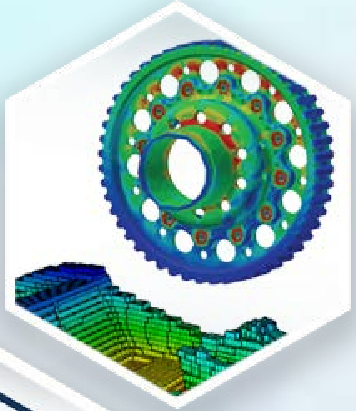


Simulation of High Pressure Resin Transfer Molding

Design, Modeling and Simulation Technology Area

Nathan Sharp, Ph.D.
Validation Engineer, CMSC

About the Presenter

Originally from Mesa, AZ.

BSME from BYU in 2010.

MSME from Purdue in 2012 under Professor Doug Adams (now at Vanderbilt).

Ph.D. from Purdue in 2015 under Professor R. Byron Pipes.

Validation Engineer at CMSC since August 2015.

Design, Modeling, and Simulation TA

Technology Areas

Wind Turbines
Colorado

Vehicles
Michigan

Compressed Gas Storage
Ohio

Design, Modeling, and Simulation
Indiana

Composite Materials & Process
Tennessee

Software and Industry Partners

Integration of many major commercial simulation tools

ESI get it right®
PAM-FORM
PAM-RTM
PAM-DISTORT
PAM-CRASH

Dassault Systemes
CATIA
SIMULIA
BIOVIA
ENOVIA
DELMIA

Altair
HYPERWORKS
MDS

AnalySwift
SwiftComp
VABS

digimat

Convergent Manufacturing Technologies
COMPRO
RAVEN

Moldex3D Molding Innovation

We are developing techniques to integrate commercial simulation tools so that we can create end-to-end process models that allows for manufacturing induced performance simulations.

We are involved in several projects and are eager to assist in others.

26 Project Team Participants with others in queue

Ford, VW, GE, FCA Fiat Chrysler Automobiles, Eaton Powering Business Worldwide, Honda, Lockheed Martin, tpi Delivering Composite Solutions, Local Motors

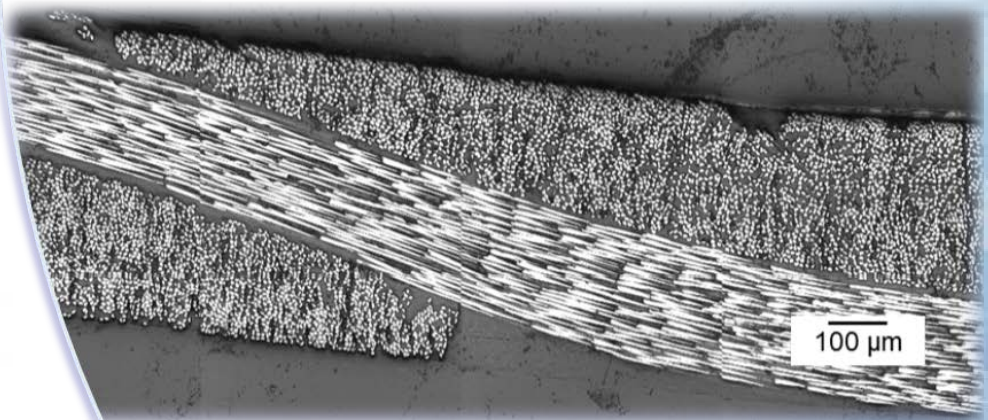
DowAksa, American Chemistry Council, DuPont, Zoltek Toray Group, PPG, BASF The Chemical Company, Cytec Solvay Group, Dow, Huntsman Enriching lives through innovation, Toray Innovation by Chemistry, Continental Structural Plastics, Arkema, Reichhold, Fibrtec, Johns Manville

Dassault Systemes, UAM Universal Asset Management, GLOBE, Materials Innovation Technologies, MVP Magnum Venus Products

Why Process Simulation?

Composite materials are actually **structures**.

Most composite parts cannot actually be produced with the designed properties because the **manufacturing process** will **change** the **microstructure**.

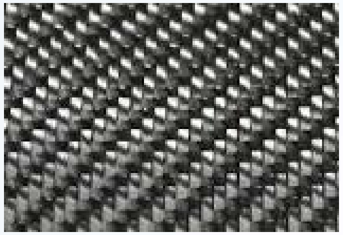


High Pressure RTM Process Flow Diagram

Fabric

Material Types


Glass

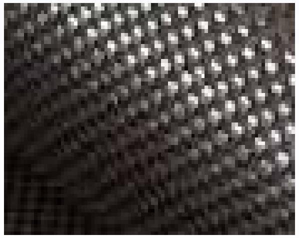

Carbon

Better specific stiffness

Better specific strength

Lower cost

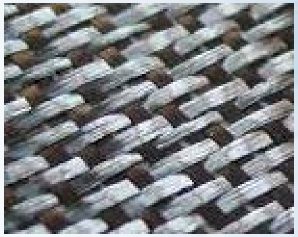
Woven Fabric Types


Plain Weave

symmetric


Twill

symmetric


Satin

asymmetric

Better mechanical properties

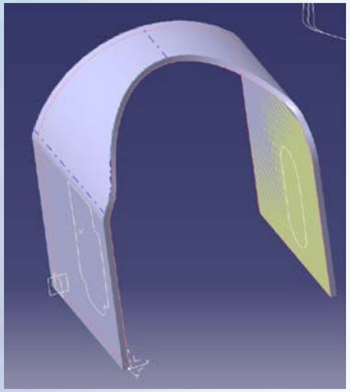
Better draping

Better stability

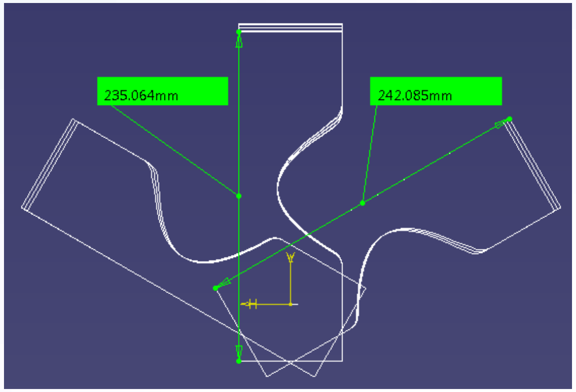
Non-Crimp Fabric

Non-crimp fabric uses stitching to create multiaxial fabrics. The lack of crimp provides better mechanical properties.

Cutting & Assembly



Part shape definition



Flat shape definition

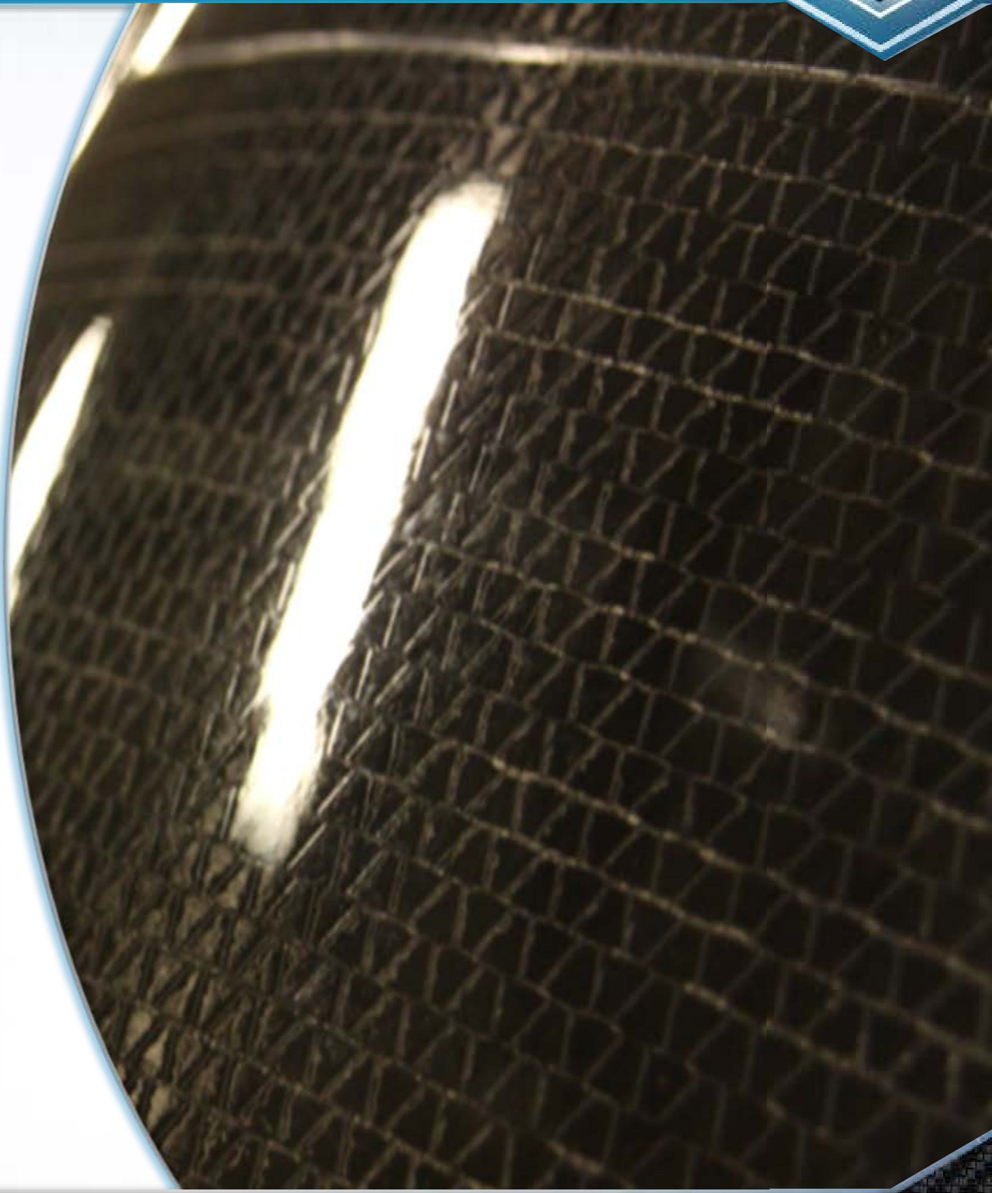
Flat shape creation

Once a fabric has been chosen and a part shape is generated, the flat shape needed to create the final shape can be calculated and the information is then sent to an automatic cutter to generate the flat shapes. The flat plies are then stacked into the designed configuration at which point they are ready to be placed in the mold.

Preforming / Draping

Fiber directions **diverge significantly** from the nominal when a fabric is formed over a **complex shape**.

Fiber direction plays the **principal role** in determining **warpage and strength**, while shear angles affect fabric permeability.



