVEs) in WEAV3D Samples





FEA Workflow Overview

Develop
Representative Volume Element in ANSYS Material Designer

Build
3D Shell Part in ANSYS ACP

Solve
FEA

Identify
Critical Stress Regions

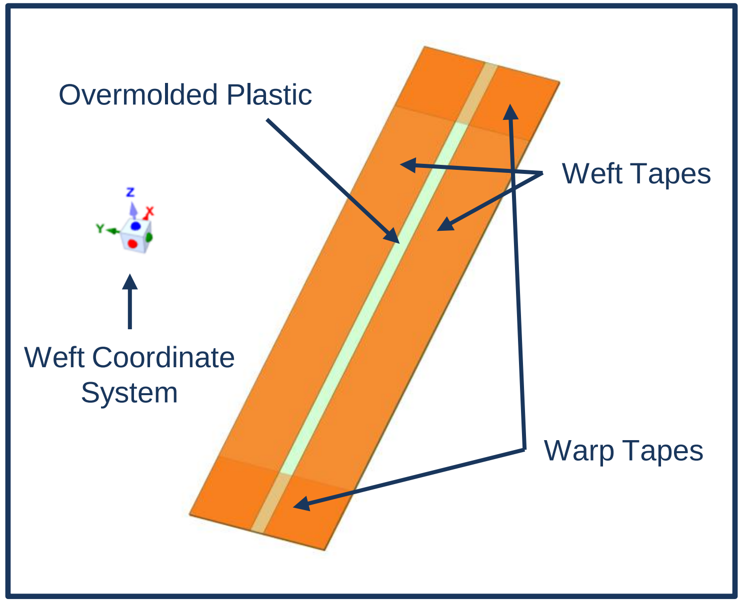
Submodel
Distinguish stresses in UD tapes and overmolded plastic

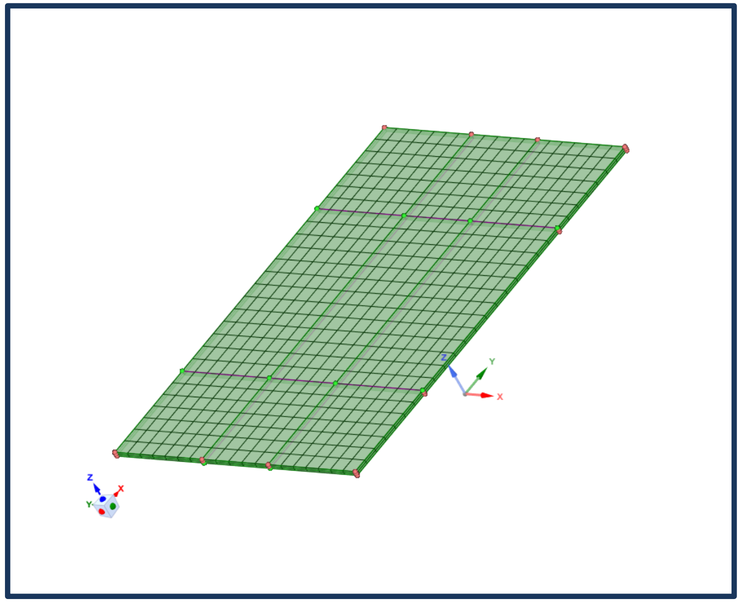
Experiment Design for Flexural Samples

- Plaque dimensions : 6.25 in X 6.25 in X 3mm
- Plaque designs were initially developed using the MATLAB model

Design No.	Tape Material	Overmolded Plastic Material	Weft Tape Spacing, C-to-C, inches	Warp Tape Spacing, C-to-C, inches	Single Tape Thickness, mm	No. of Lattice Layers
1	Carbon/PC **(44%Vf)**	Unfilled PC/ABS	1.75	2	0.17	3
2	Carbon/PC **(44%Vf)**	Unfilled PC/ABS	1.5	2	0.17	3
3	Carbon/PC **(44%Vf)**	10% Glass filled PC/ABS	1.1	2	0.17	3
4	Glass/PA6 **(39.5%Vf)**	30% Glass filled PA6	1.38	2	0.25	2
5	Carbon/PA6 **(39%Vf)**	30% Glass filled PA6	4.76	4	0.25	1
6	Carbon /PA6 **(39%Vf)**	30% Glass filled PA6	1.11	4	0.25	1

