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3DEXPERIENCE®

Composite Forming

Advanced Modeling & Simulation

CONVERGENT MANUFACTURING TECHNOLOGIES

DASSAULT SYSTEMES | The 3DEXPERIENCE® Company

Agenda

1. About Composite Forming
2. CATIA Composites Forming
3. Convergent Manufacturing Technologies
4. CATIA /COMPRO Integration Summary & Demo

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About Composites Forming

What is it?

Common Types of Forming

Advantages & Challenges

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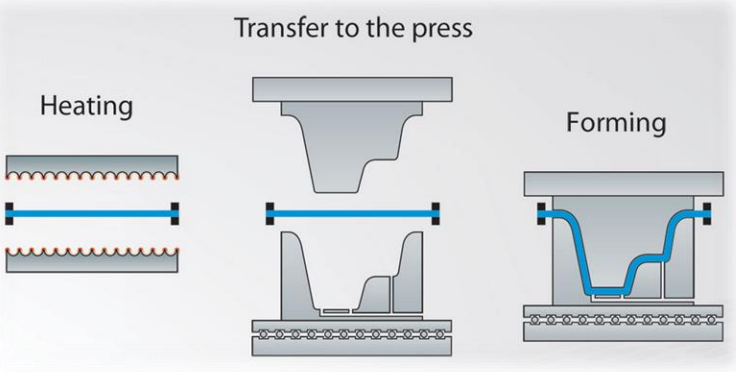
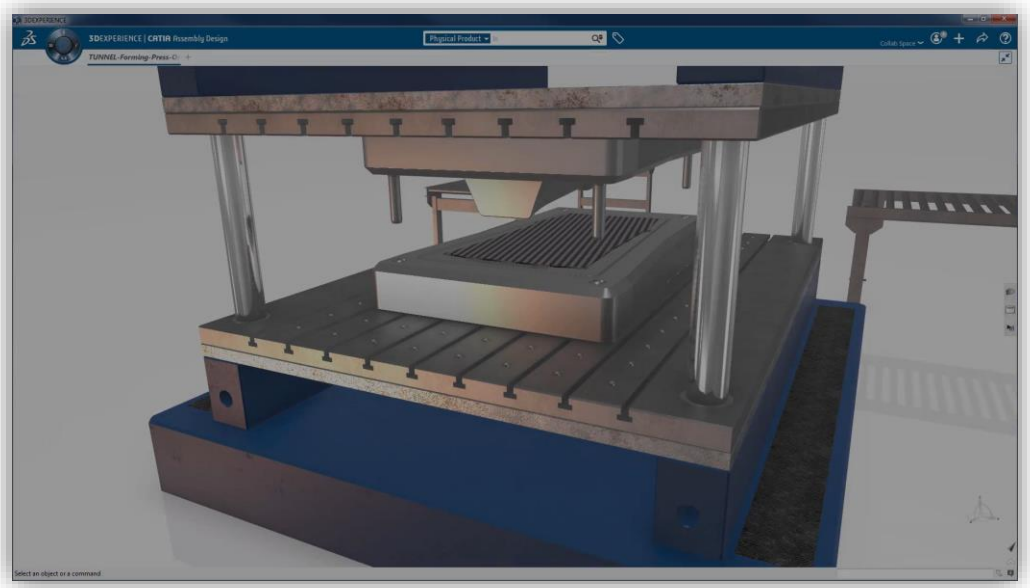
What is Composites Forming?

Multiple plies deformed from a 2D flat shape into a 3D shape by forcing the stack onto a tool surface





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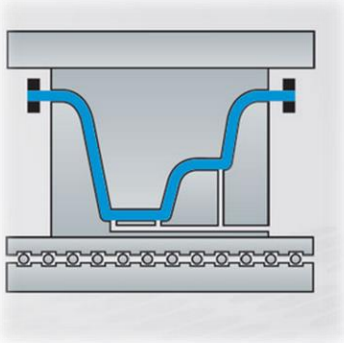
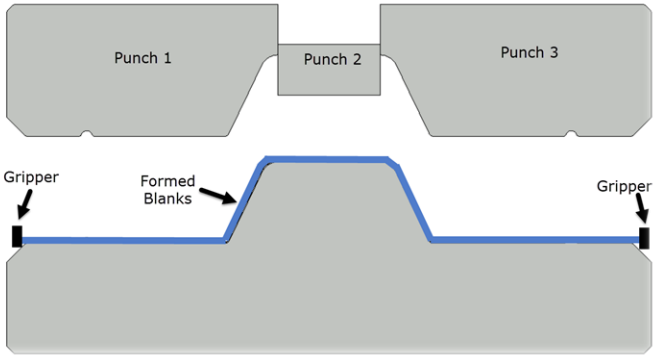
Common Types of Composites Forming

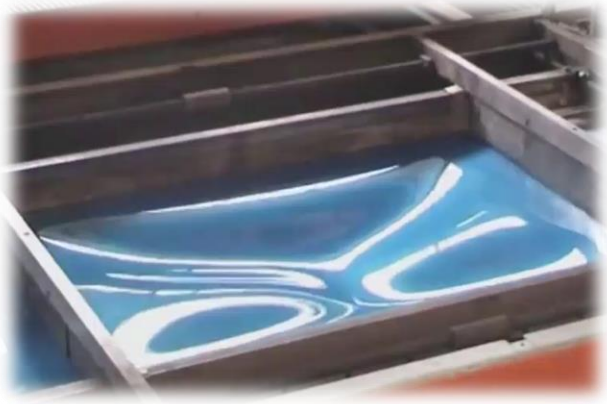
Matched Die/Stamp Forming



Punches & Grippers Forming



Diaphragm Forming



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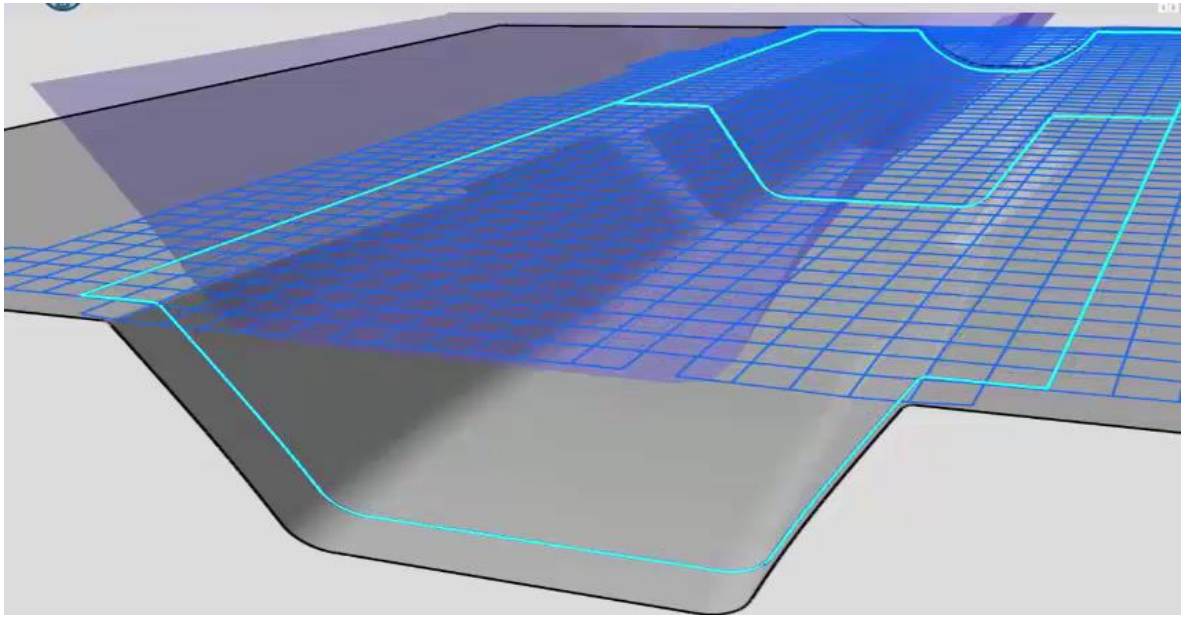
Forming Advantages & Challenges

- Advantages
  - High production rates
  - Similar tooling to metal forming
  - Compatible with a variety of blank shapes
  - Economical precursors
- Challenges
  - Deformation
  - Movement
  - Wrinkling
  - Variability



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CATIA Composites Forming

Role Description

Technical Overview

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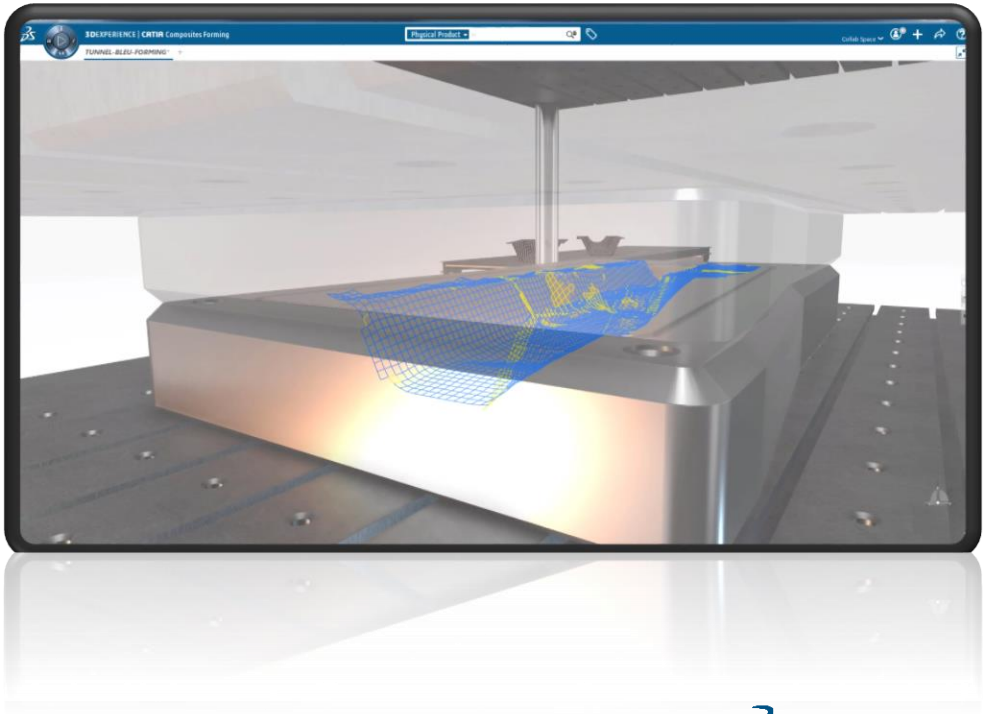
Composites Forming Designer

Accelerates the design of formed Composites parts with scalable validation

- **Accelerates the design of Composites parts**
  - By validating the forming manufacturing process
  - Editable associative parts with GSD tools
- **Usable by designers new to composites**
  - Fully integrated in CATIA
  - Extremely efficient workflow
- **Supports typical processes and materials**
  - Matched Die & Diaphragm
  - Directional & General materials
- **Provides Scaled Quick and Detailed Validations**
  - Quick in real time, Detailed within hours
  - Comparison between results
- **Unmatched Integration with Structural Analysis**