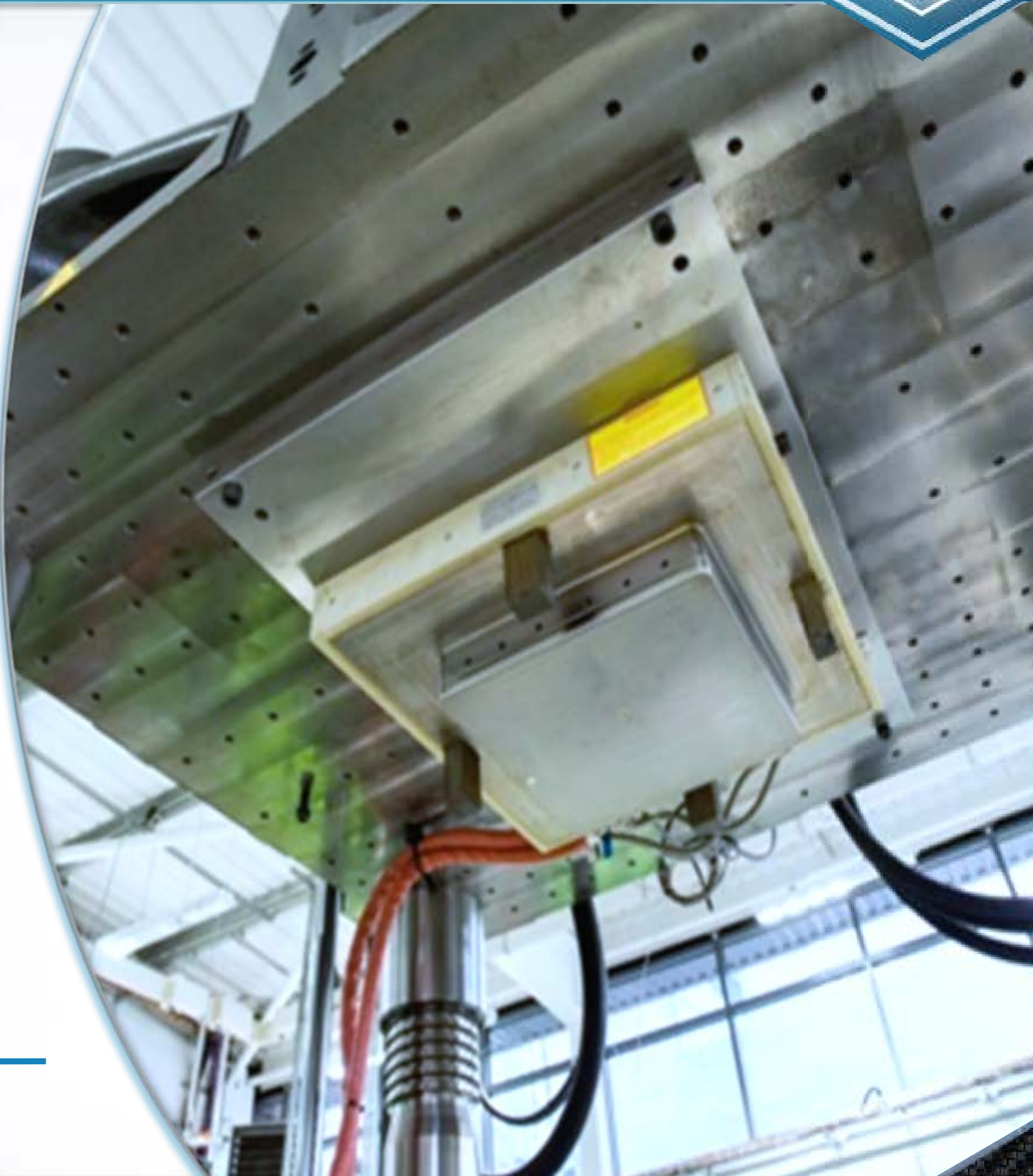
Infusion & Cure

Resin velocity is a function of pressure, viscosity, and fabric permeability.

Viscosity is a function of temperature and degree of cure.

Resin cure kinetics is a function of temperature.

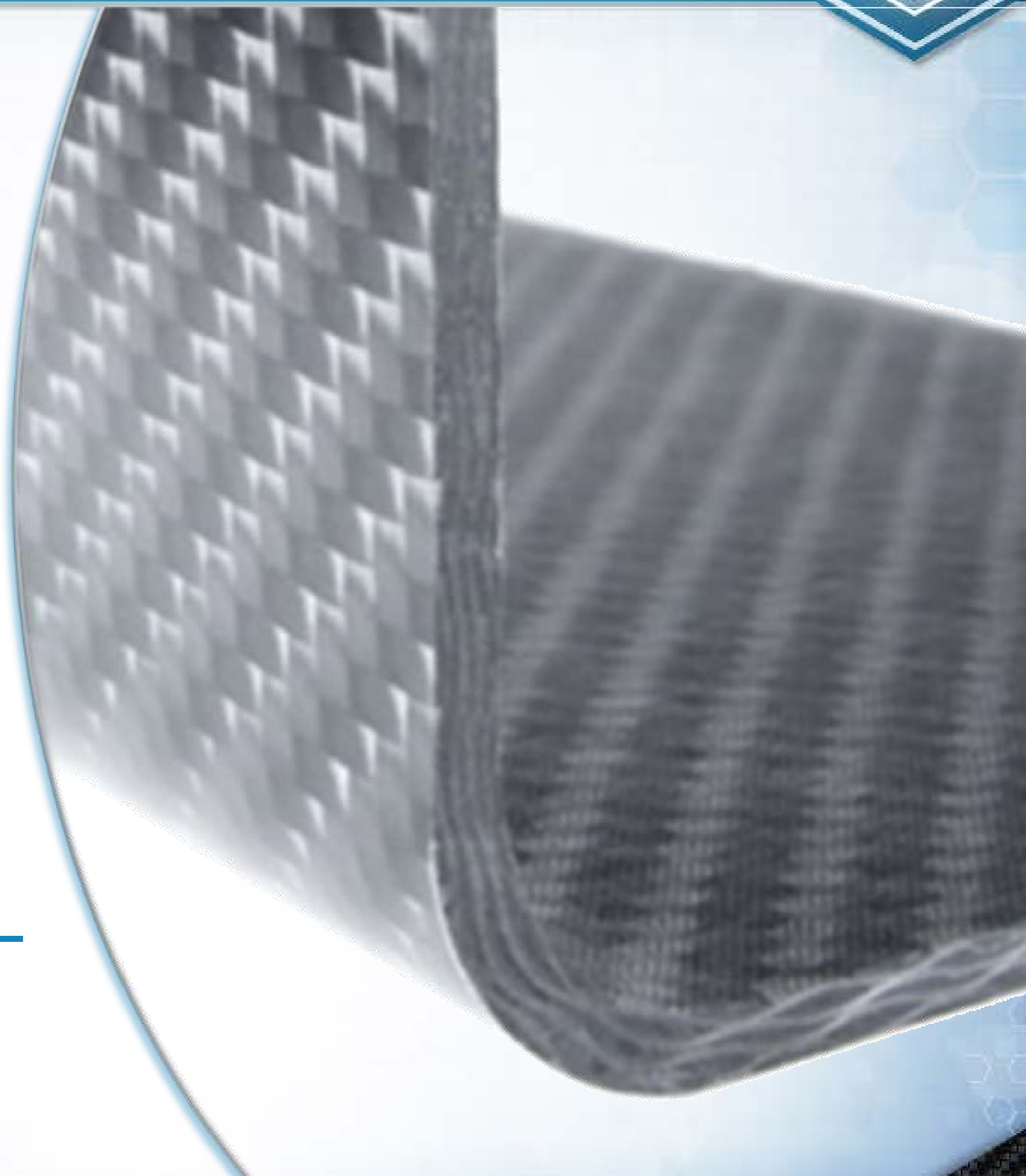
Fabric permeability is a function of shearing angle and fiber volume fraction (compaction).



Demolding

There is **no way** to prevent composite parts from warping after demolding.

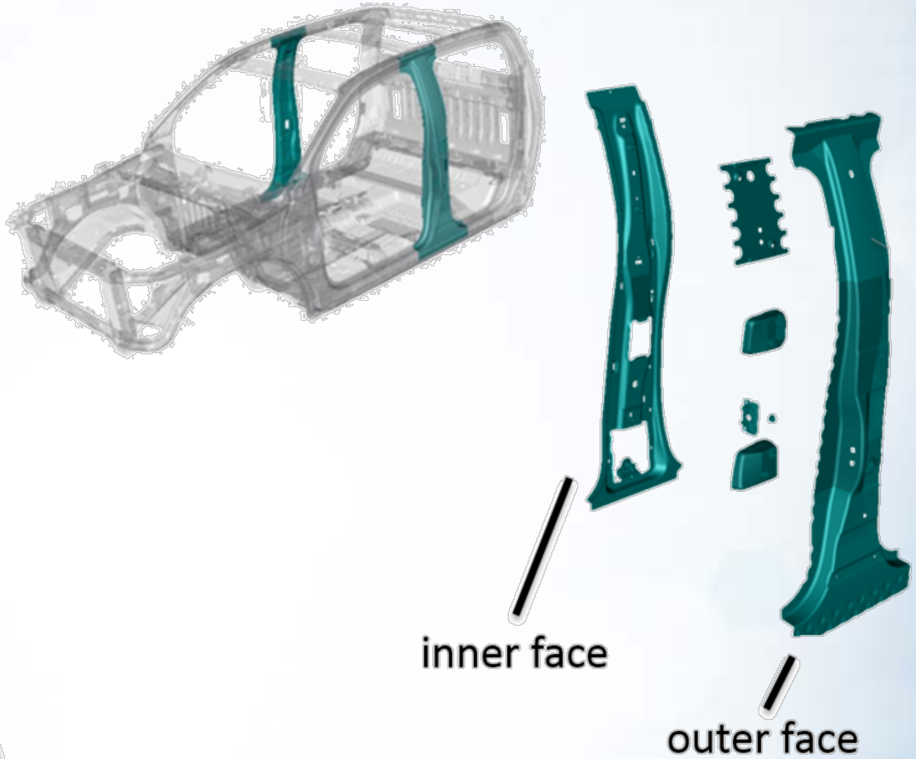
CTE mismatch between in-plane and through-thickness directions is the **dominant driver of part deformation**. Others causes include **cure shrinkage**, **cure gradients**, and **mold-part interaction**.



Demonstration Part

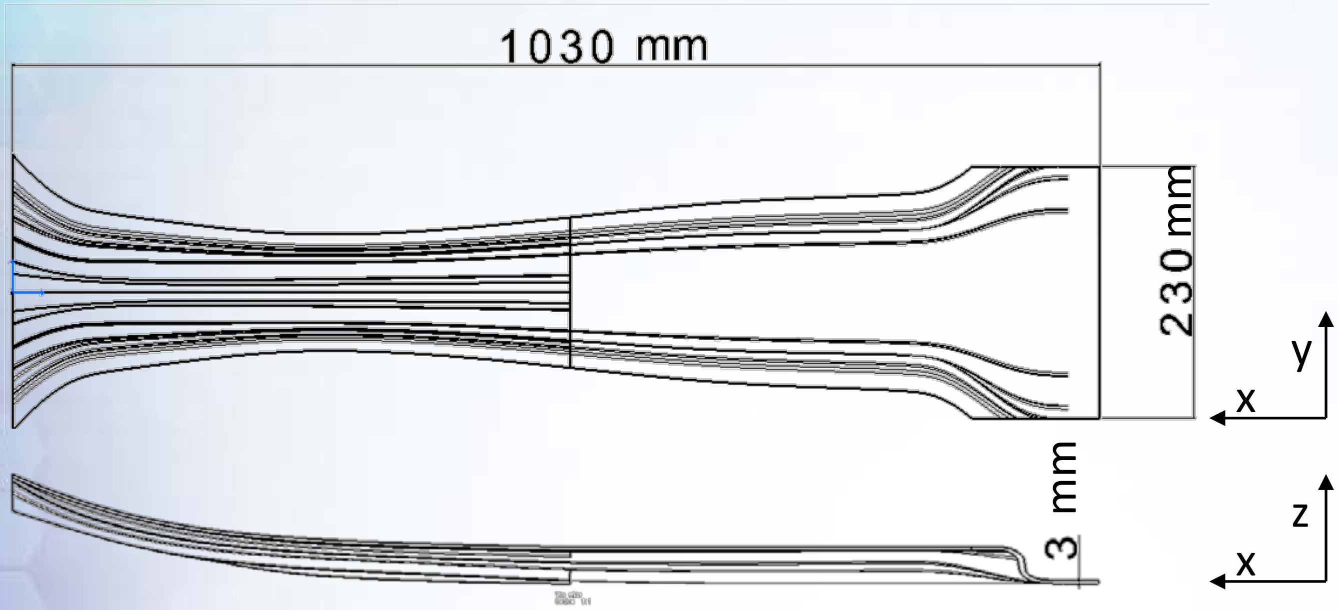
B Pillar outer face

A “B Pillar” was selected as the demonstration part for the HP-RTM process. HP-RTM works well for structural automotive parts because HP-RTM can create parts with **continuous fiber (high strength)** and **fast cycle times**. Also, the process uses the **same presses** as are used in metal stamping, which prevents the necessity of costly capital purchases.