Develop RVEs using ANSYS Material Designer





E1	1.2702E+10	Pa
E2	9.667E+09	Pa
E3	3.9889E+09	Pa
G12	8.1385E+08	Pa
G23	7.6434E+08	Pa
G31	7.4516E+08	Pa
nu12	0.10082	
nu13	0.55552	
nu23	0.58653	
Density		
rho	1564.3	kg m^-3

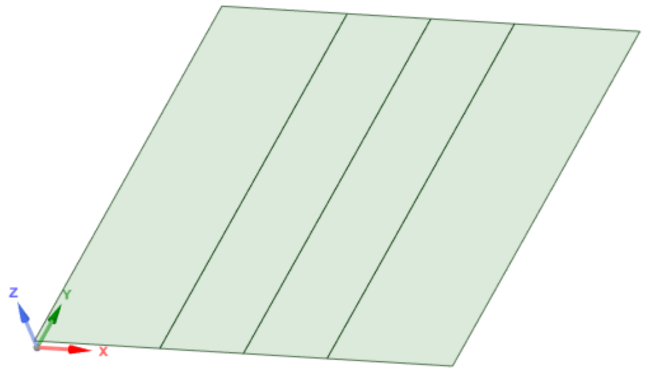
Develop RVE geometry

ANSYS Material Designer

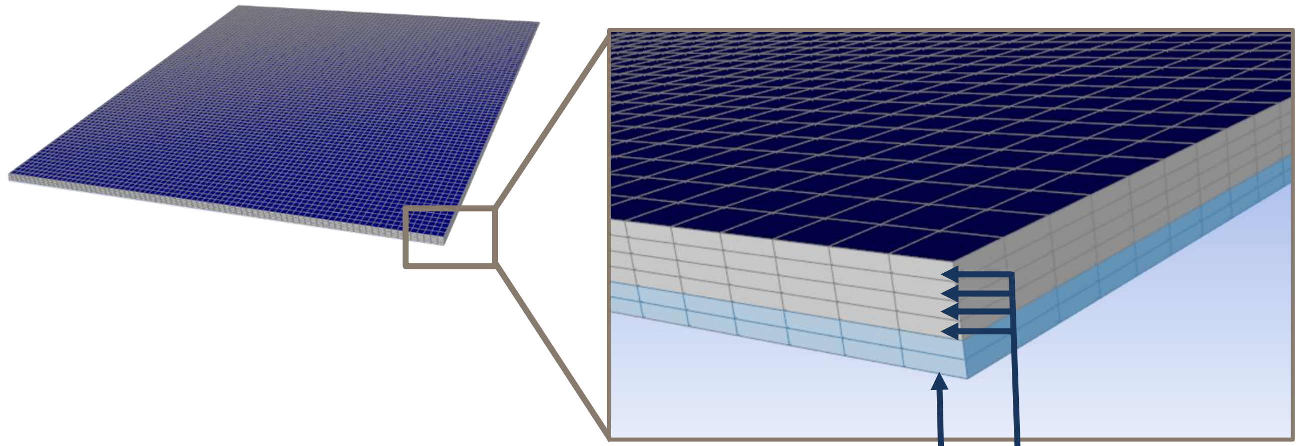
- Assign material properties
- Mesh the geometry