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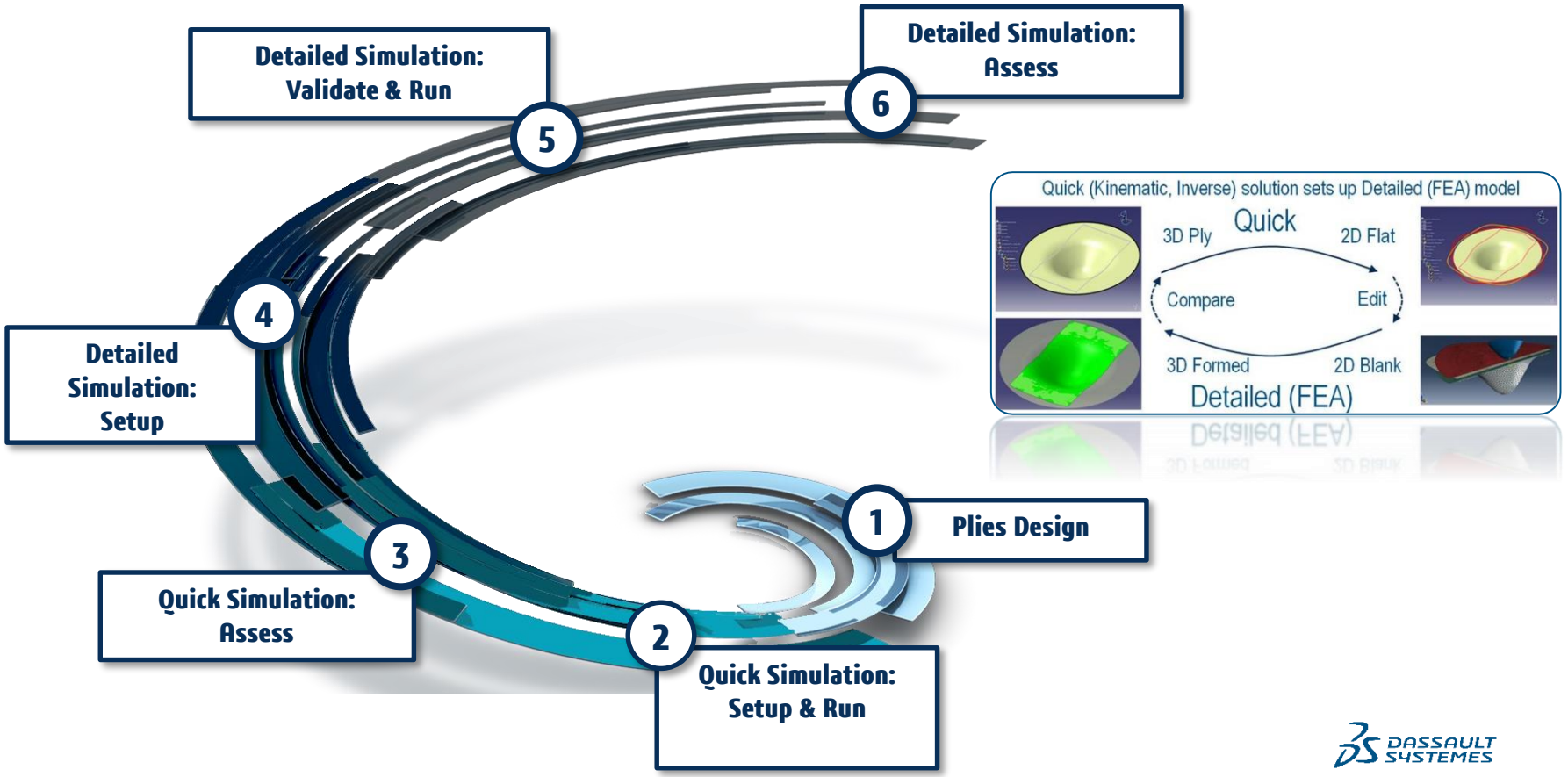
Process Overview



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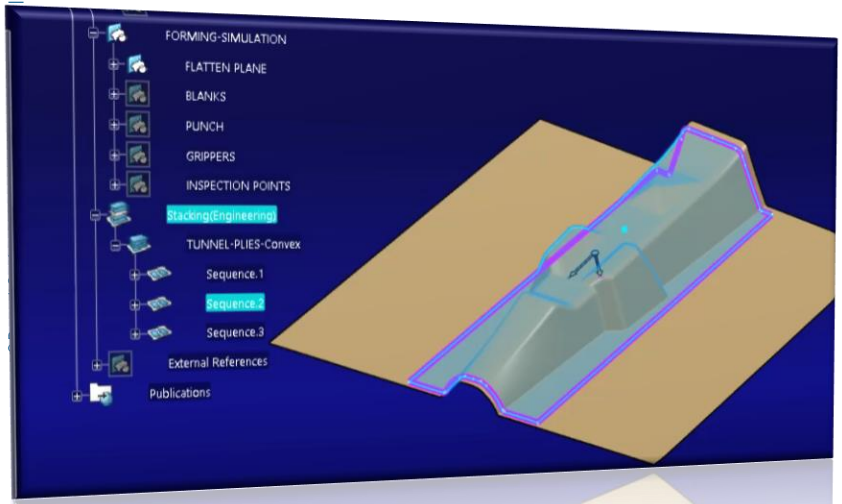
1. Plies Design

- Create or manipulate plies directly from Composites Forming Designer app using CATIA Composites Plies Design technology
  - For more scalable composites design approaches, Composites Designer or Composites Engineer role is needed



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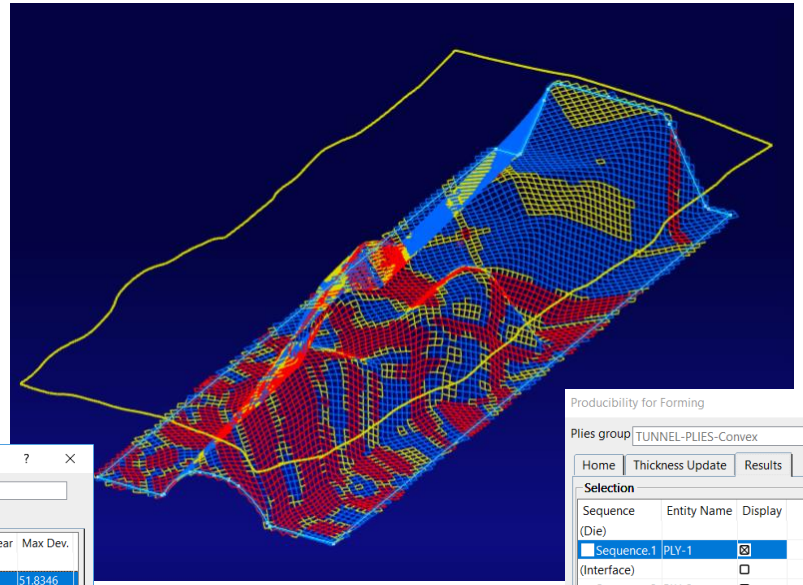
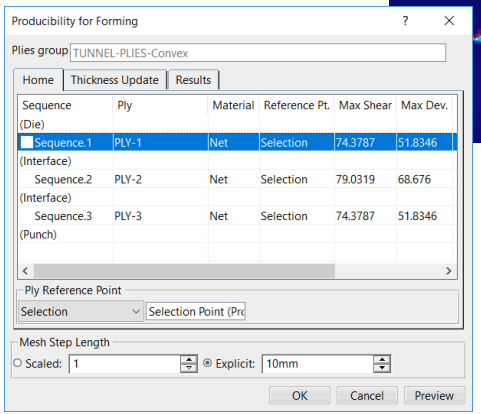
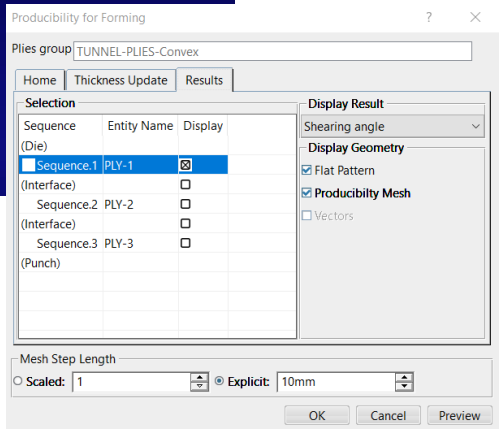
2. Setup & Run Quick Simulation

Producibility for Forming:

- Performs a quick forming simulation to identify un-formable geometry using new CATIA Fiber Modeler “frictionless” algorithm







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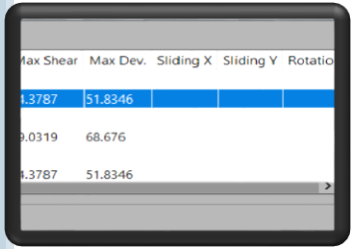
3. Assess Quick Simulation Results

High Level

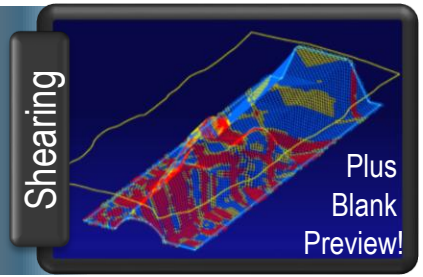
Table Summary:
- Max Deviation Estimation
- Max Shear Estimation

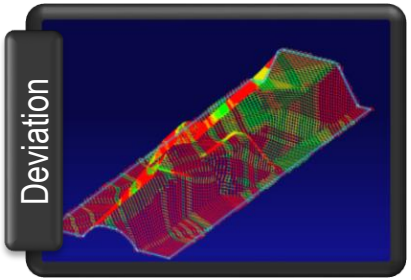


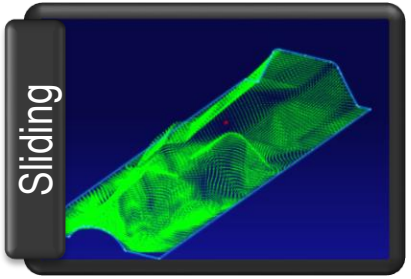
Instant results!

Mid Level

3D Results

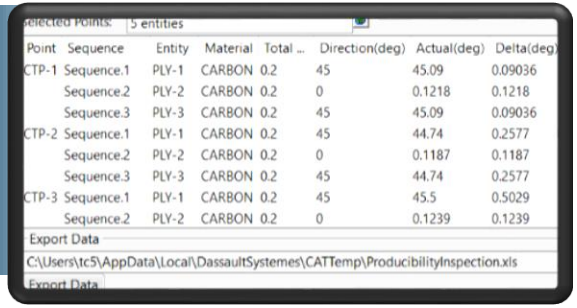






Detail Level

Producibility Inspection:
- Actual & Delta Results
- Can be exported



Export Formats:
- xls
- xlsx
- txt

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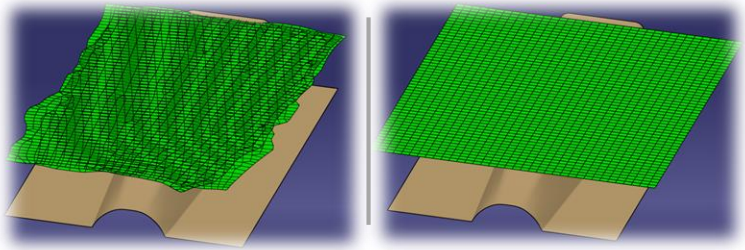
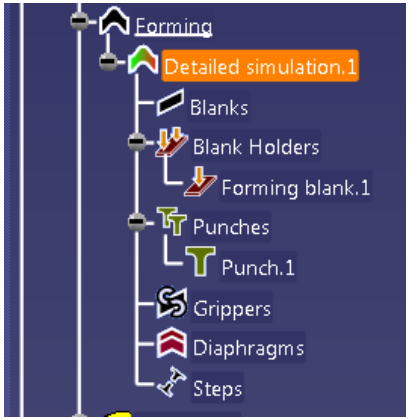
4. Setup Detailed Simulation

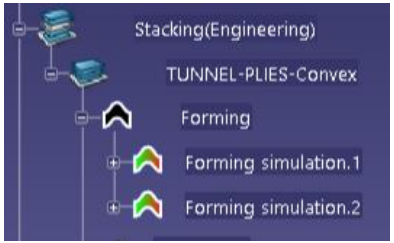
Define loads for detailed simulation:

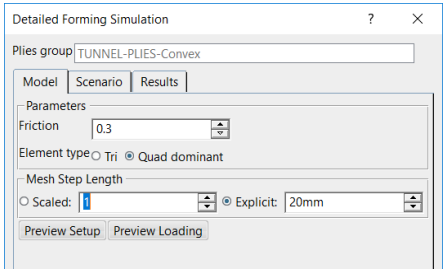
- **Automated setup:**
  - Blank shapes: Blanks from quick simulation automatically populated!
- **Analyze & compare multiple scenarios**
  - Extensive tooling load options
- **Quick variation of mesh size**

Efficiently optimize blank shapes









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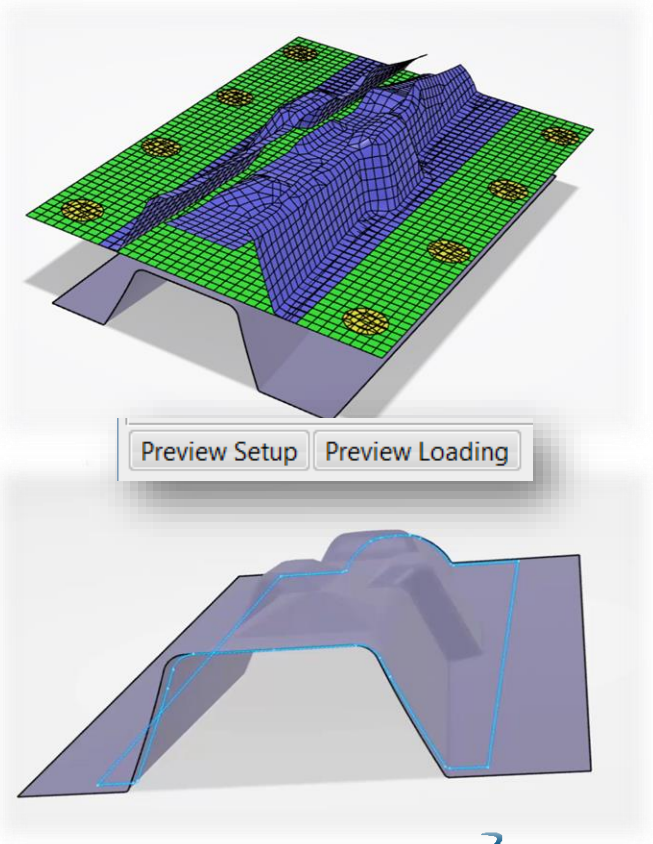
5. Validate & Run Detailed Simulation