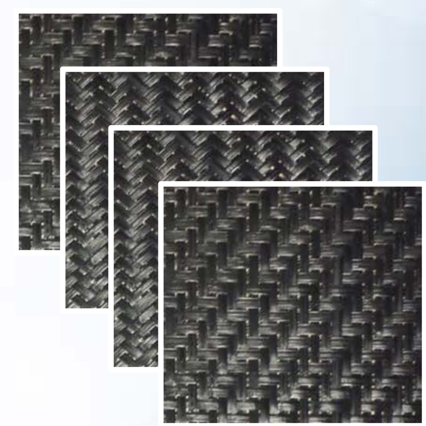
*only the outer face will be modeled in this presentation

Part Dimensions and Layup



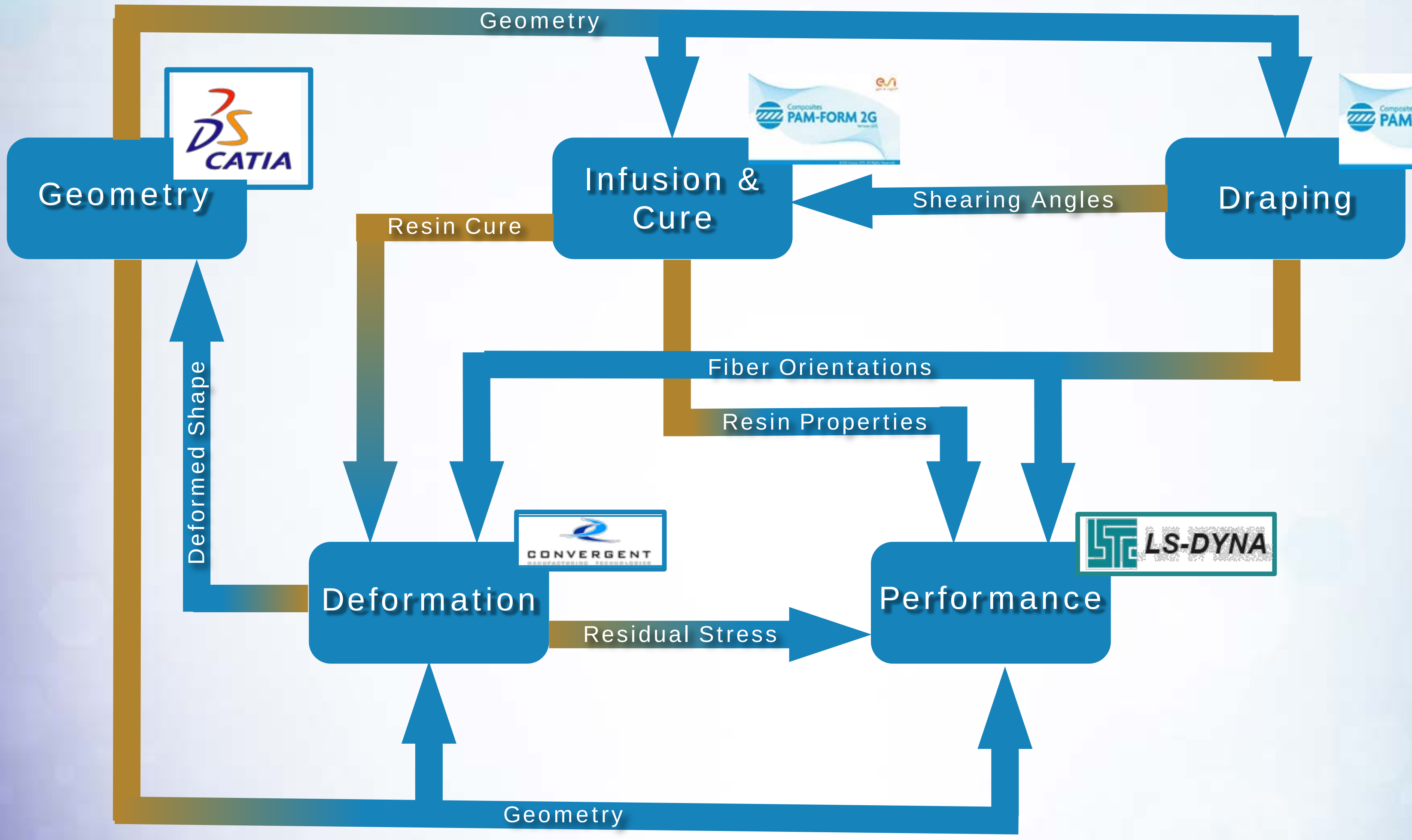
Material: Carbon Twill Fabric

Stacking sequence: [0,45,45,0]



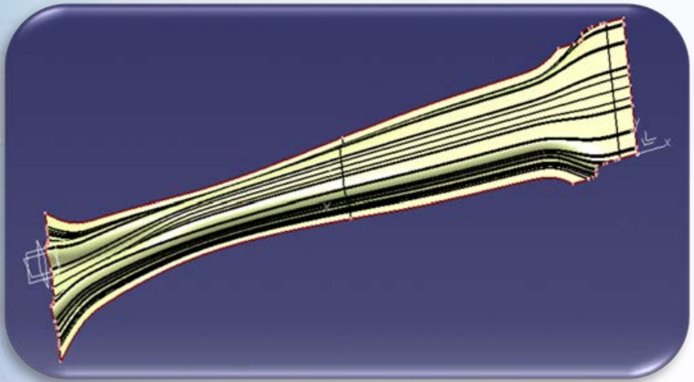
As the focus of the present study is to **demonstrate the physical phenomena** central to the HP-RTM process as well as the **integration of commercial simulation tools** for this simulation, we have chosen a generic B-Pillar geometry shown above.

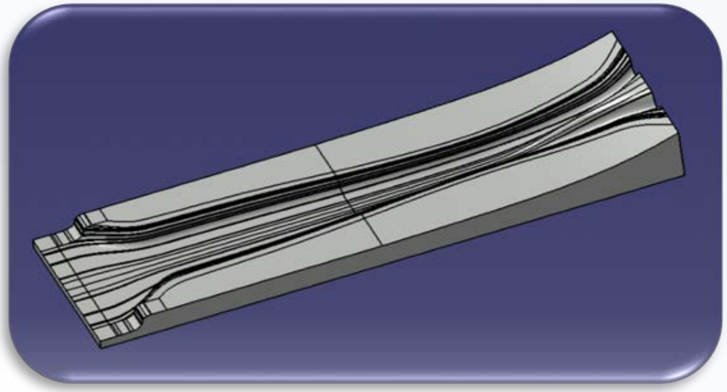
HP-RTM Simulation Flow Diagram

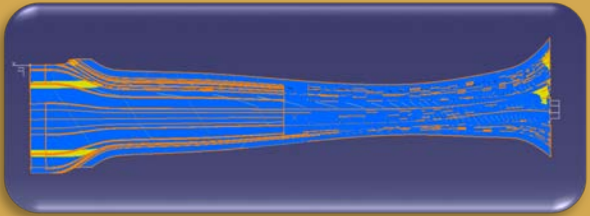


Geometry Definition

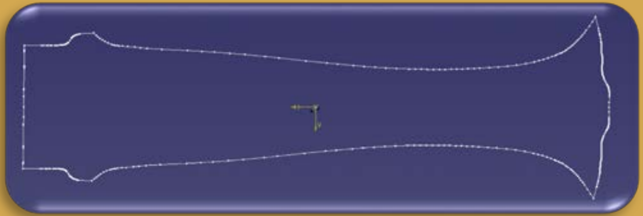
CATIA



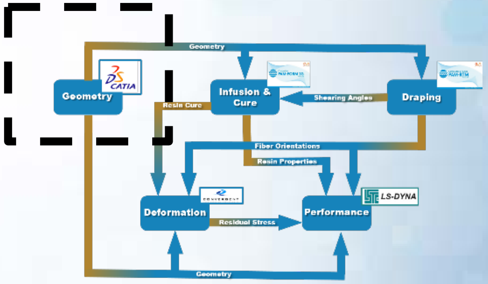




Producibility

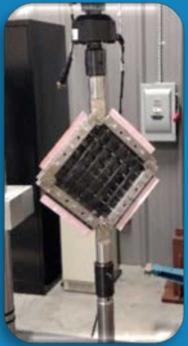


Flat ply shapes

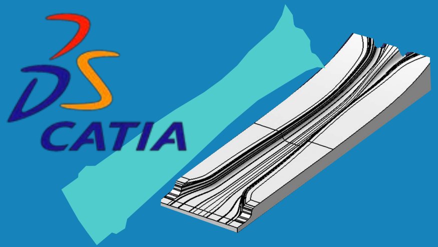


Draping Overview

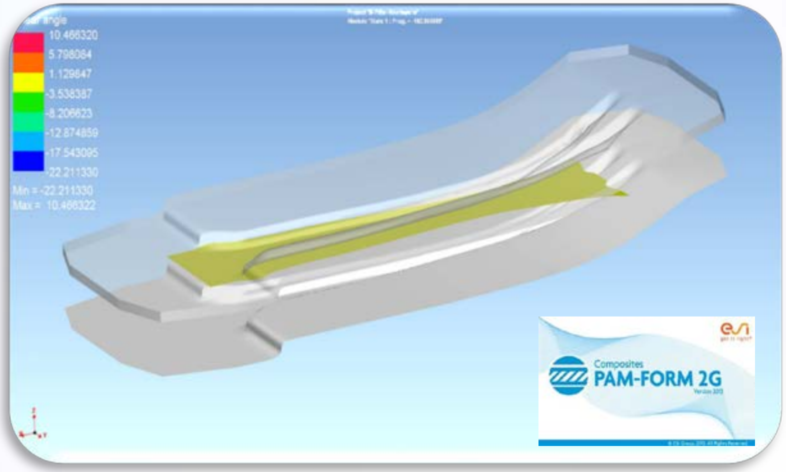
PAM-FORM



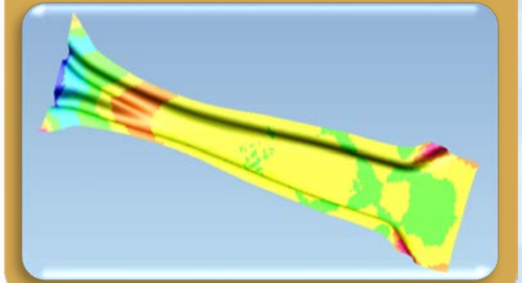
Fiber modulus, fabric bending stiffness, picture frame test