Solve to obtain the orthotropic properties

Creating the Plaque Thickness in ANSYS ACP

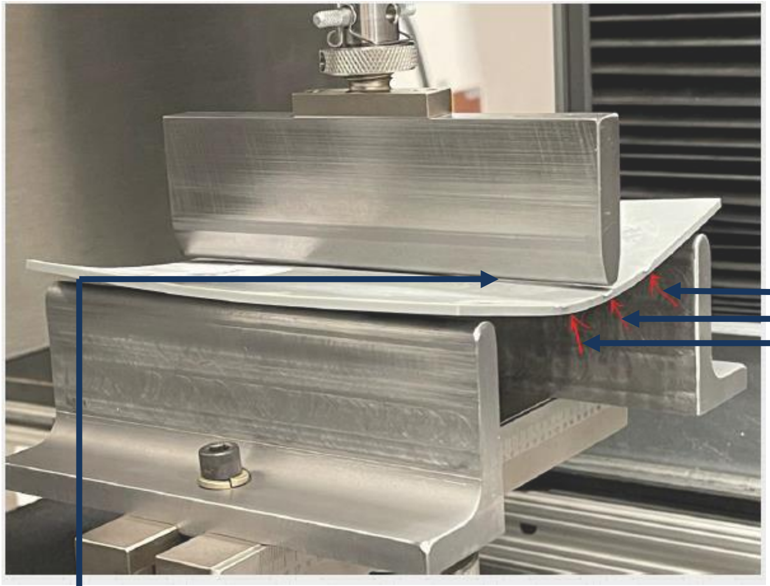


Develop a shell surface



- Develop plaque thickness by creating RVE layers of appropriate thickness and multiple overmold plastic layers
- 3D – shell part is developed

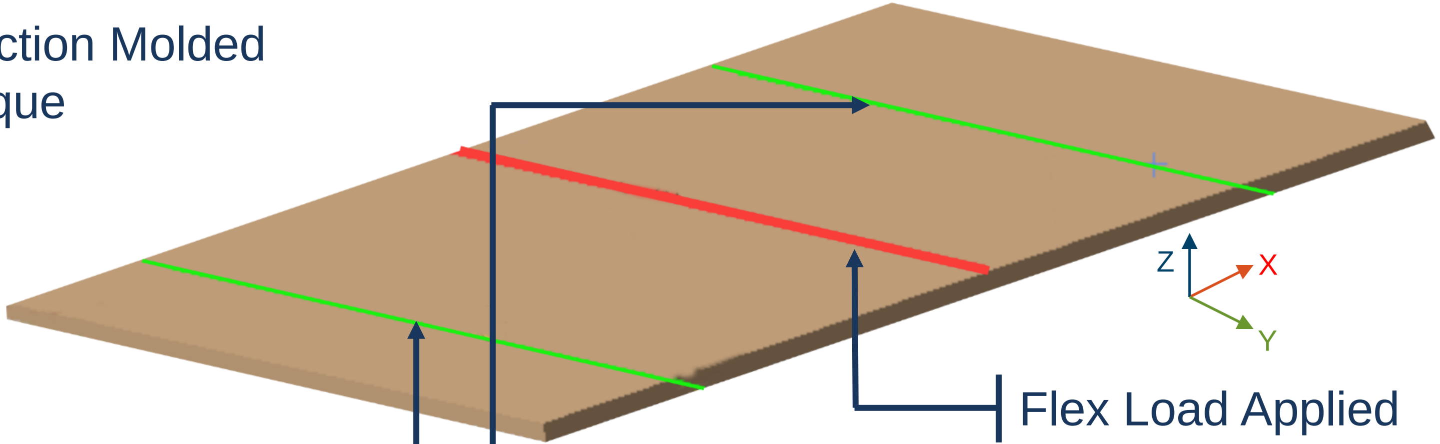
Flexure Test Results – Von Mises Stresses (MPa)