- Preview Setup:
  - Can be previewed at any time to validate scenario setup
  - Instant mesh at user-defined resolution
- Preview Loading
  - Can be previewed to validate user-defined movements (steps) are as expected
- Run simulation using explicit FEA methods



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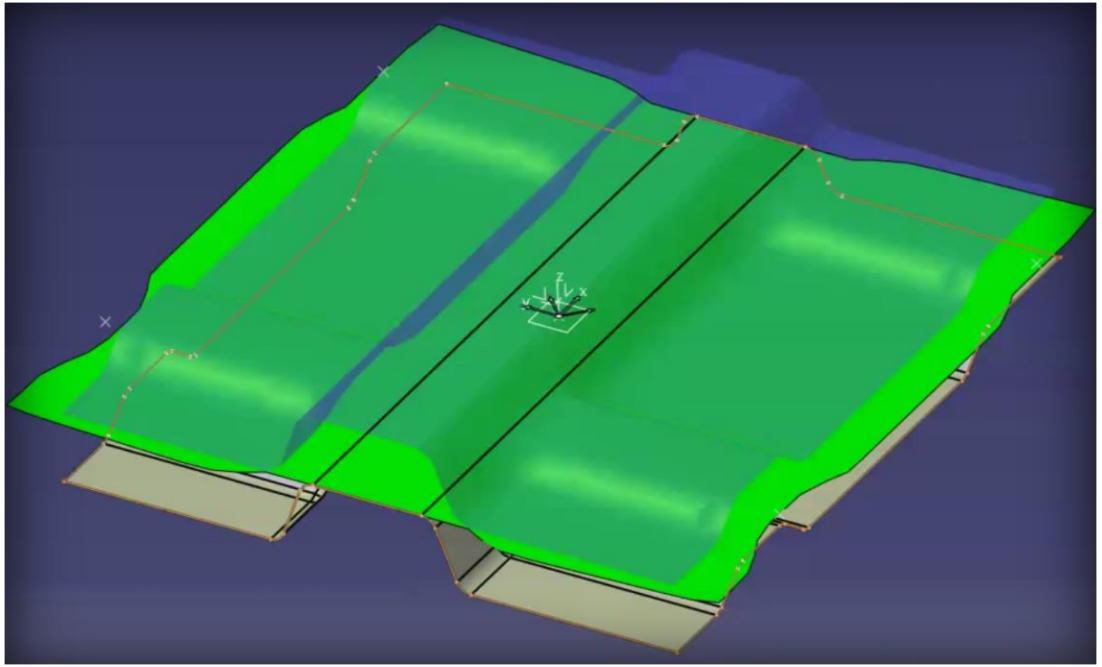
6. Assess Results of Detailed Simulation

- Instant simulation replay
- Live monitoring of computation progress
- Animated simulation replay
  - Highlight wrinkling during forming



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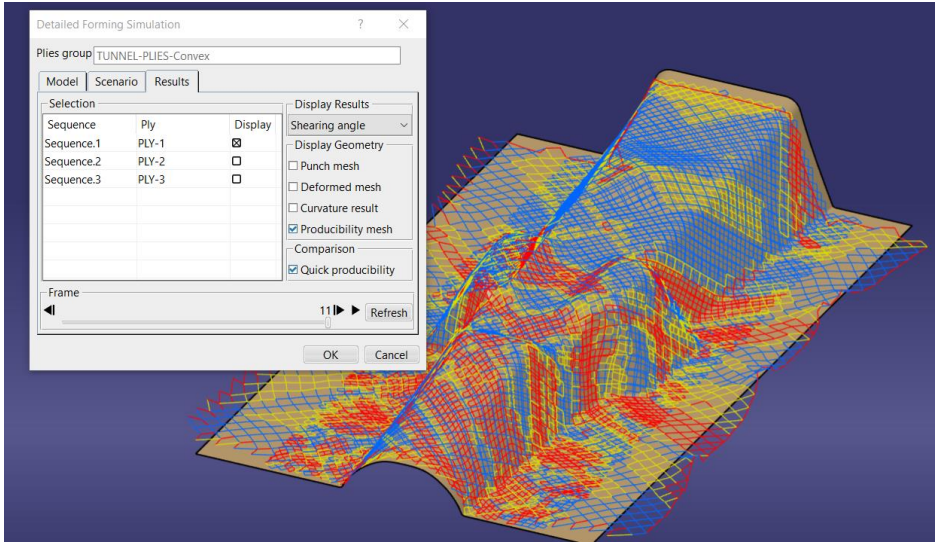
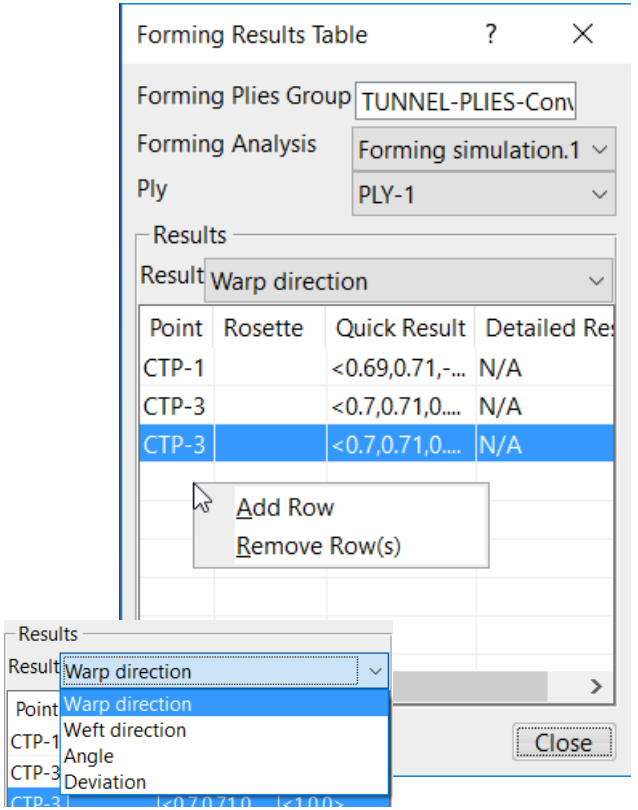
Quick vs. Detailed Simulation

Comparing Results:

- Two options:
  - Overlay Quick and Detailed Results
  - Forming Results Table





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Convergent Manufacturing Technologies

Products & Services

COMPRO Forming

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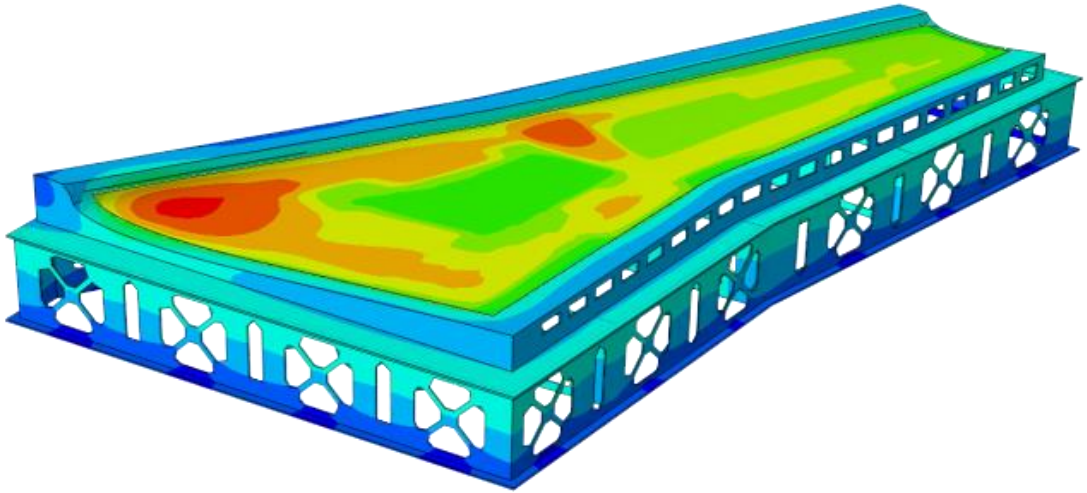
CONVERGENT
MANUFACTURING TECHNOLOGIES

EFFICIENT COMPOSITES PROCESSING

Reduce manufacturing risk

Shorten development times

Lower manufacturing cost



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CONVERGENT MANUFACTURING TECHNOLOGIES

- Established in the 90's
- 2 offices in Vancouver with +25 employees (7 PhDs)
- Developer of Simulation Software and Process Monitoring Hardware
- Consulting and Engineering Services, Materials Characterization

CONVERGENT MANUFACTURING TECHNOLOGIES

- Established in 2015
- Office in Seattle
- Developer of technologies and tools that build on, and integrate with, existing Convergent technology framework
- Consulting and Engineering Services, Program Support, Materials Characterization

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Partners and Customers

Selected Academic and Research Partners

UBC
CRN Composites Research Network
CMC Composites Manufacturing & Simulation Center
NIAR
McGill
NRC · CNRC
University of Delaware
DLR
accis Advanced Composites Collaboration for Innovation & Science
National Composites Centre
UDRI University of Dayton Research Institute
SwRI

Selected Software Partners

DASSAULT SYSTEMES
ANSYS
SIEMENS

Selected Industrial Customers and Partners

Federal Aviation Administration
BOEING
GE Aviation
NORTHROP GRUMMAN
LOCKHEED MARTIN
MITSUBISHI HEAVY INDUSTRIES, LTD.
SAFRAN
KOREAN AIR
NORDAM
'TORAY' Innovation by Chemistry
HEXCEL
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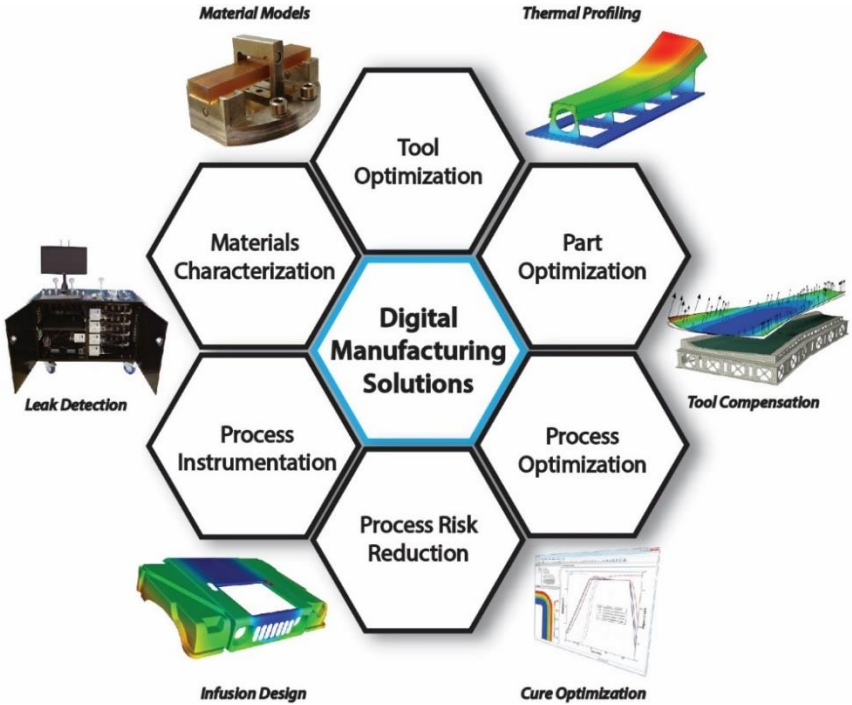
CONVERGENT MANUFACTURING TECHNOLOGIES



▶Products & Services

- Software
- Hardware
- Testing
  - Materials characterization
  - Specialized testing
- Applications Consulting

▶Primary Industries Served:

- Aerospace
- Wind energy
- Automotive

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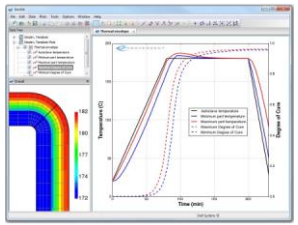
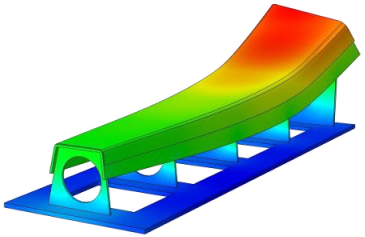
Convergent Manufacturing Technologies