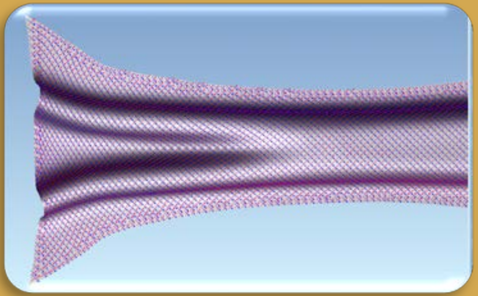
Mold and blank geometry



Shear Angles



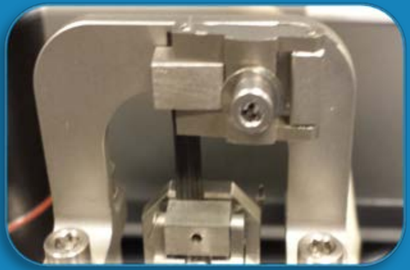
Fiber Directions



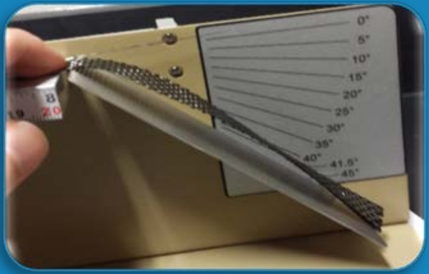
Draping Inputs

PAM-FORM

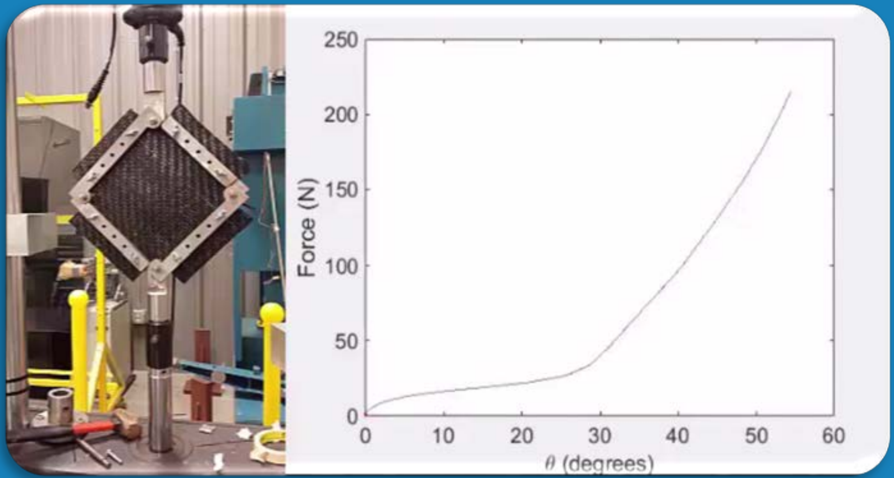
Tow modulus

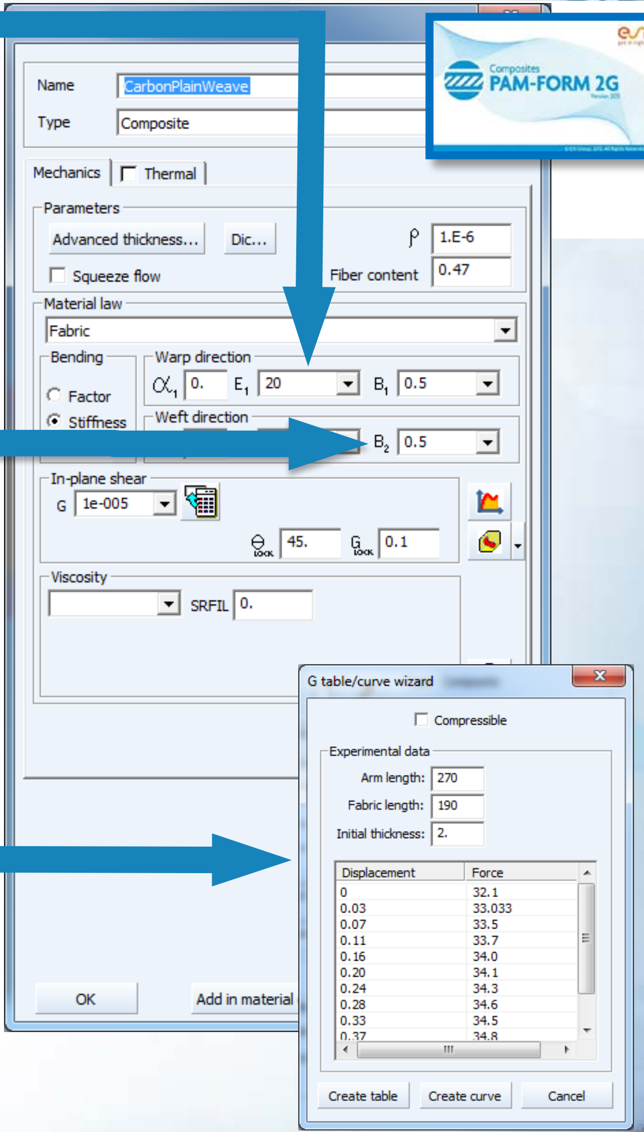


Bending Stiffness



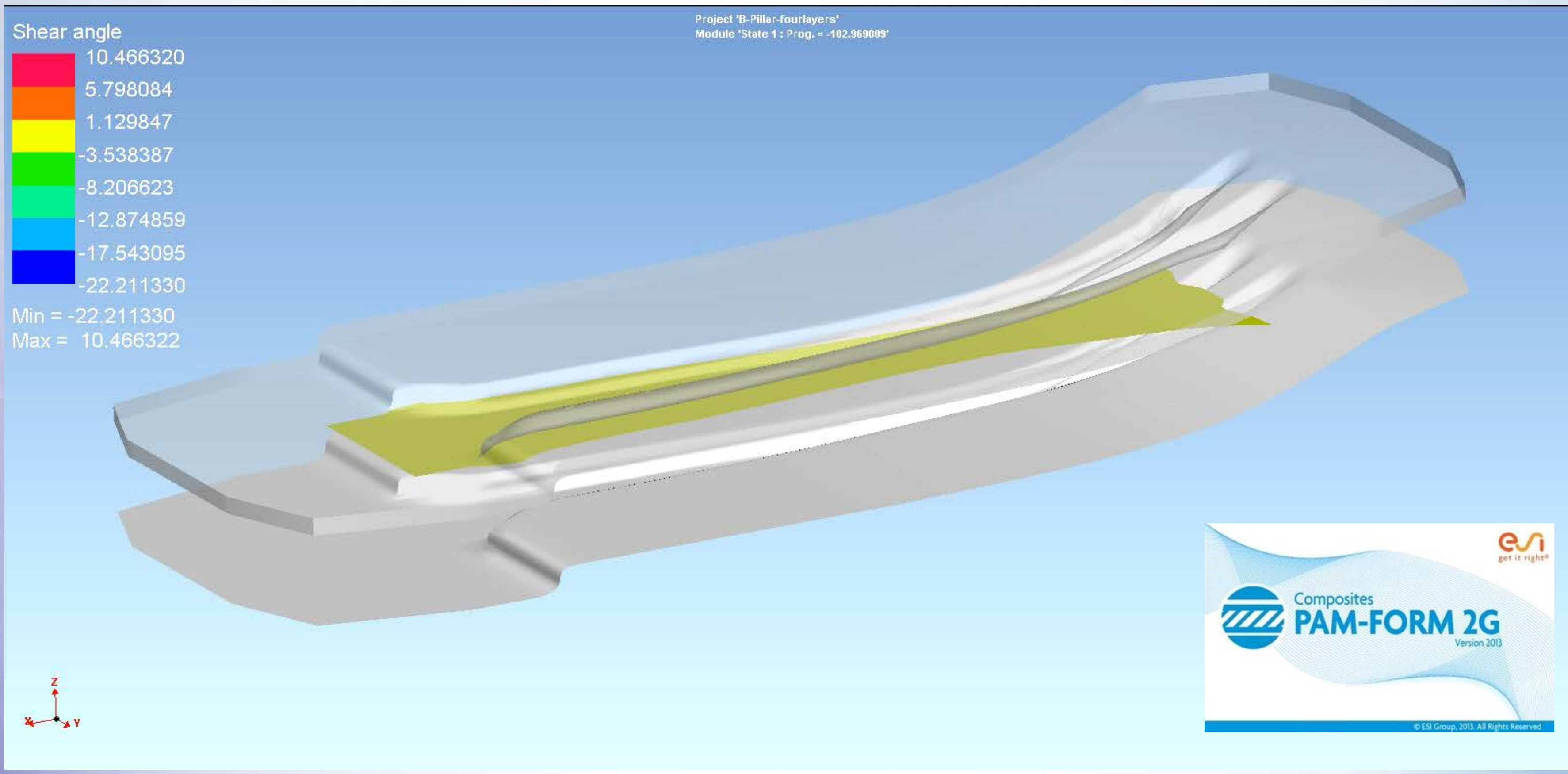
Picture Frame Test





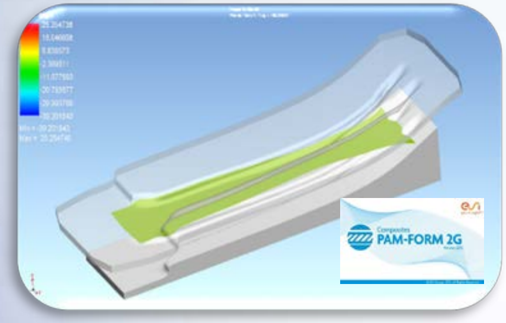
Draping Simulation

PAM-FORM

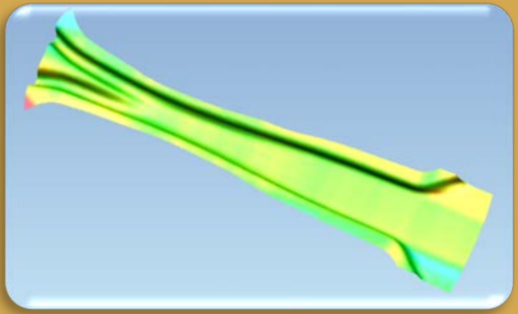


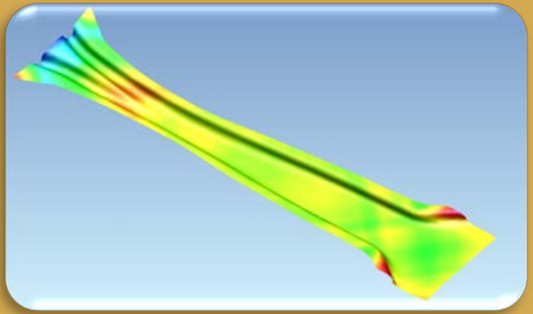
Draping Outputs

PAM-FORM



Shear Angles

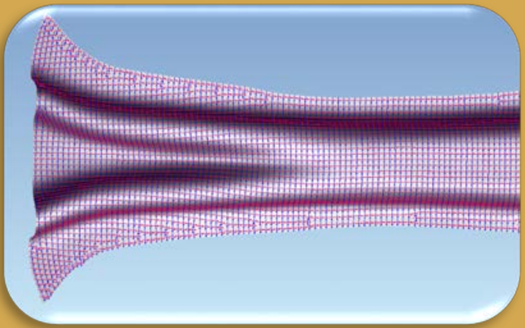


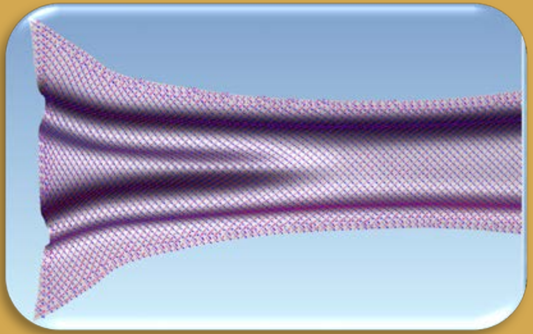


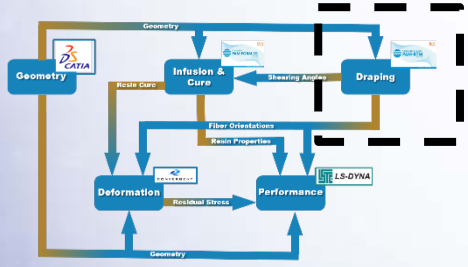
0/90 ply

45/-45 ply

Fiber Directions





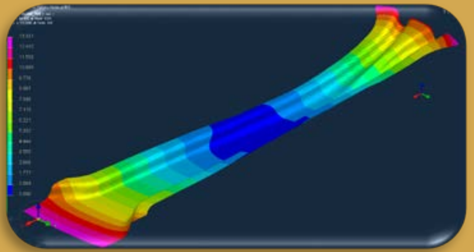


Infusion and Cure Overview

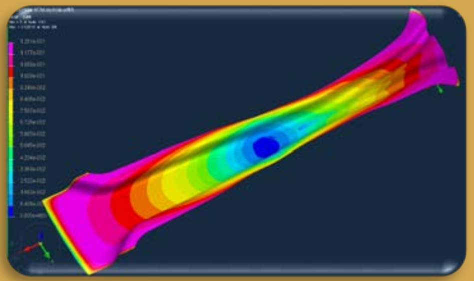
PAM-RTM

Permeability, cure kinetics, viscosity

Shear angles

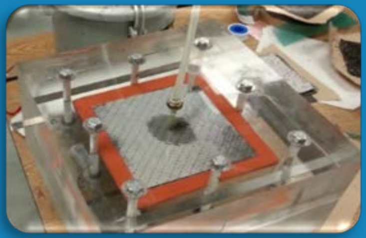


Fill time



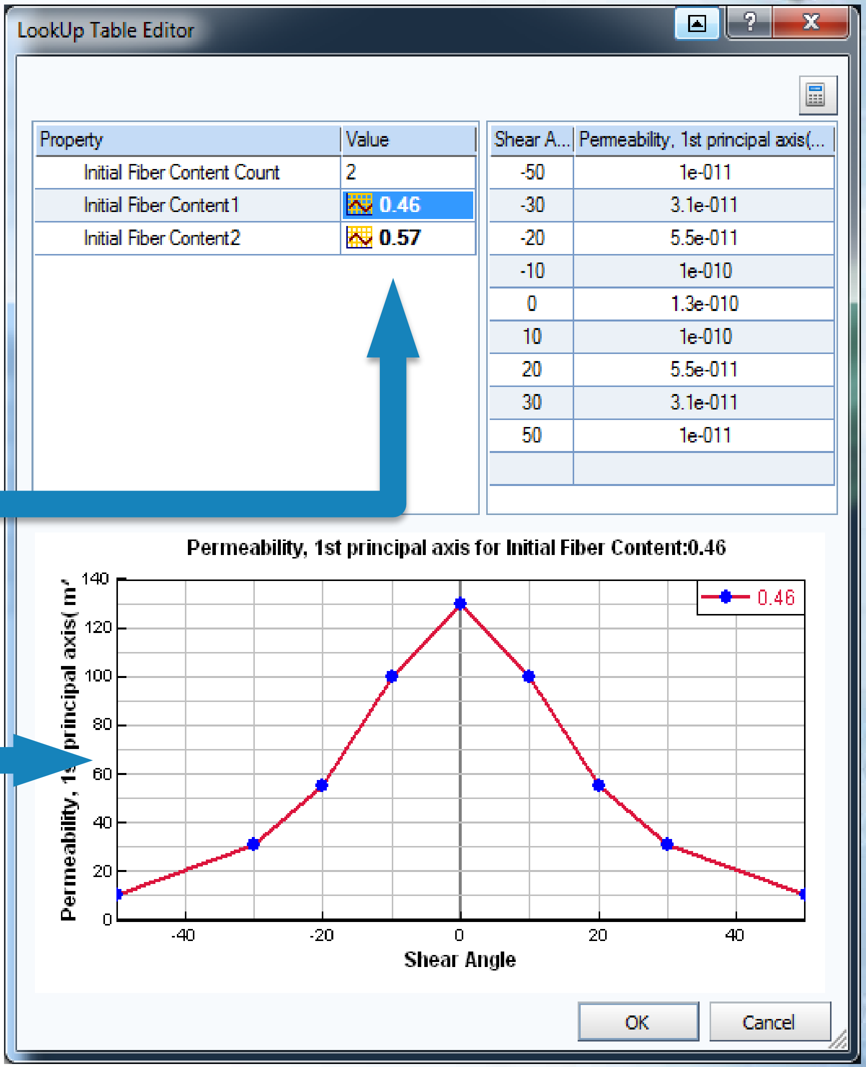
Degree of cure

Filling Inputs: Permeability

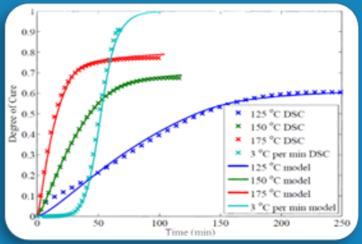


Permeability defined at multiple fiber volume fractions