Injection Molded Plaque

Lattice at the bottom face

Load applied on the top face



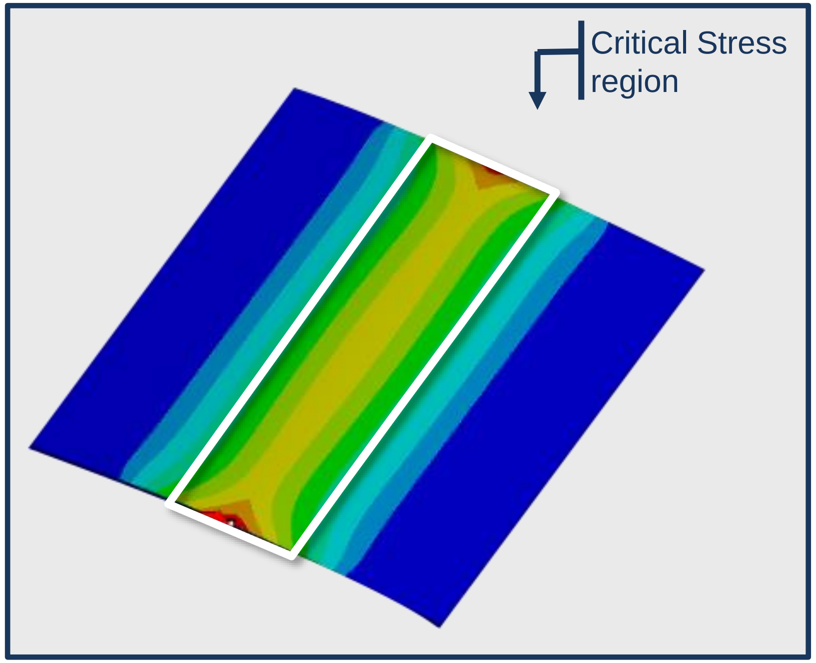
Flex Load Applied

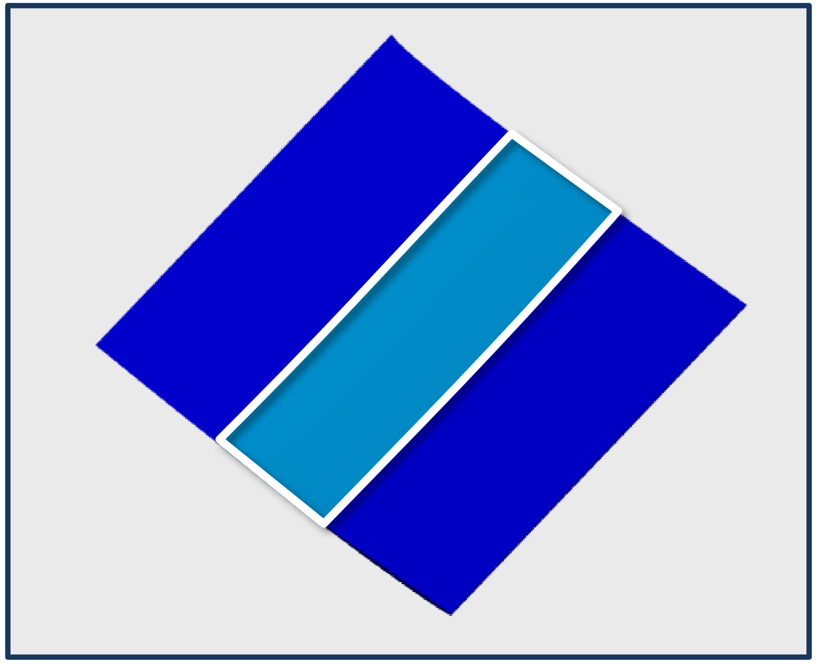
Fixed in Y and Z axis, free in X axis

Flexure Test Results – Von Mises Stresses (MPa)

Equivalent von-Mises Stress, MPa

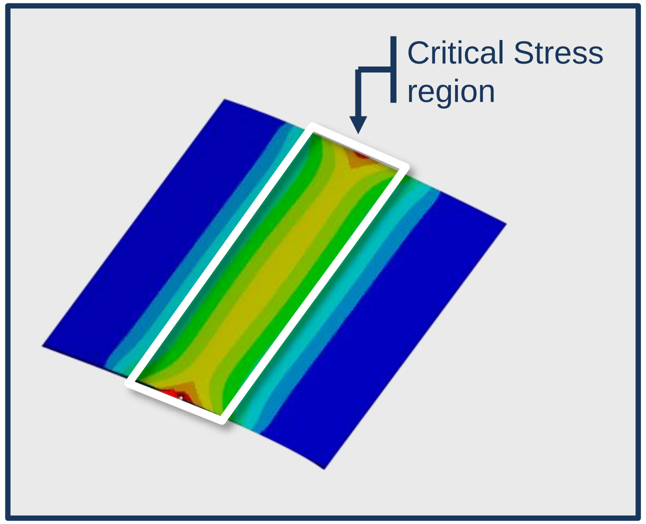
198.63 Max
176.57
154.5
132.44
110.38
88.311
66.247
44.183
22.119
0.055004 Min