Process Simulation

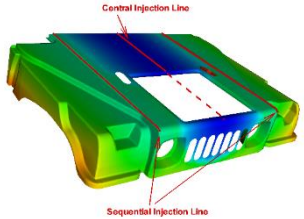
RAVEN
Fast and Easy to Use



COMPRO
Powerful with Wide Applications

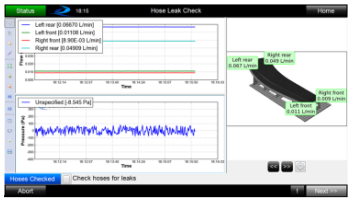


LIMS
3D Mold Filling



Process Monitoring

COHO
Gas Flow and Vacuum Leak Detection Systems

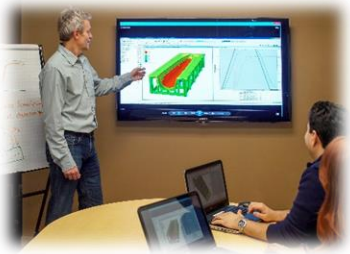


Engineering Services

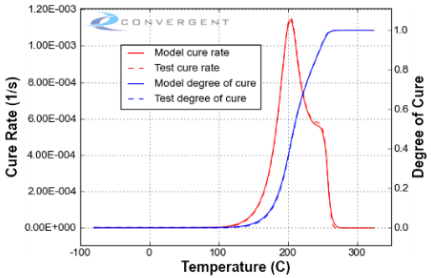
Engineering and Program Support

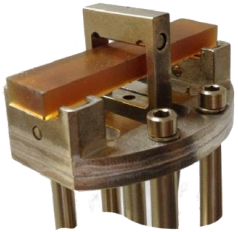
Process Analysis and Design

Training and Education



Materials Characterization





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RAVEN

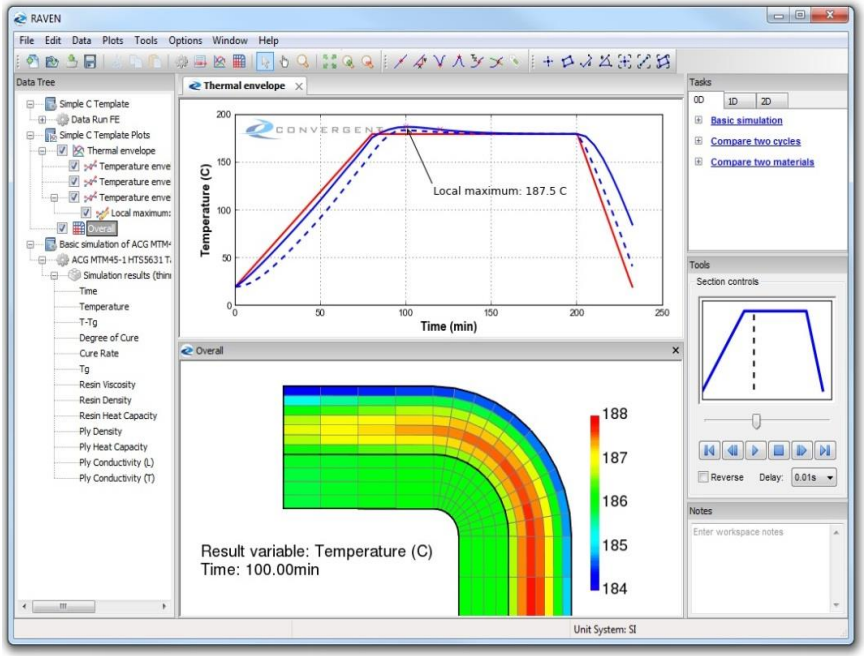
▶ *Process Simulation – Fast and Easy to Use*

Software for THERMAL PROFILING

▶ **Locate** hot and cold spots

▶ **Optimize** cure cycles and tooling

▶ **Control** exotherms



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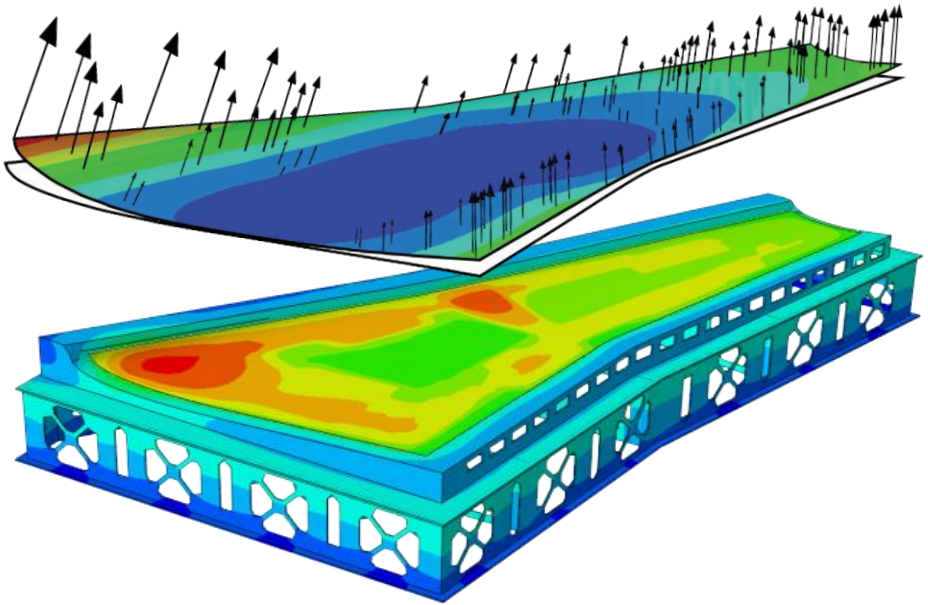
COMPRO

- *Process Simulation – Powerful with Wide Applications*

Software for DIMENSIONAL CONTROL

- **Calculate** residual stresses
- **Predict** spring-in and warpage
- **Compensate** process tooling



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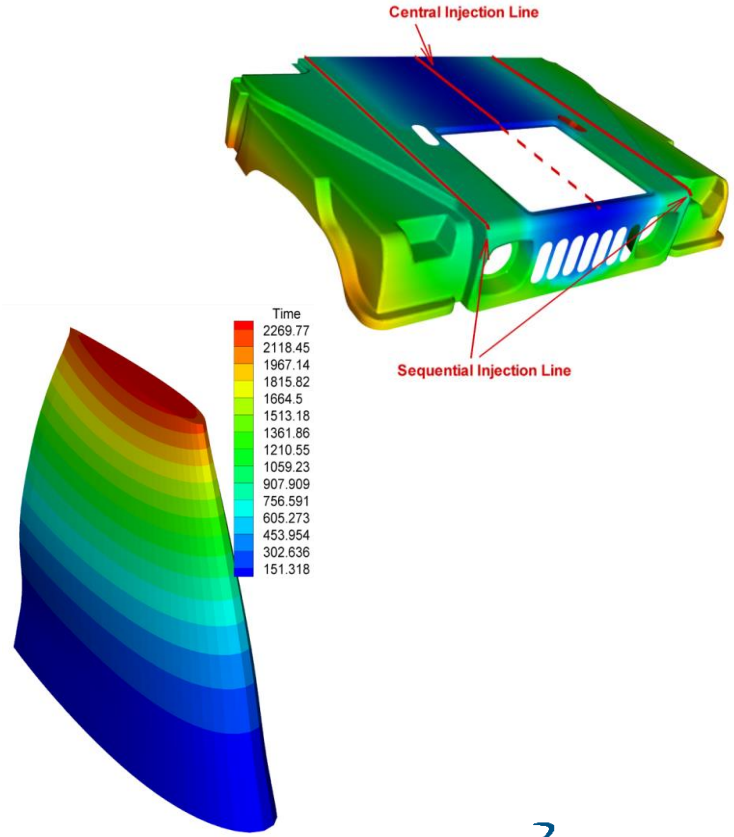
LIMS

- *Process Simulation – 3D Mold Filling*

Software for accurate MOLD **FILLING**

- **Reduce** process design cost, time and risk
- **Optimize** fill time and gave/vent locations
- **Evaluate** process changes



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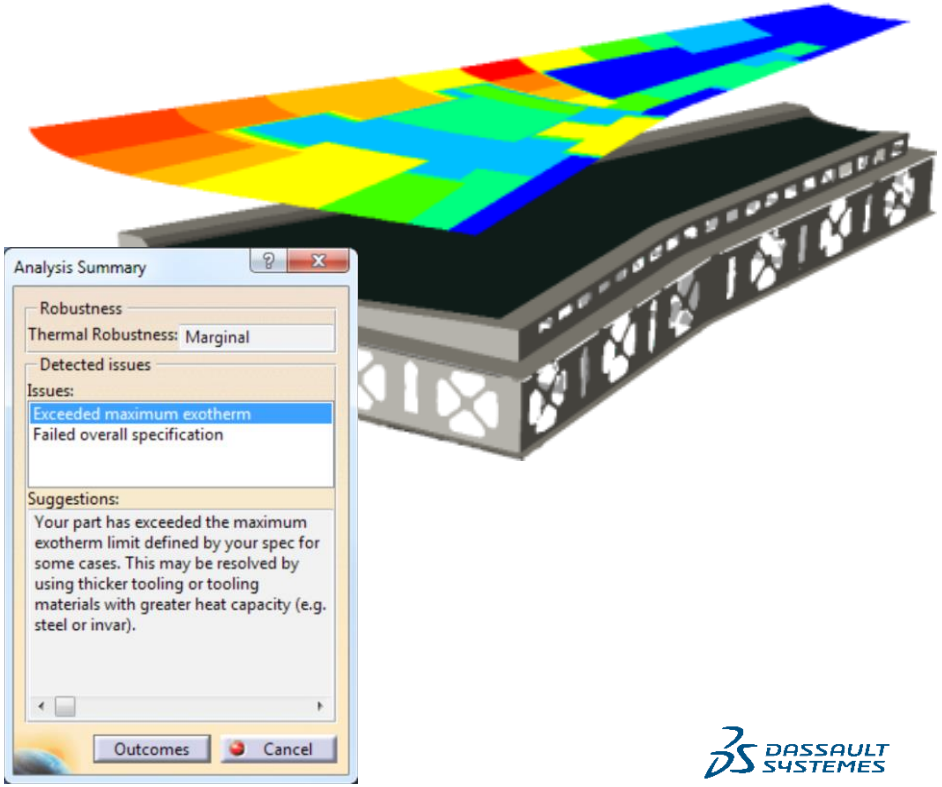
CPA-TA

- *Composites Producibility Assessment – Thermal Assessment*

Software for DESIGN EVALUATION

- **Identify** thermal and cure issues
- **Validate** against specs
- **Avoid** unforeseen redesign



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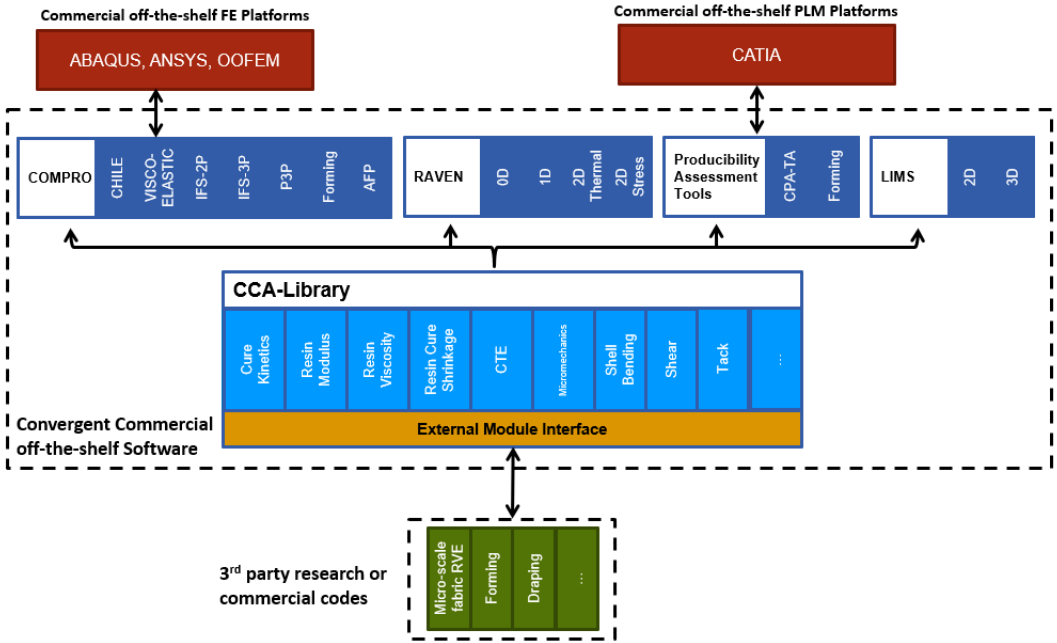
Common Component Architecture (CCA)