Permeability as a function of shear angle for a specific fiber volume fraction

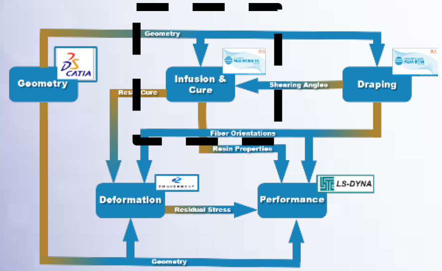


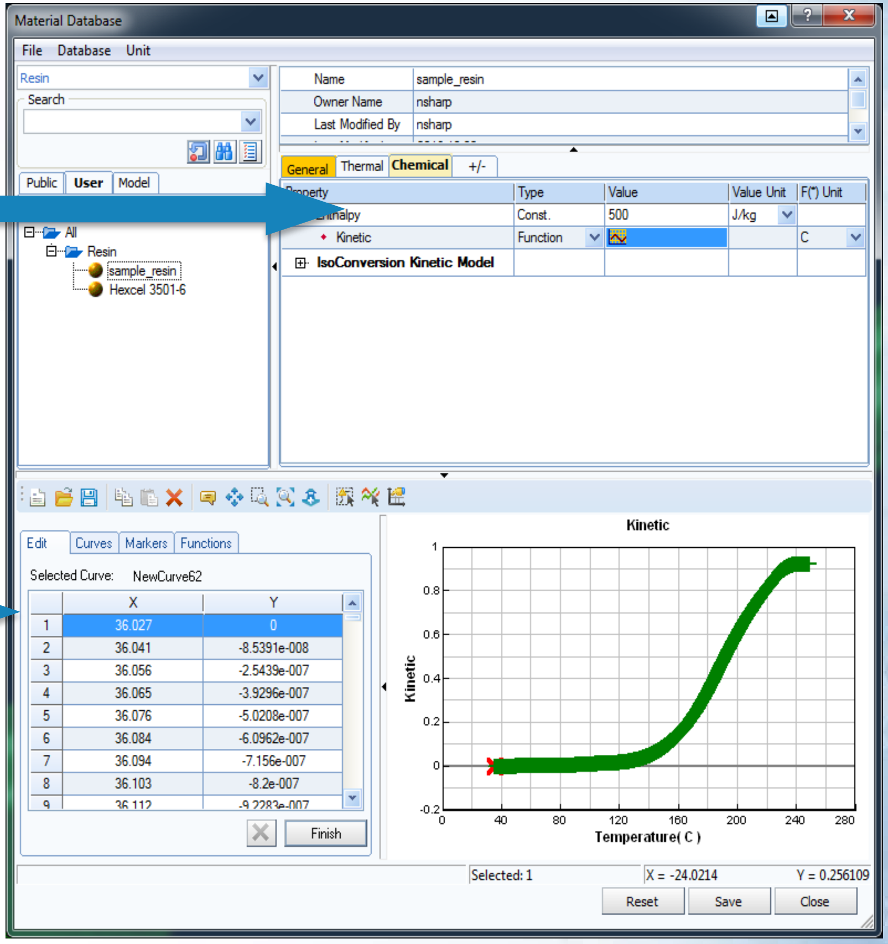
Filling Inputs: Cure Kinetics



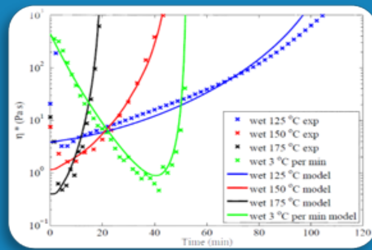
Heat of Reaction

Cure kinetics data from DSC



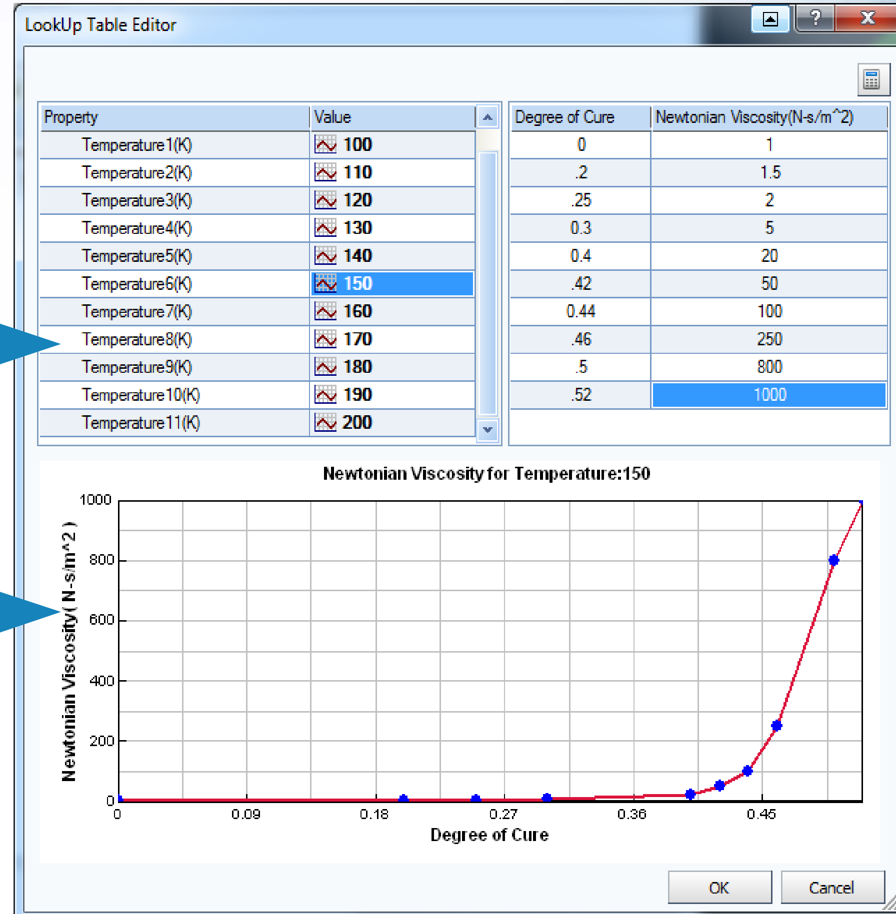


Filling Inputs: Viscosity

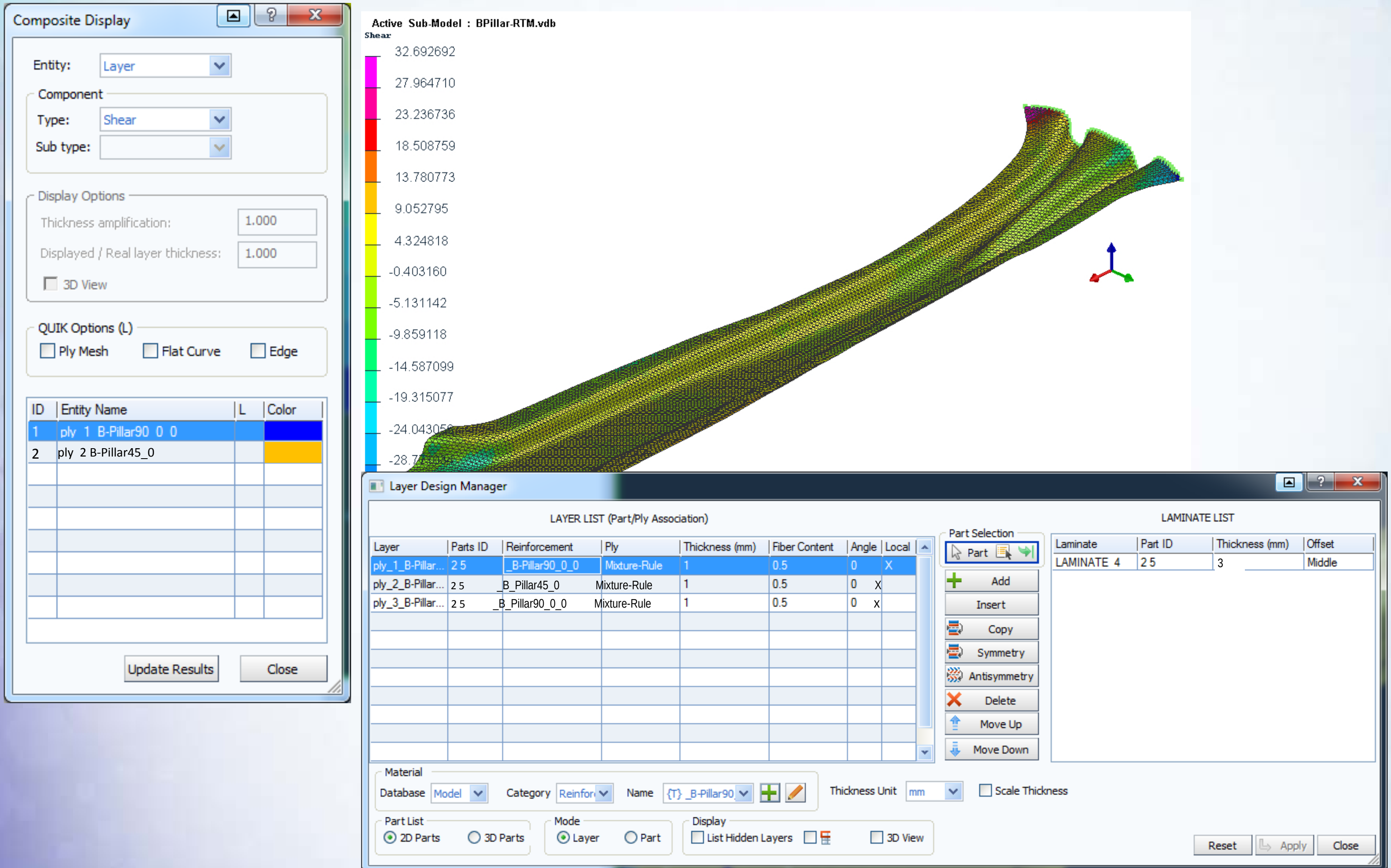


Viscosity defined at multiple temperatures

Viscosity as a function of degree of cure for each temperature

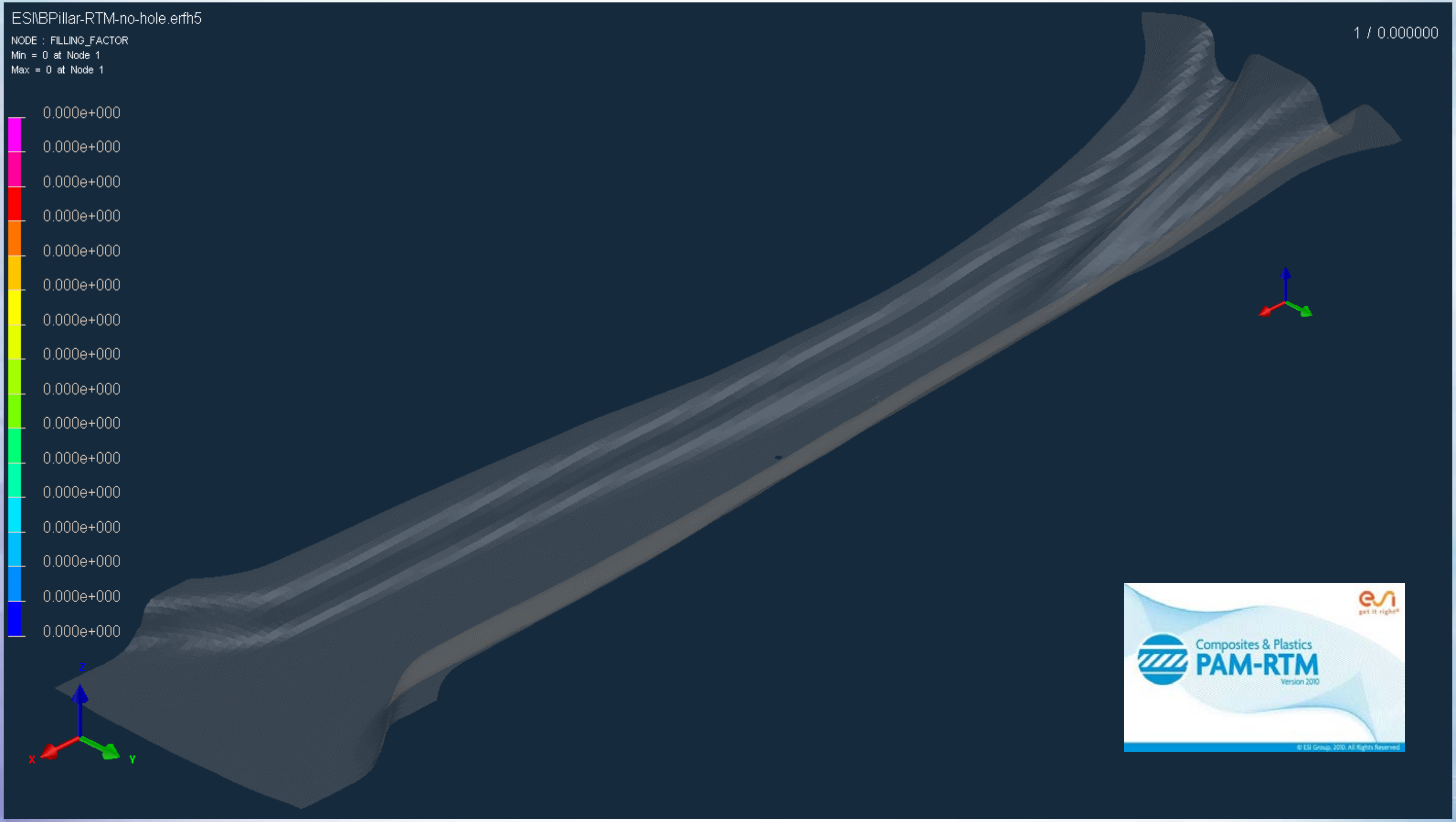


Filling Inputs: Shear Angle



Filling Simulation

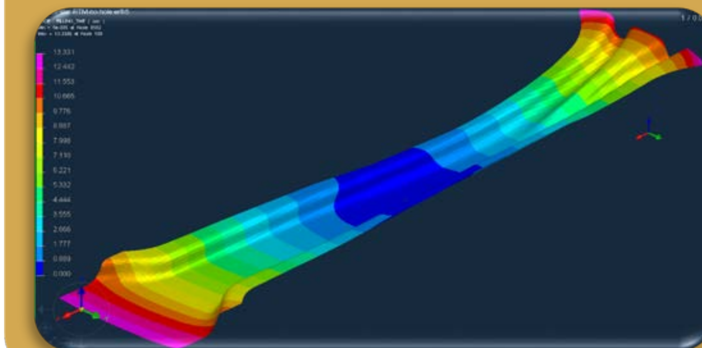
PAM-RTM



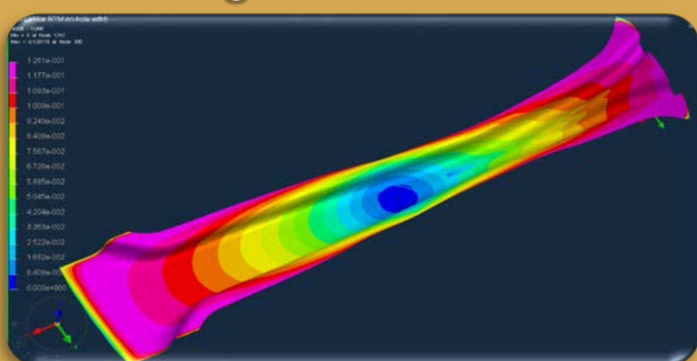
Filling Outputs

PAM-RTM

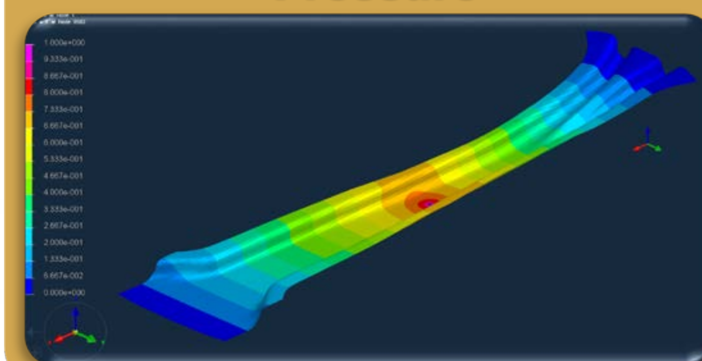
Fill time



Degree of cure



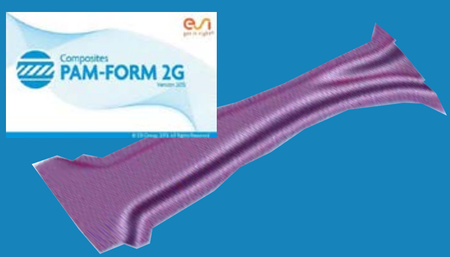
Pressure



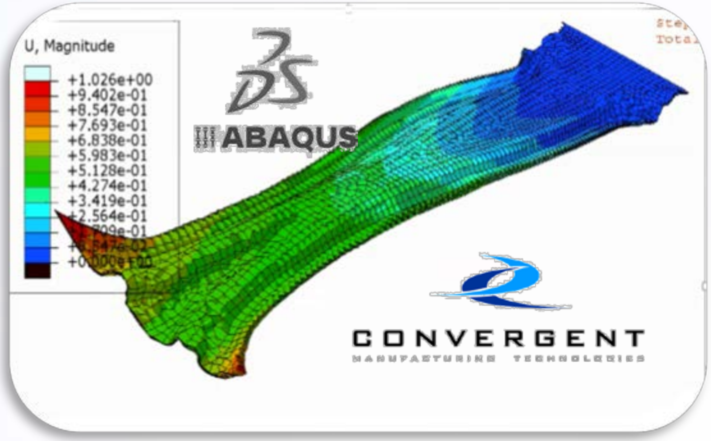
Deformation Overview

COMPRO

Elastic constants, thermal properties, cure kinetics

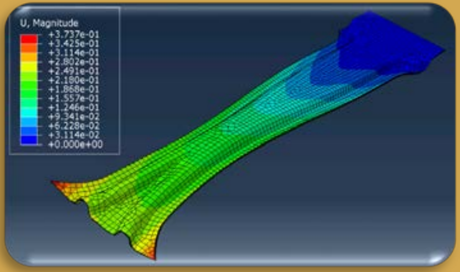


Fiber directions

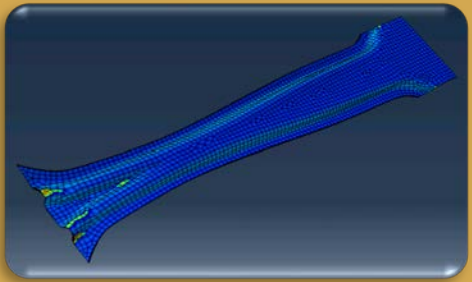


python

Deformation



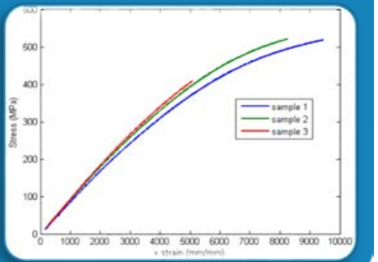
Residual Stress



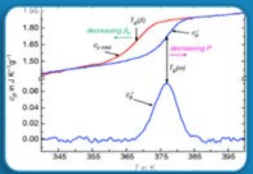
Deformation Inputs