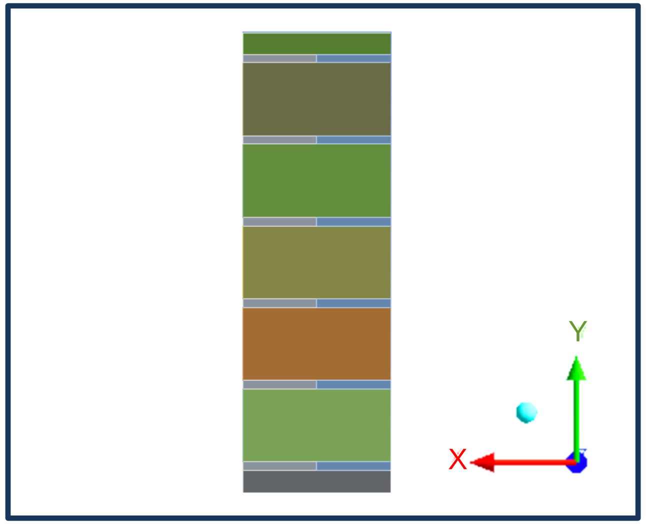


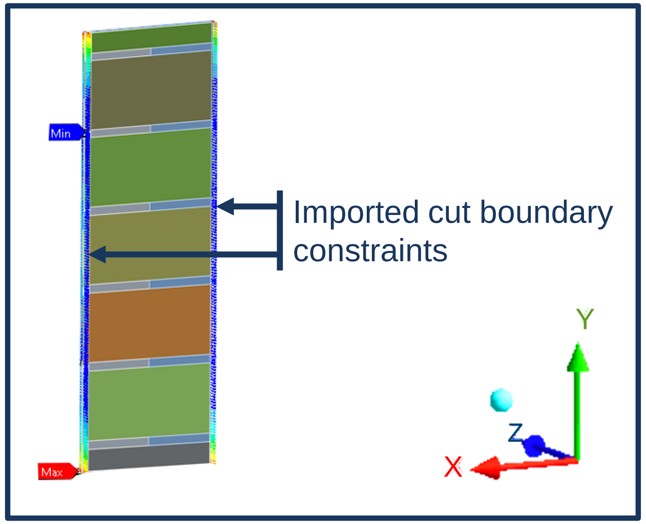


Submodeling

- Submodeling is a technique where a coarsely meshed model can be solved followed by a subsequent solution using only a portion of the coarse model with a more refined mesh and detailed geometrical features
- This portion of coarse model, which in general is a stress critical region, is called the submodel
- The displacements from the coarse model are mapped to the cut boundary locations on the submodel from the corresponding locations on the coarse model