- *State-variable based, expandable material model database*

Integrated MATERIAL PROPERTIES

- **140+** constitutive models
- **30+** open composite materials
- **Interlink** process parameters



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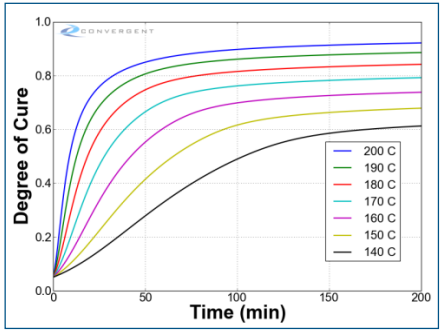
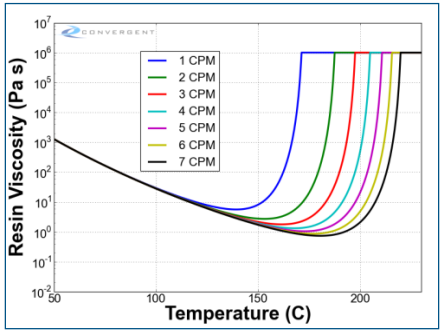
Materials Characterization

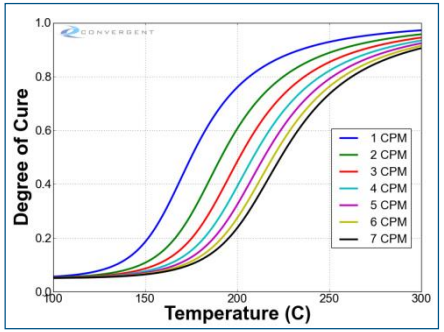
▶ *Expand Understanding of Materials and Processes*

Material properties for COMPOSITE PROCESS SIMULATION

- ▶ Specialized materials **characterization**
- ▶ Material model **development**
- ▶ Material model **validation**







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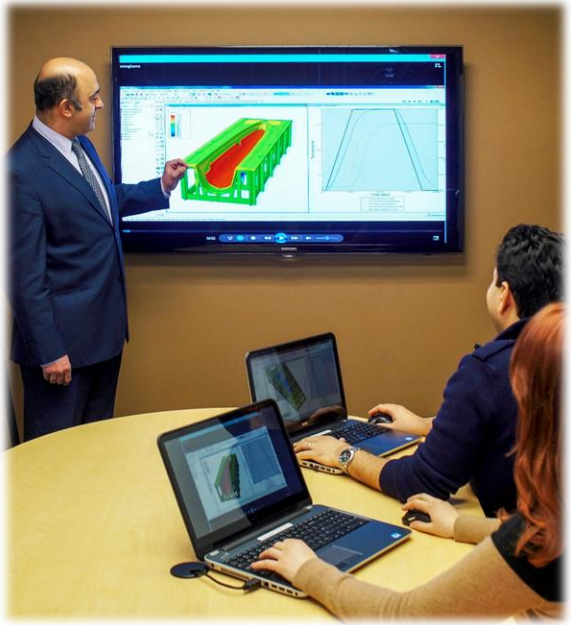
Engineering Services

- *Enhance Understanding of Materials and Processes*

Services for PROCESS DEVELOPMENT

- Engineering and Program **Support**
- Process Analysis and **Design**
- Training and **Education**



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DASSAULT SYSTEMES

COHO

- *Gas Flow and Vacuum Leak Detection Systems*

Hardware for VACUUM LEAK DETECTION

- **Instantly** identify vacuum leaks
- **Determine** leak location
- **Immediate** feed-back

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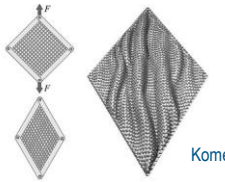
COMPRO Forming

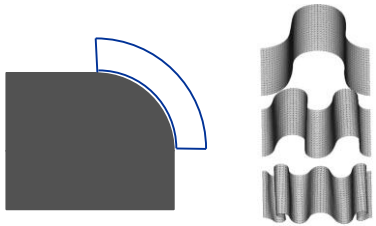
- Physics-based phenomenological modeling approach

Shell Element

Ply's In-plane (axial, shear)



Ply Bending



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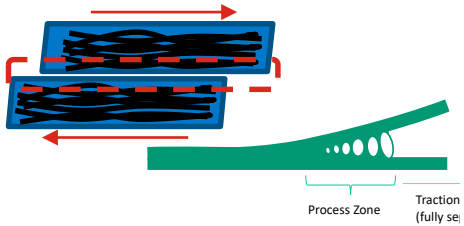
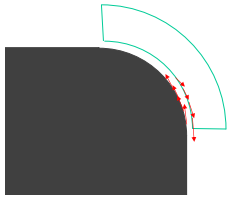
Contact

Inter-ply friction, stick-slip, tack



Tool-part interaction



Key Phenomena
Axial Inextensibility
In-plane shear (and locking)
Bending
Friction
Tack (cohesion)
Temperature Dependency
Rate Dependency

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COMPRO Forming

CCA Material Model Expansion

- Material models:
  - Elastic
    - Temperature dependent, degree-of-cure dependent
  - Viscoelastic
    - Temperature and rate dependent
- Interface models:
  - Viscous friction*
  - Tacky*
- Current overall state: TRL3

Feature		
Fully decoupled bending behavior		
Deformation described by characteristic curves		
Deformation described by constitutive models		
Membrane Behaviour	Temperature dependent	
	Rate dependent	
Bending Behaviour	Temperature dependent	
	Rate dependent	
Interface Behaviour	Temperature dependent*	
	Rate dependent*	
	Pressure Dependent	
Materials Characterization Services*:		
Bending		
Membrane (In-plane shear)		
Interface (Interlaminar shear)		

*under development

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COMPRO Forming

- Integrated with Abaqus/Explicit solver
  - Powerful and flexible general purpose solver that allows tailored definition of parts, BCs, loads, meshes and contact properties.
- Wide applicability:
  - Material forms
    - Thermoset and thermoplastic matrix composites
    - Unidirectional and woven fabric prepregs
  - Processes:
    - Single and double diaphragm forming
    - Compression and punch forming
- Extensible to thermal and stress analyses:
  - CCA availability of thermo-chemical and thermo-mechanical material models
    - Cure Kinetics, heat capacity, stiffness, cure shrinkage, thermal expansion, etc.

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CATIA/COMPRO Integration

Summary

Case Study

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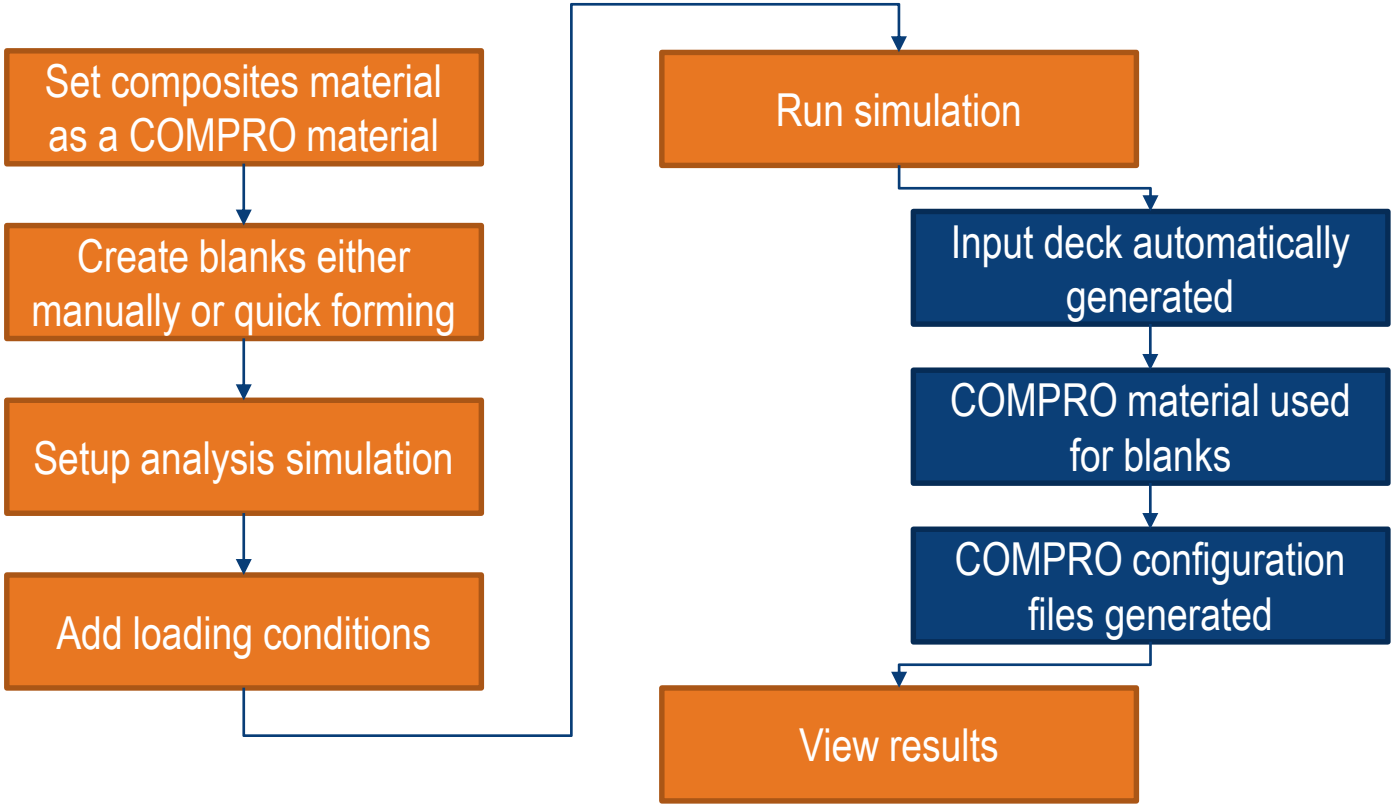
Model Generation



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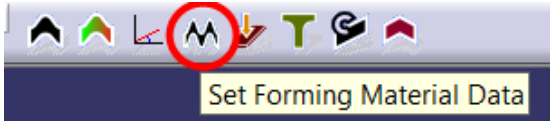
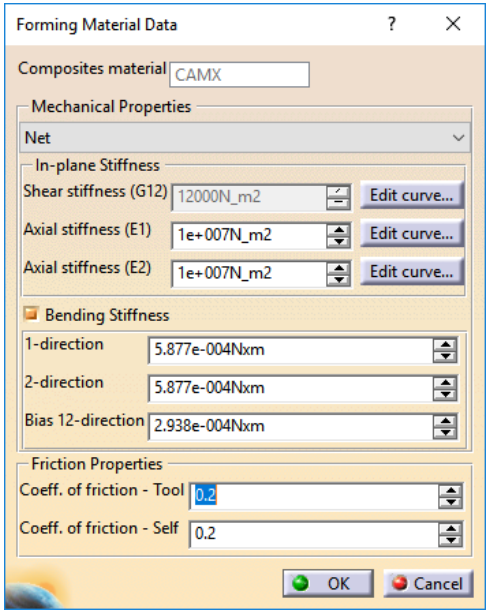
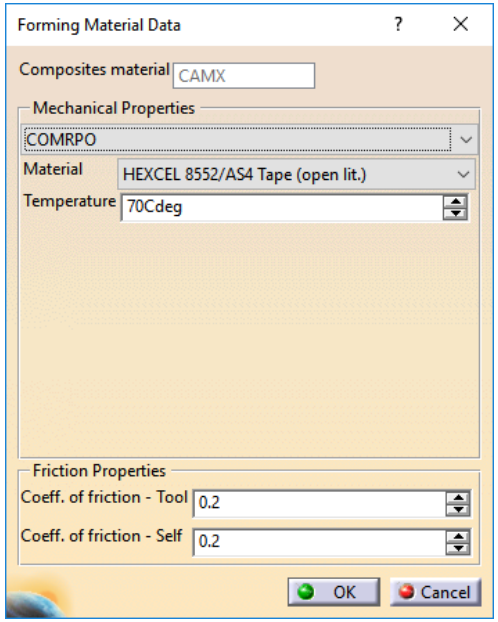
Material Data

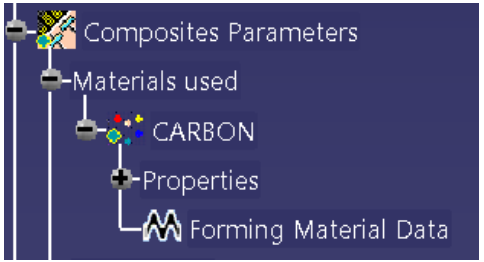


New Forming Material Data

- Integration with COMPRO now allows designer access to additional mechanical properties