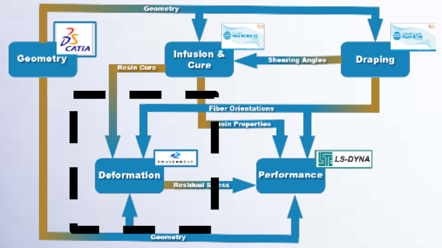
COMPRO

Elastic Constants



Thermal and Cure Properties



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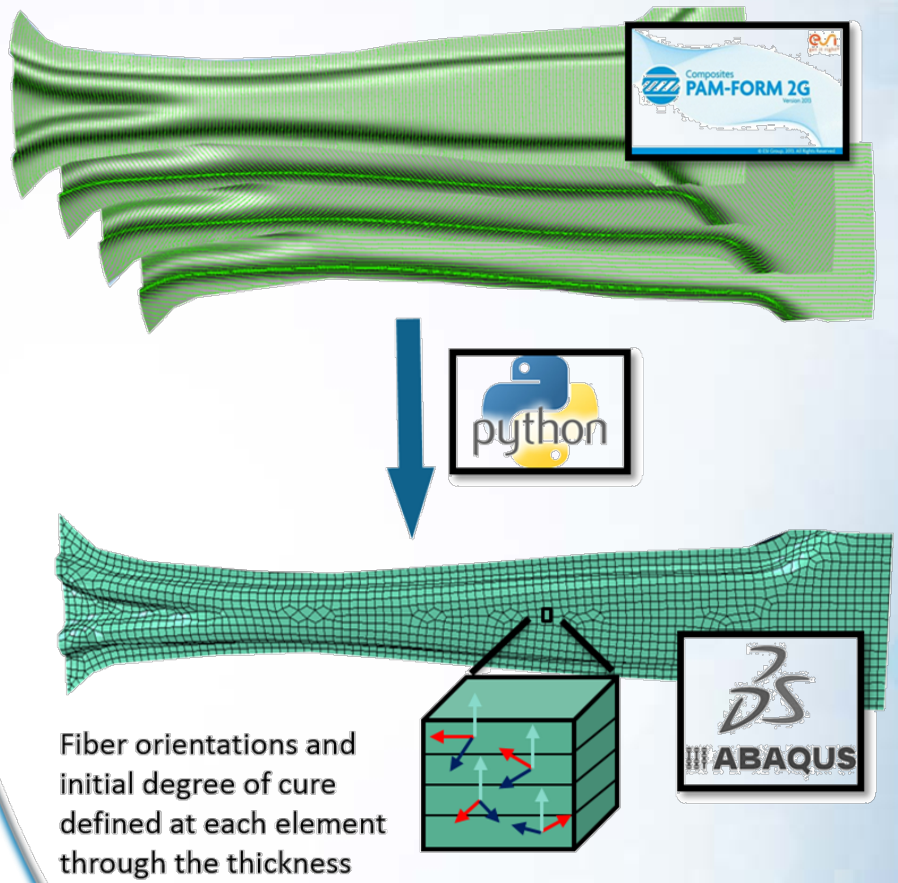
          name="NominalCTEt"/>
        <parameter value="20." units="C" parameter_number="3" name="T0"/>
        <parameter value="0." units="unknown" parameter_number="4" name="Tft"/>
        <parameter value="0." units="unknown" parameter_number="5" name="Tfl"/>
      </cte>
    - <specific_heat number_of_parameters="3" model="default">
        <constraint value="0" severity_parameters="30.;1.;" initial_severity="30" severity_model="1"
          isMinimum="false" variable="temp"/>
        <parameter value="711.76" units="J/(kg K)" parameter_number="1" name="NominalCp"/>
        <parameter value="0." units="C" parameter_number="2" name="T0"/>
        <parameter value="0." units="J/(kg K2)" parameter_number="3" name="Tf"/>
      </specific_heat>
    - <conductivity number_of_parameters="5" model="default">
        <constraint value="0" severity_parameters="60.;1.;" initial_severity="60" severity_model="1"
          isMinimum="false" variable="temp"/>
        <parameter value="2.4" units="W/(m K)" parameter_number="1" name="NominalKt"/>