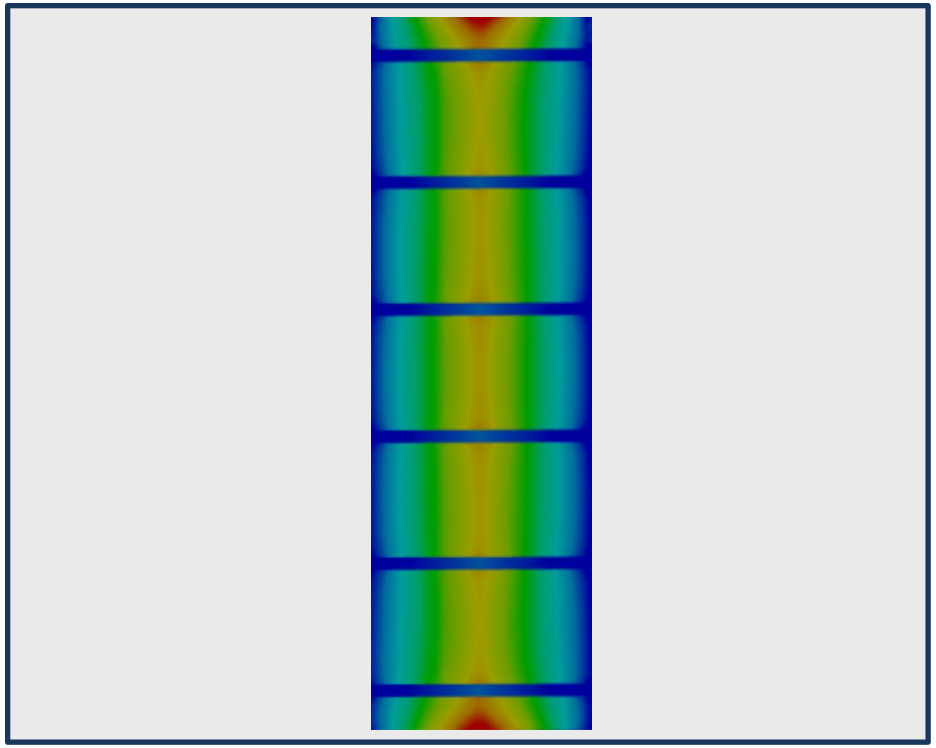


Identify stress critical region in the part → Design 3D solid submodel → Define cut boundaries

Submodel Results – Von Mises Stresses (MPa)

Equivalent von-Mises Stress, MPa

138.07 Max
122.81
107.55
92.283
77.019
61.755
46.491
31.227
15.963
0.69861 Min



Stresses in the plastic are lower than stresses in the tapes

Comparison of Flexural Results vs. Initial FEA Results

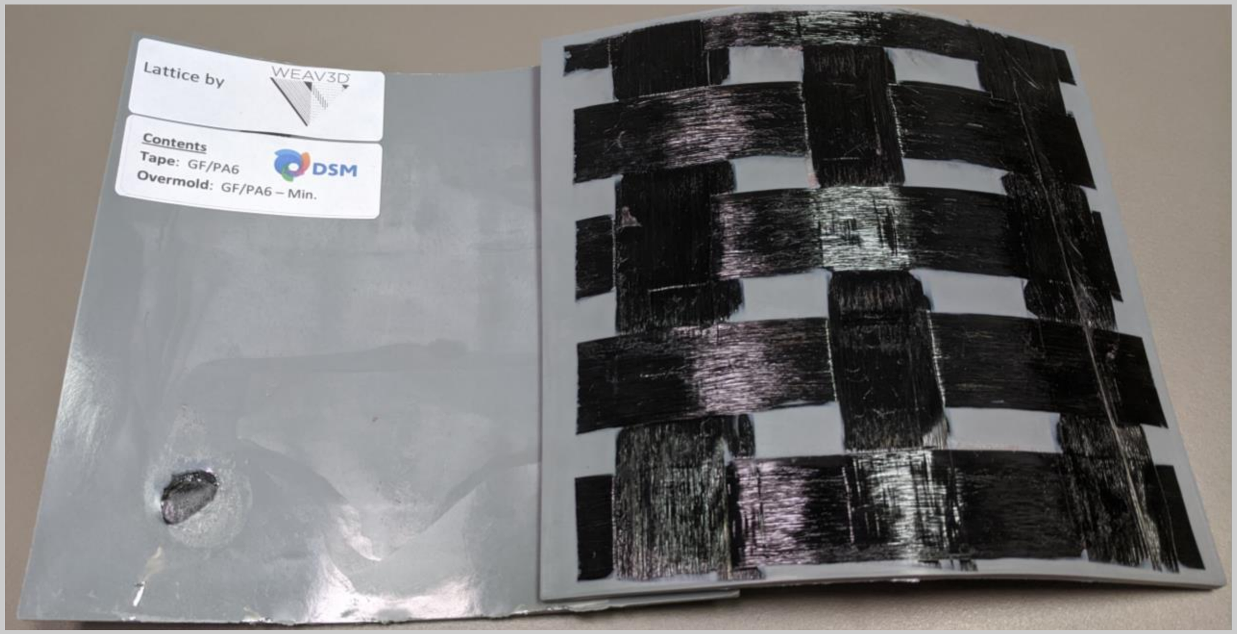
Lattice Design Configuration	Overmolded Plastic	Experimental Modulus, GPa	ANSYS FEA Modulus, GPa	Percent Error, %
Design 1	Unfilled PC/ABS	6.15	5.84	-4.98
Design 2	Unfilled PC/ABS	6.73	6.09	-9.62
Design 3	10 % Glass filled PC/ABS	9.53	19.9	24.40
Design 4	30 % Glass filled PA6	3.57	8.06	125.6
Design 5	30 % Glass filled PA6	2.99	8.49	183.85
Design 6	30 % Glass filled PA6	5.34	12.8	139.71