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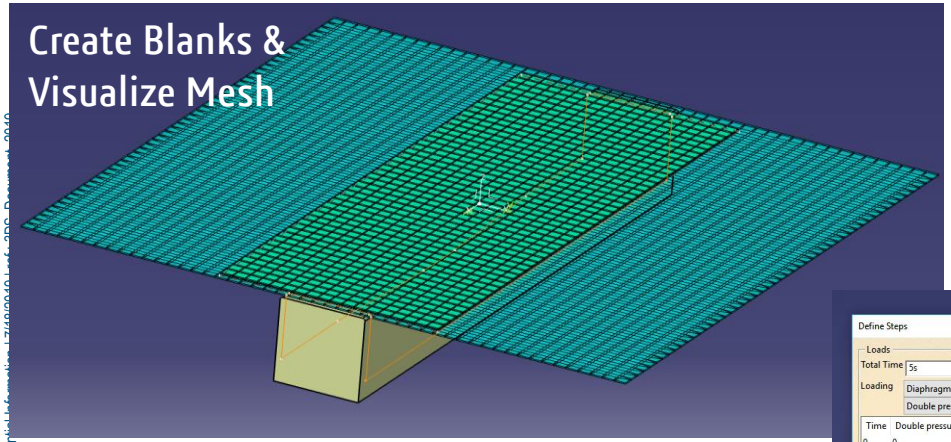
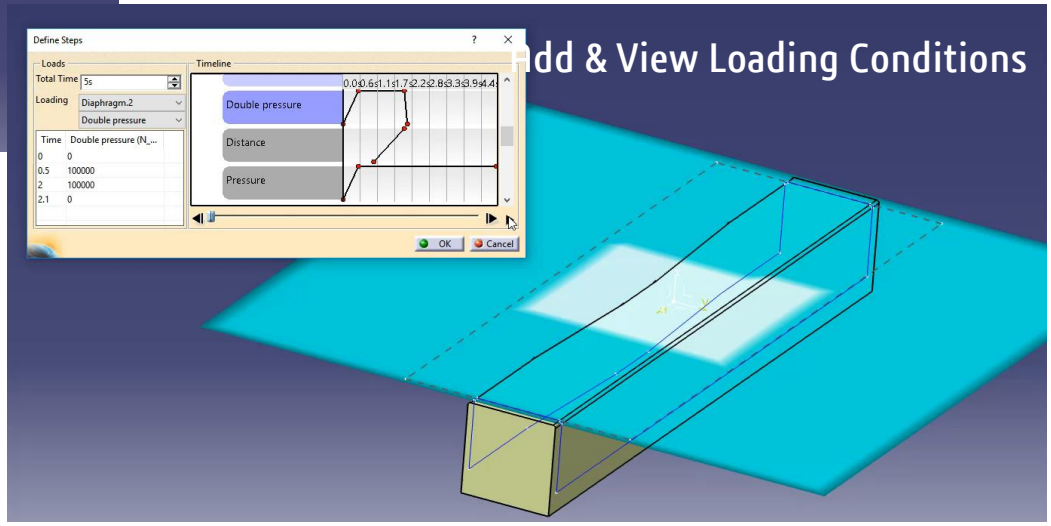
Model Prep





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Run Simulation

- Auto generated files
  - Input deck (.inp)
  - COMPRO configuration (.xml)

forming1_3_new_numbering_compro.inp

```
*Heading
** Job name: Forming Model name: Forming
** Generated by: CATIA Forming Workbench 1.1
*** Writing Blank Blank1 with material S1454_G803 Biaxial 1mm***
*Part, name=Blank1
*Node, nset=Blank1MembraneSetN
1, 0.000511495828629, -0.178396911621, 0.0005
2, 0.0107743997574, -0.177393936157, 0.0005
3, 0.0213136711121, -0.174350494385, 0.0005
4, 0.0313356742859, -0.170046203613, 0.0005
5, 0.0409541015625, -0.164987686157, 0.0005
6, 0.0502369232178, -0.159576690674, 0.0005
7, 0.0593353729248, -0.154068130493, 0.0005
8, 0.0683671722412, -0.148114456177, 0.0005
9, 0.0772606658936, -0.142067718506, 0.0005
10, 0.085964674561, -0.135589416504, 0.0005
11, 0.0945419158936, -0.128939971924, 0.0005
12, 0.102718490601, -0.121970664978, 0.0005
13, 0.110726249695, -0.11454549408, 0.0005
14, 0.118235977173, -0.106920463562, 0.0005
15, 0.125458839417, -0.0987354736328, 0.0005
16, 0.132312927246, -0.0902364807129, 0.0005
```

cca-configuration.xml

```
<?xml version='1.0' encoding='UTF-8'?>
<configuration>

    <directory path="cca-data" type="data" />
    <directory path="" type="output" />

    <model_units system="SI" />

    <analysis_code engine="ABAQUS" />

    <license mode="queue" />

    <debug debug_element="1" file="true" filename="debug.csv" screen="true" />

        <user_material id="Blank1MembraneSet">
        <composite_file name="COMPOSITE-HEXCEL-8552-AS4-Tape-v1_vugens=1.xml" />
        <initial_doc DOC="0.05" />
    </user_material>
        <user_material id="Blank2MembraneSet">
        <composite_file name="COMPOSITE-HEXCEL-8552-AS4-Tape-v1_vugens=1.xml" />
        <initial_doc DOC="0.05" />
    </user_material>
        <user_material id="Blank3MembraneSet">
        <composite_file name="COMPOSITE-HEXCEL-8552-AS4-Tape-v1_vugens=1.xml" />
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    </user_material>


</configuration>
```

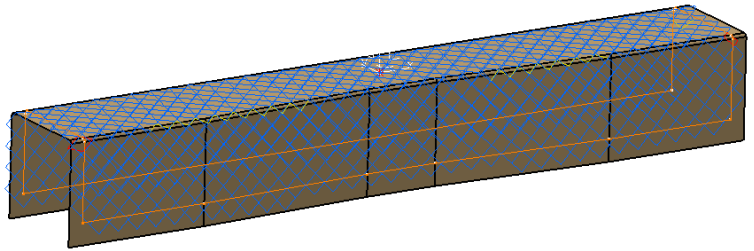

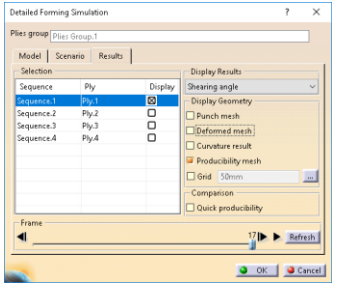

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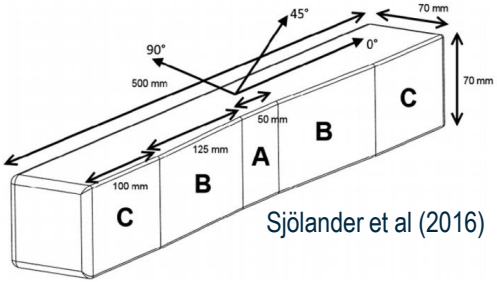
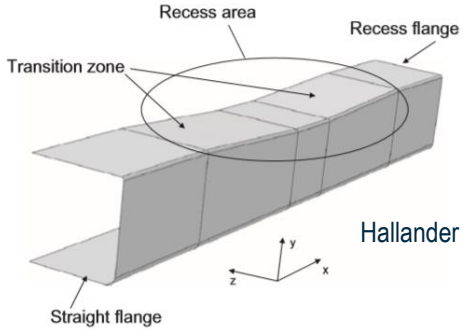
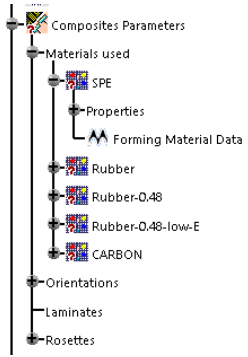
Case Study – C-Channel

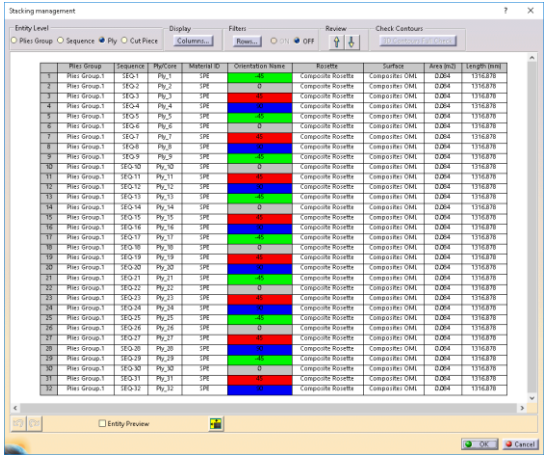


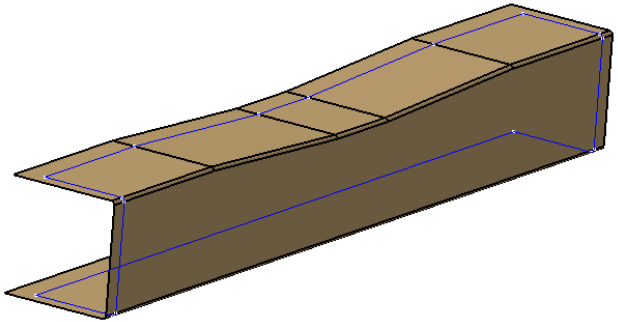
Sjölander et al (2016)



Hallander et al (2015)







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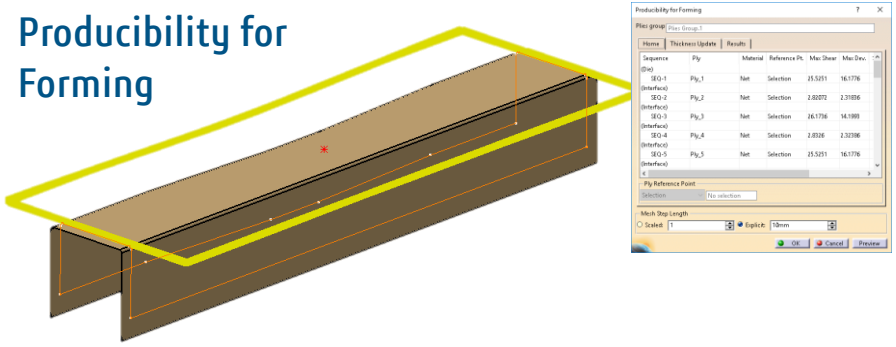
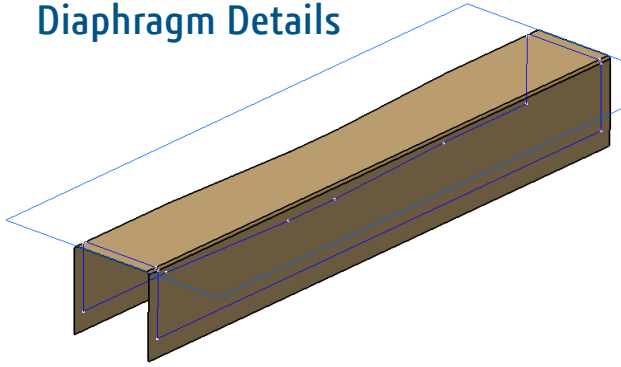
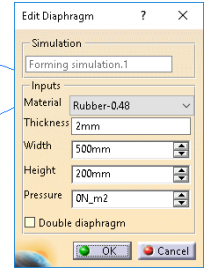
Case Study – C-Channel