        <parameter value="11.8025" units="W/(m K)" parameter_number="2" name="NominalKl"/>
        <parameter value="0." units="C" parameter_number="3" name="T0"/>
        <parameter value="0." units="W/(m K2)" parameter_number="4" name="Tft"/>
        <parameter value="0." units="W/(m K2)" parameter_number="5" name="Tfl"/>
      </conductivity>
    </revision>
  </material>
```

Property Mapping

Fiber directions from **PAM-FORM surface mesh** need to be mapped to the **ABAQUS solid mesh**. ABAQUS does not have a built in way to import fiber directions.

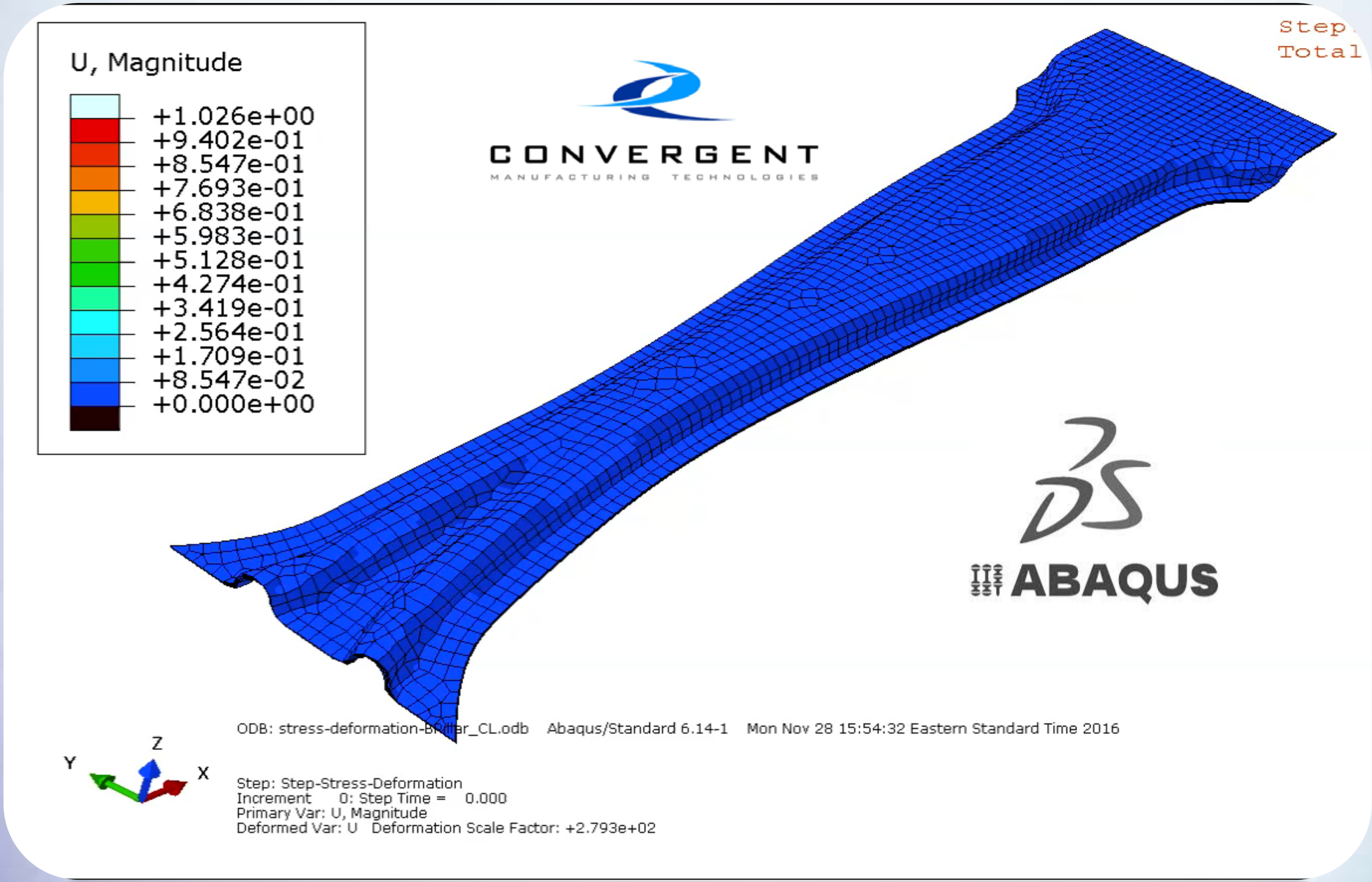
A Python script was written which maps each solid mesh node to its nearest surface mesh counterpart and **defines the properties through the thickness**.

Degree of cure data is also mapped from PAM-RTM into ABAQUS using the same method.



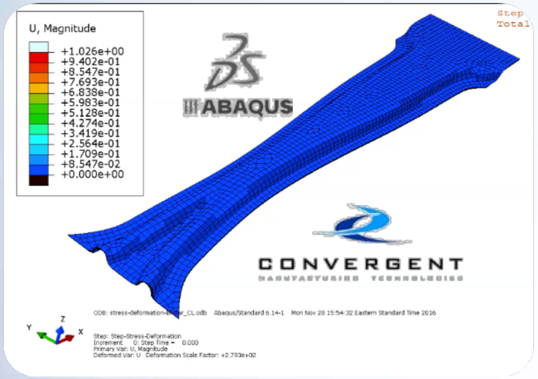
Deformation Simulation

COMPRO

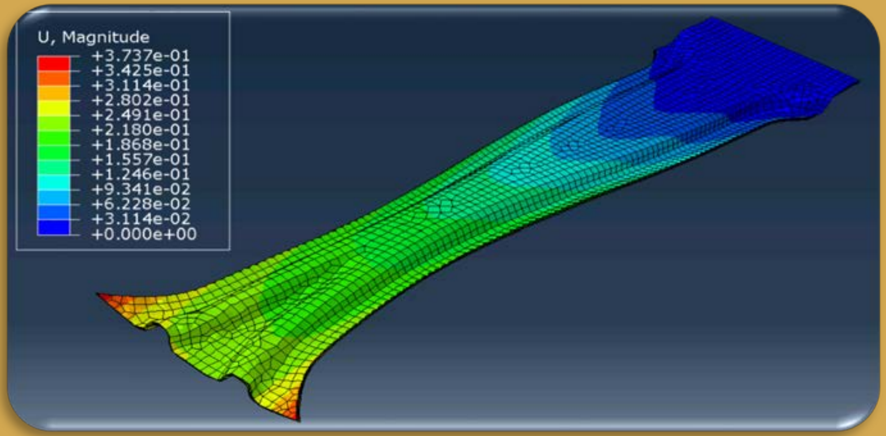


Deformation Outputs

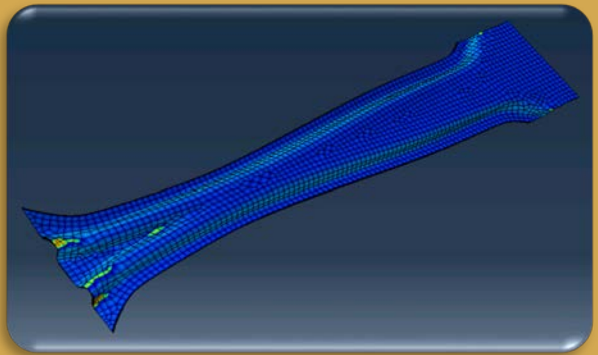
COMPRO



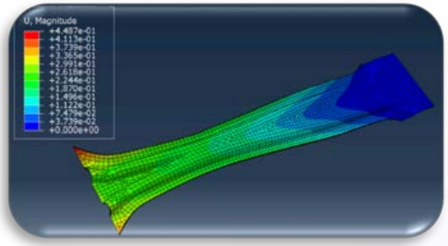
Deformation



Residual Stress



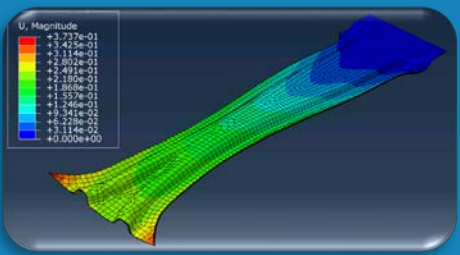