Effect of Fiber Alignment in the FEA Model

- FEA material cards of the glass filled plastics developed from manufacturer's data sheets were characterized with fiber alignment along the load path

- Perpendicular to load path fiber alignment, in the injection molded samples was not factored into the FEA material cards, causing significant overprediction of FEA moduli in design 3 through 6

Fiber Alignment Direction



Load Path Direction

Comparison of Youngs Moduli with Fiber Alignment Parallel and Normal to Load Path

Overmolded Plastic	Youngs Modulus Fiber Parallel to Load Path, GPa	Youngs Modulus Fiber Normal to Load Path, GPa
10% Glass Filled PC/ABS	5.99	1.19
30% Glass Filled PA6	5.1	2.1

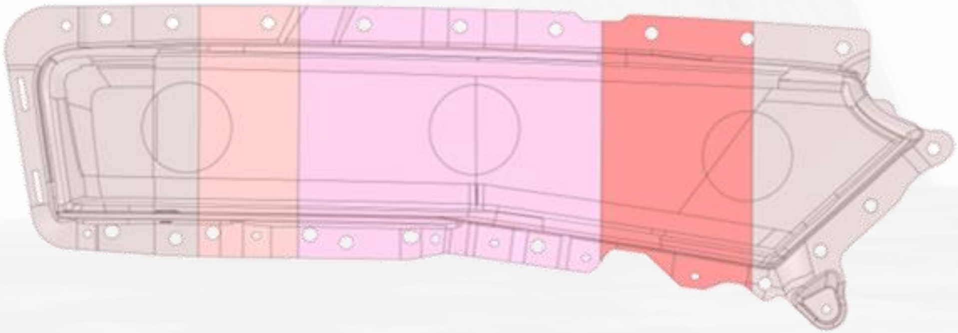
- Material data cards of the glass filled plastics were revised by rotating the properties from the manufacturer's datasheet to align them perpendicular to the load path
- Fiber reorientation reduced Young's Modulus values of the filled overmolded plastics and improved FEA accuracy relative to the experimental results

Updated Results : FEA of Flexure Test

Lattice Design Configuration	Overmolded Plastic	Experimental Modulus, GPa	ANSYS FEA Modulus, GPa	Percent Error, %
Design 3	10 % Glass filled PC/ABS	9.53	9.78	2.53
Design 4	30 % Glass filled PA6	3.57	3.08	-13.89
Design 5	30 % Glass filled PA6	2.99	3.15	5.33
Design 6	30 % Glass filled PA6	5.34	5.04	-5.61

Conclusions and Future Work

- Fiber alignment caused by overmolding shear flow must be accurately captured in the FEA setup
- RVE approach simplifies the geometry for FEA and allows rapid iterations on deformation targets, while submodeling differentiates stresses in tapes and overmolded plastic
- Predicted flexural modulus from FEA has an average error of -4.4%, with all deviations falling in the range of -14% (underpredicted) to +6% (overpredicted), relative to measured experimental modulus
- Described FEA workflow can be applied to a range of tape reinforced hybrid overmold structures
- Since this study, the workflow has been successfully applied to complex geometries demonstrating cost effective heterogenous lattice solutions
- Future work will emphasize scripting to capture manufacturing limitations and iteratively seek an optimum lattice pattern for achieving the design targets



Example of Complex Geometry with Heterogenous Lattice Design

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Questions?

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