Producibility for Forming

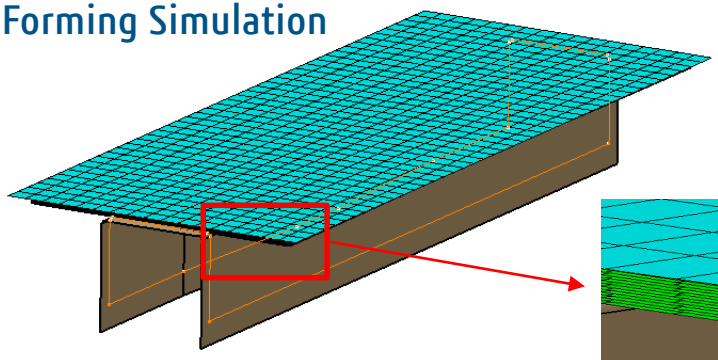


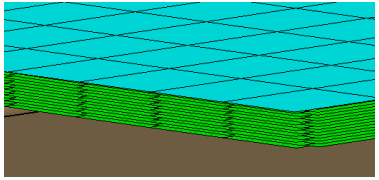
Diaphragm Details

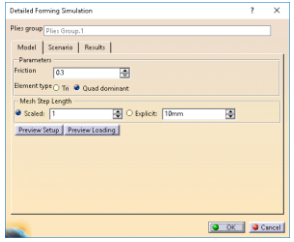


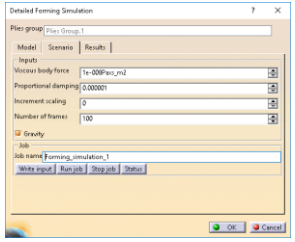


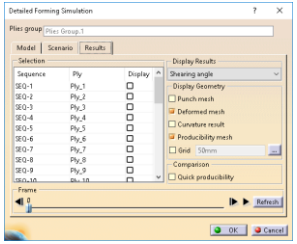
Forming Simulation











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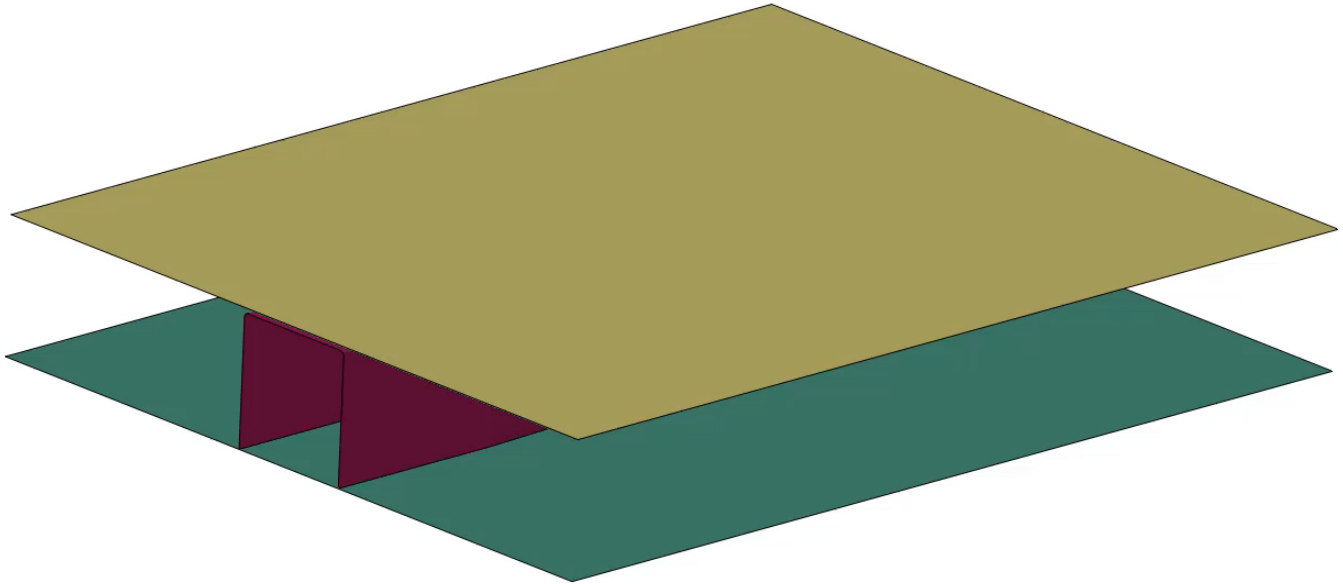
Case Study – C-Channel

- C-Channel Forming Demo



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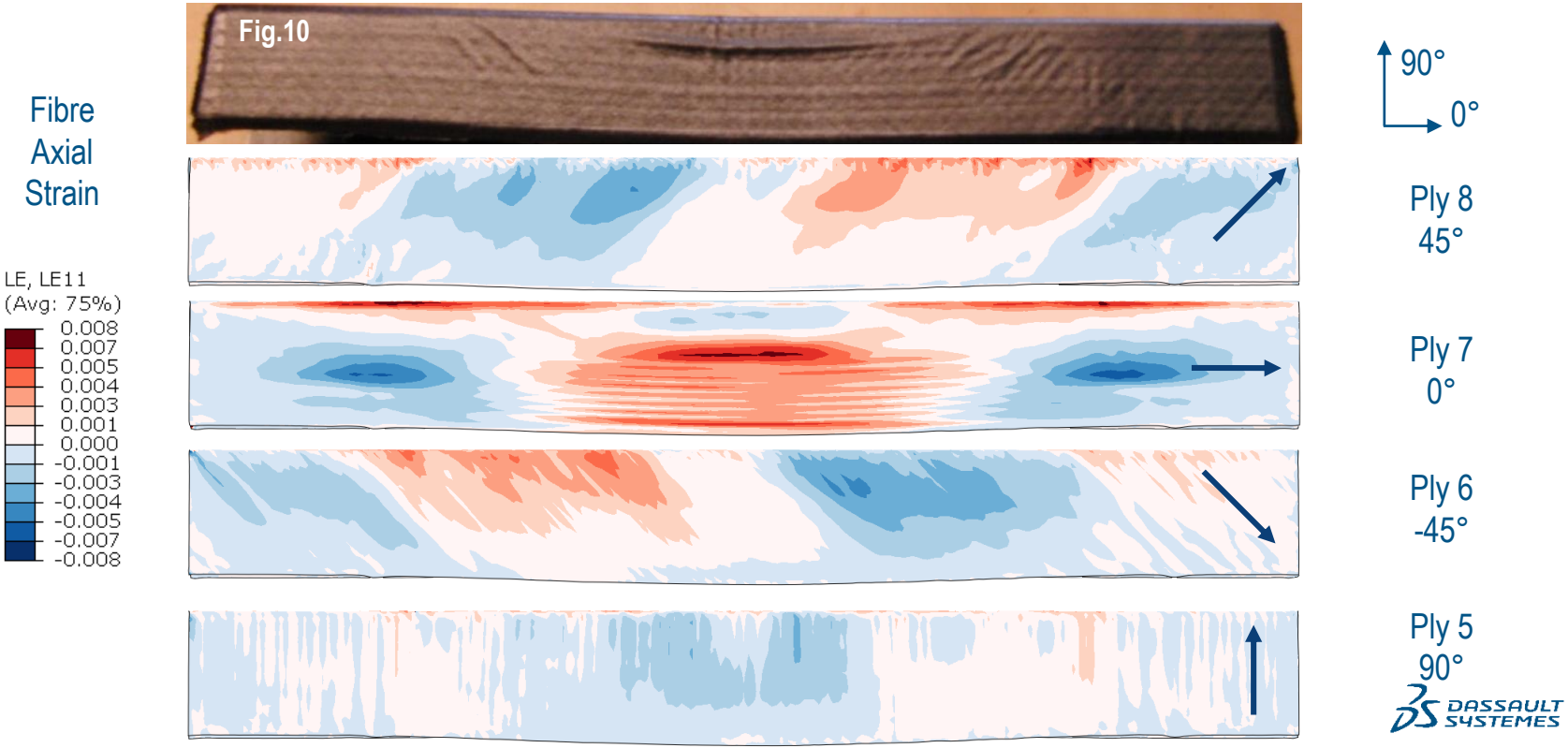
Case Study – C-Channel

- Qualitative defect prediction



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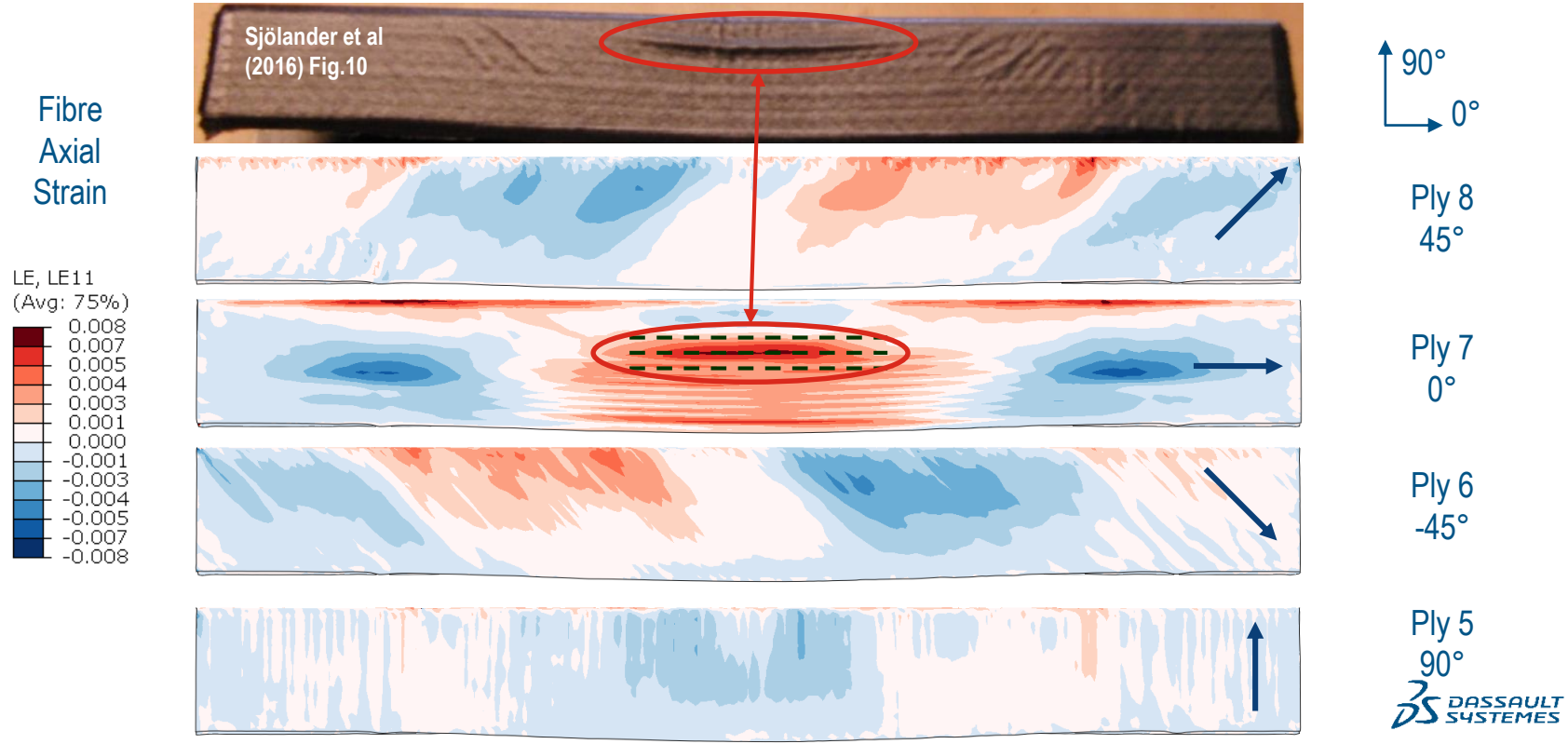
Case Study – C-Channel

- Fiber bridging

Qualitative Defect Prediction



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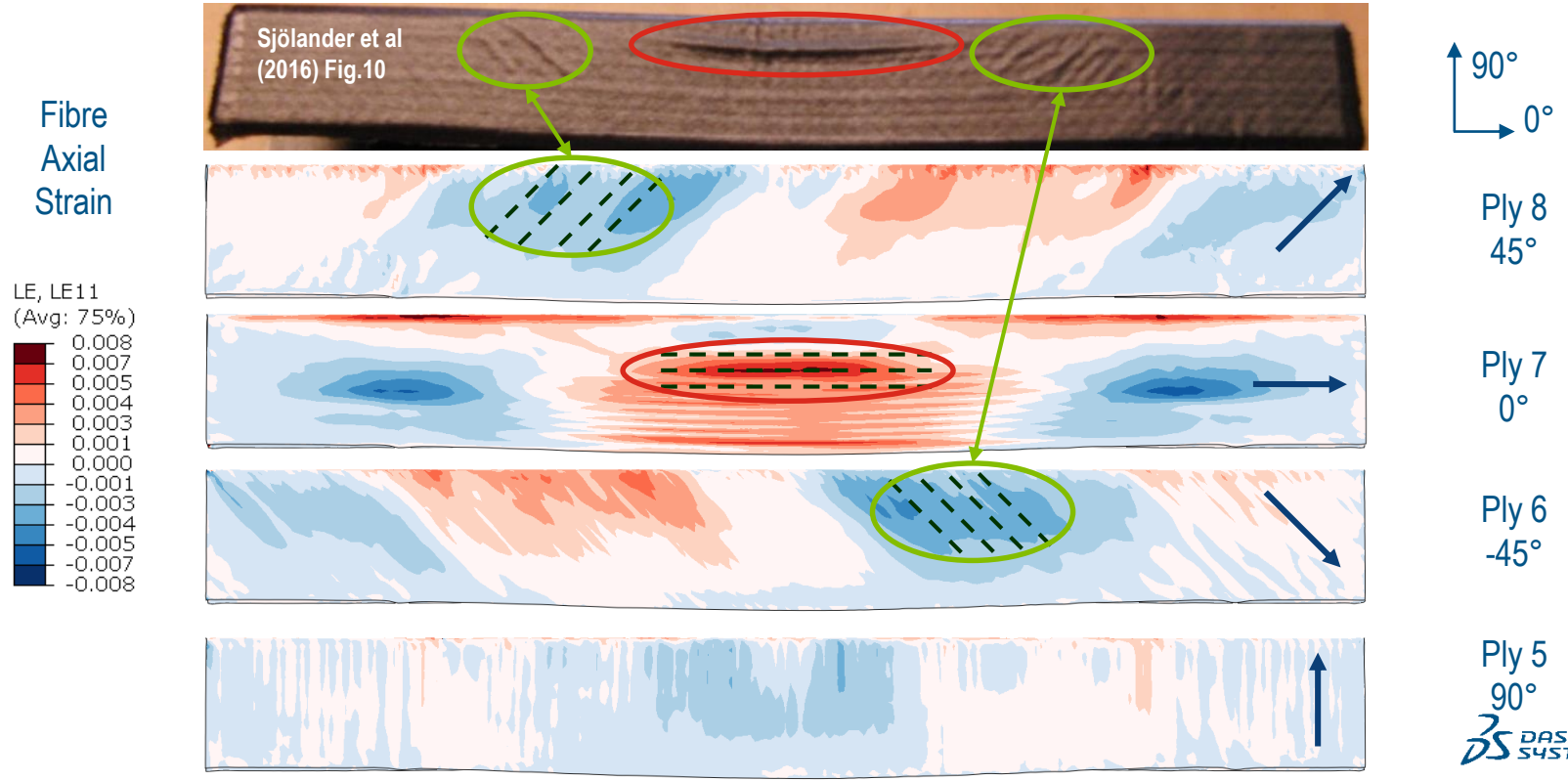
Case Study – C-Channel