Deformation without Draping:



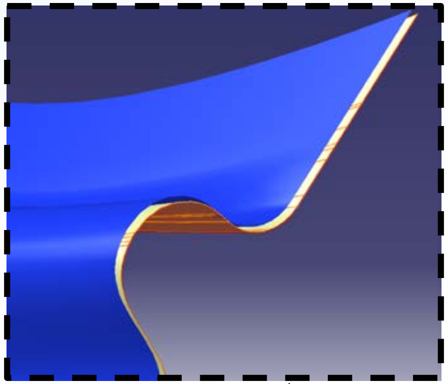
Compared to the B Pillar model without draping, there is a 17% difference in maximum deformation

Mold Geometry Compensation

CATIA



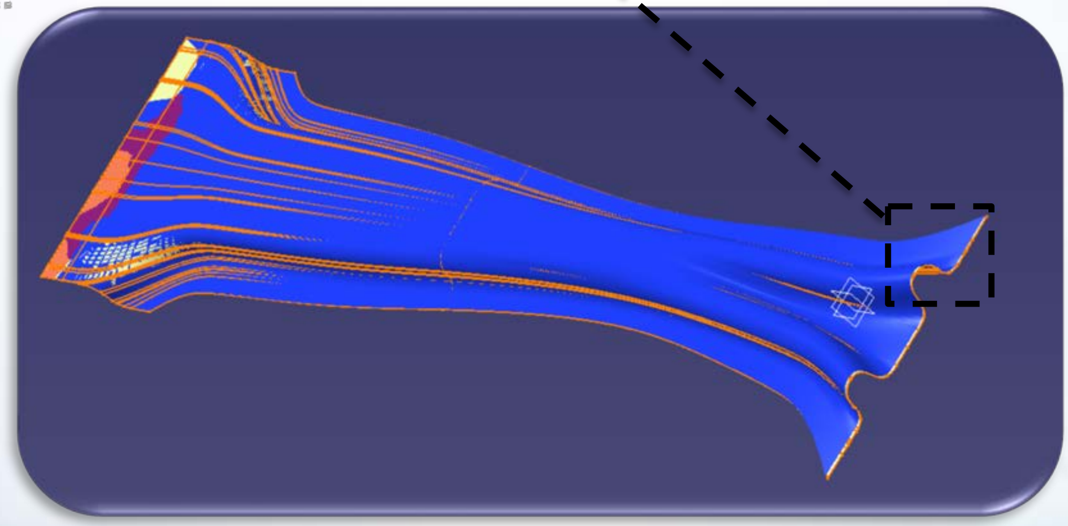
Deformation



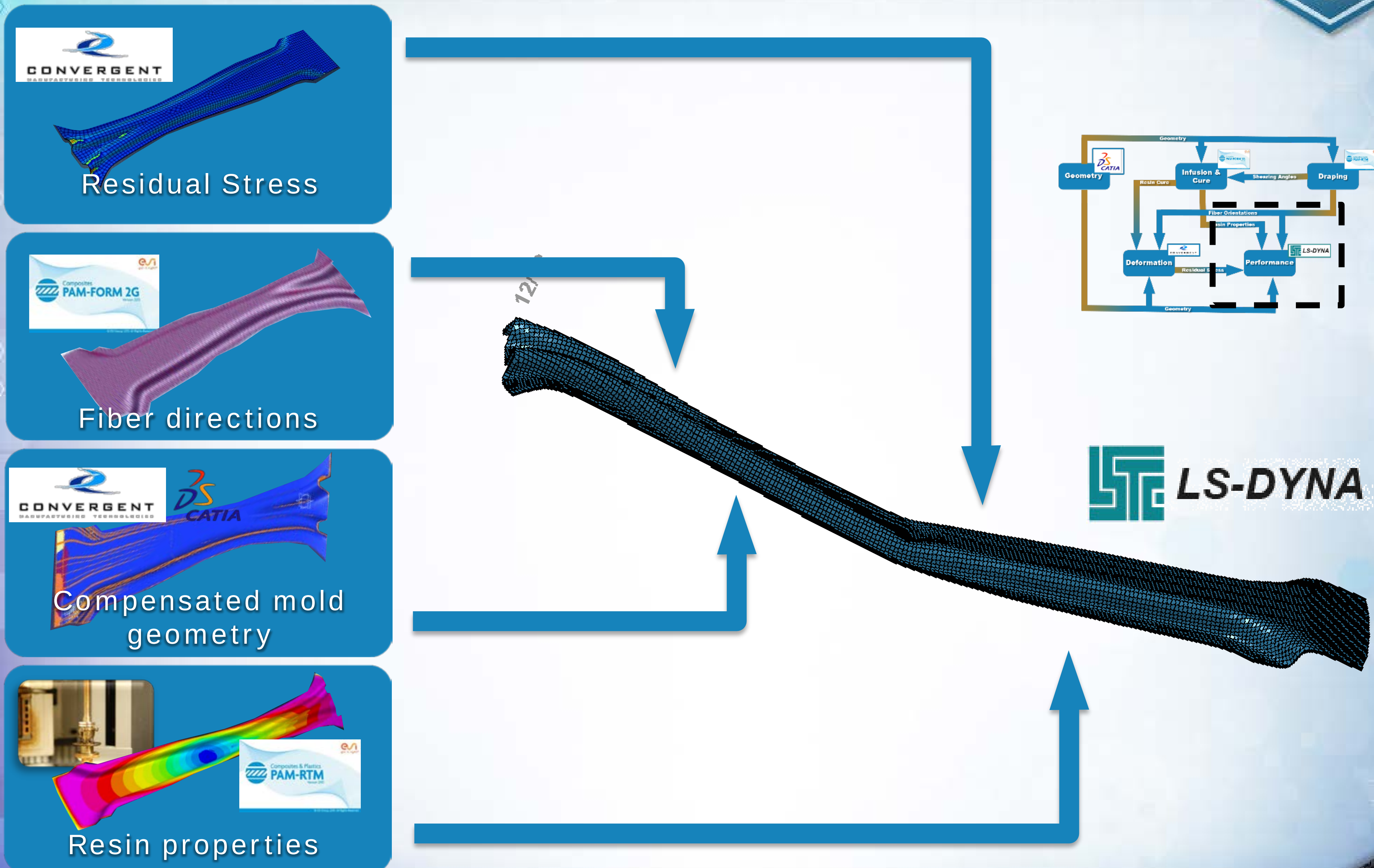
The process is iterated with the new geometry and the deformation is checked again to make sure the deformed part matches the desired geometry.

CONVERGENT
MANUFACTURING TECHNOLOGIES

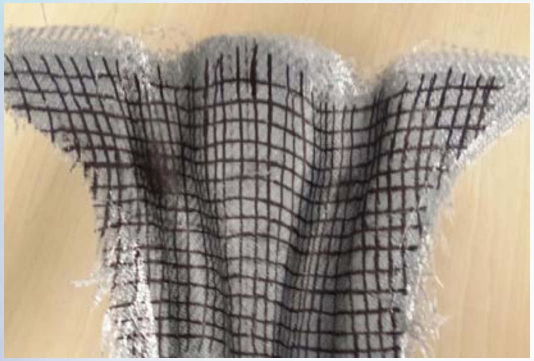
CATIA



Manufacturing Informed Performance



Validation



Draping simulations will be validated optically.

HP-RTM system will be used to validate injection.

CMM machine will be used to validate deformation.

High energy impact tester will be used to validate performance.

Summary

Any amount of geometrical complexity will **change the fiber directions** and therefore properties of the finished part.

Deformation from residual stresses built up during molding and cooldown is **unavoidable:** it can only be **compensated for, not eliminated.**

The **performance** of the finished part **can ONLY be accurately modeled** by considering changes introduced during **MANUFACTURING.**