- Fiber bridging
- Fiber buckling

Qualitative Defect Prediction



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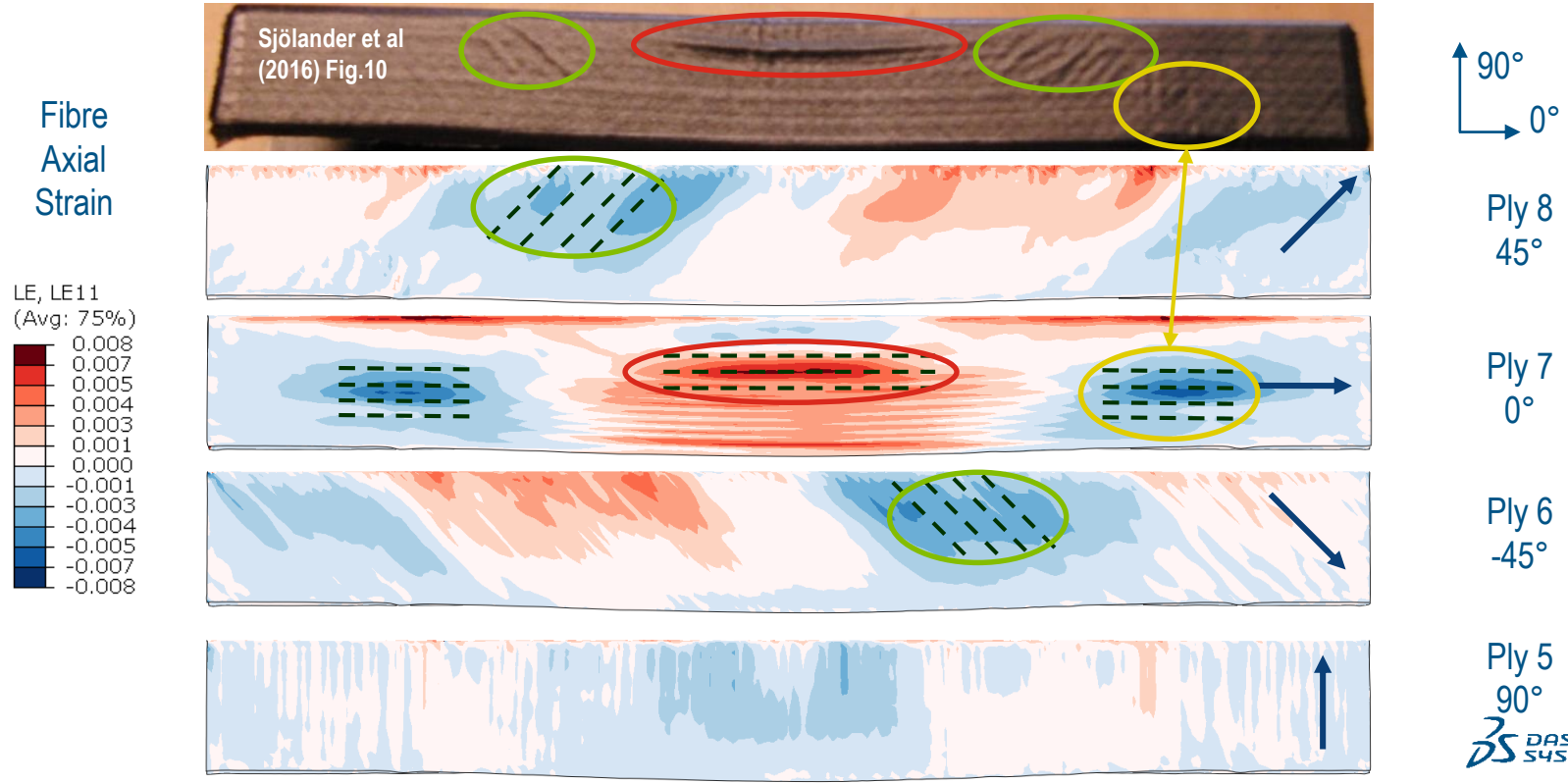
Case Study – C-Channel

- Qualitative Defect Prediction

- Fiber bridging
- Fiber buckling
- Fiber buckling



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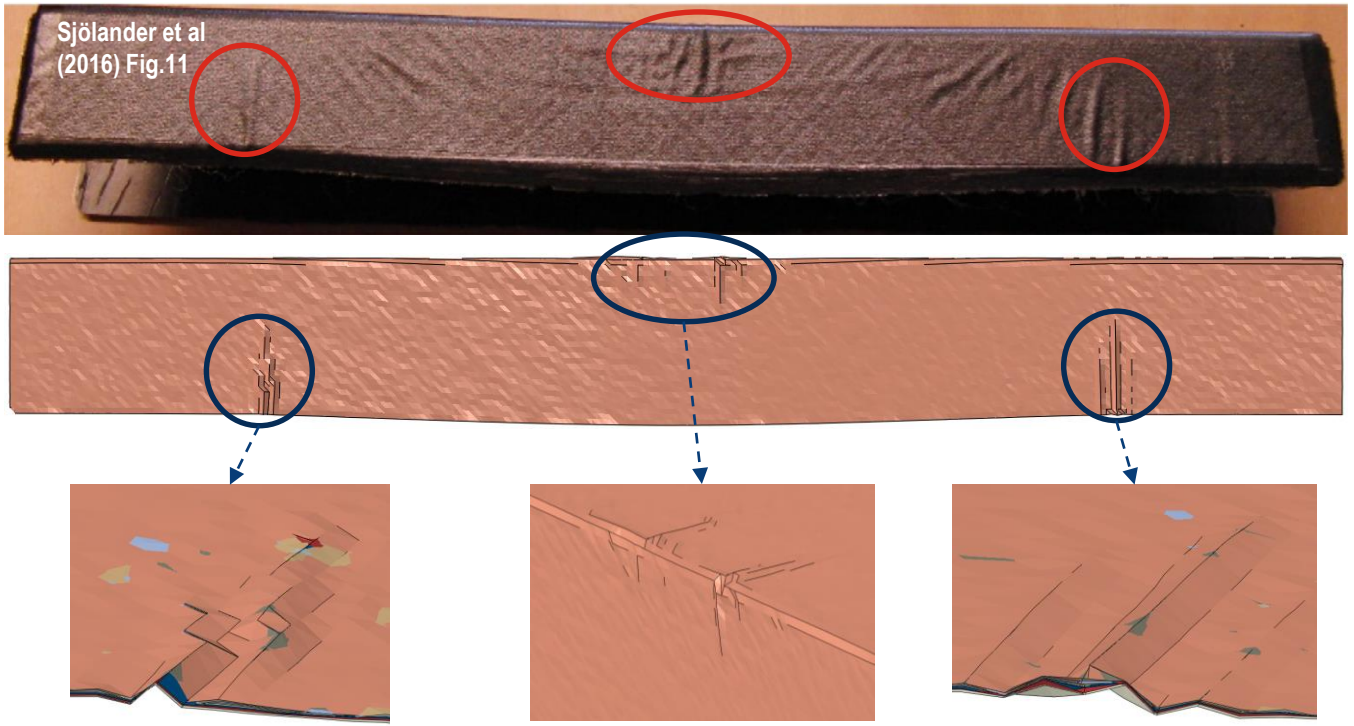
Case Study – C-Channel

- Qualitative Defect Prediction



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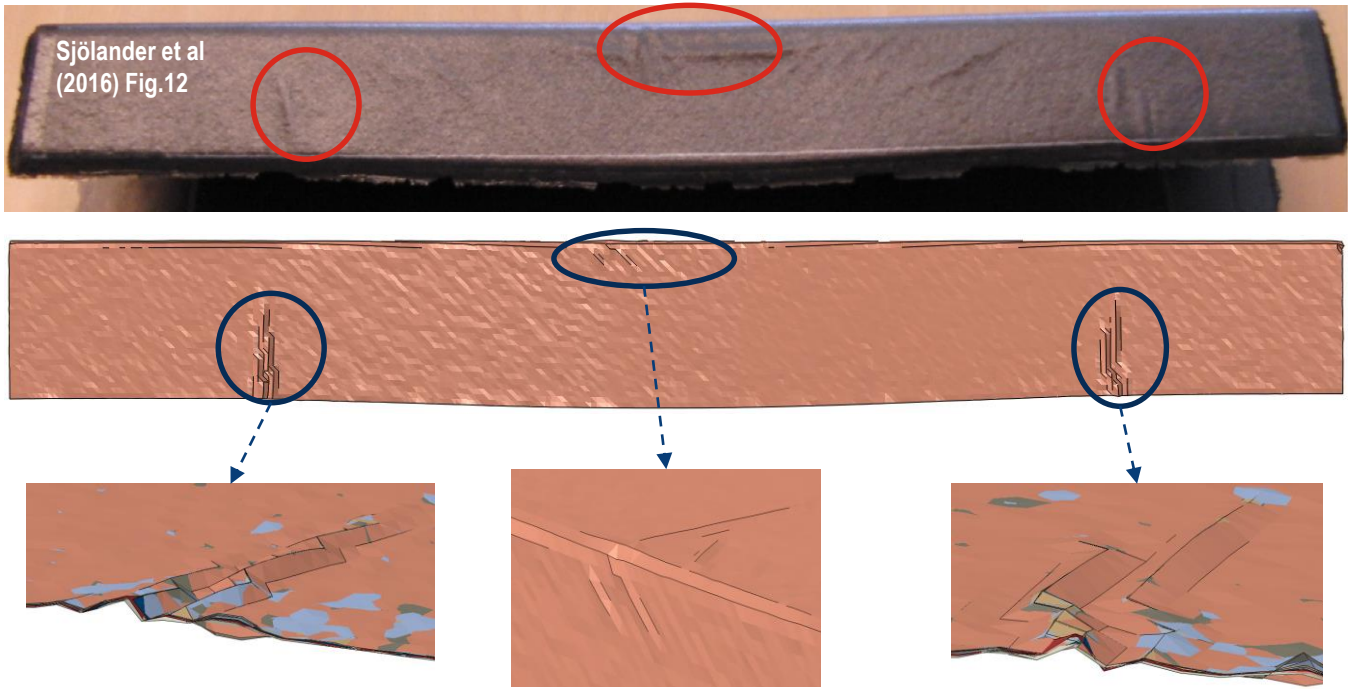
Case Study – C-Channel

- Quantitative Defect Prediction: $[45°/-45°/90°/0°]_s$



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DASSAULT SYSTEMES

Case Study – C-Channel

- Quantitative Defect Prediction: $[45°/90°/-45°/90°]_s$

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Concluding Remarks

- Composite forming is a challenging manufacturing process, but can provide value to a business.
- CATIA/COMPRO integrated composite forming solution helps identify manufacturing issues before a design is finalized.
- Run quick design iterations with producibility for forming or detailed simulations leveraging ABAQUS solvers.
- Simulation results proven with analytical model and experiments.

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