DYNAmore | Infoday ENVYO and Composite Analysis

12th March, Stuttgart

Composites Manufacturing Process Modeling with Introduction to J-Composites

JSOL Corporation

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JSOL

NTT DATA Global IT Innovator NTT DATA Group

Agenda

1. Introduction of JSOL
2. Portfolio for Composite Simulation
3. **Forming Simulation**
   of Continuous Fiber Reinforced Composites
4. **Compression Molding Simulation**
   of Discontinuous Fiber Reinforced Composites
5. Introduction to ***J-Composites®***

Introduction of JSOL

About JSOL

- System Integration and CAE solution
- 1,300 employees (150 for Simulation field)
- Tokyo, Osaka, Nagoya office in Japan
- More than 20 CAE software products

Crash / Structural Simulation

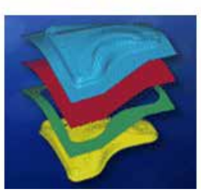
LS-DYNA

JFOLD

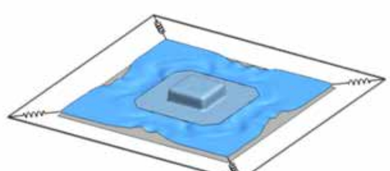
J-SEATdesigner

Manufacturing Simulation

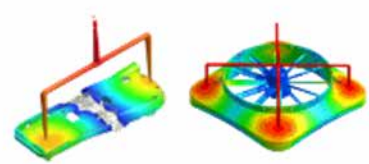
JSTAMP



J-Composites

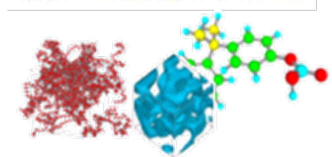


Moldex3D



Materials

J-OCTA



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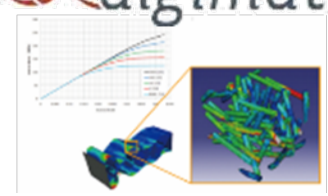
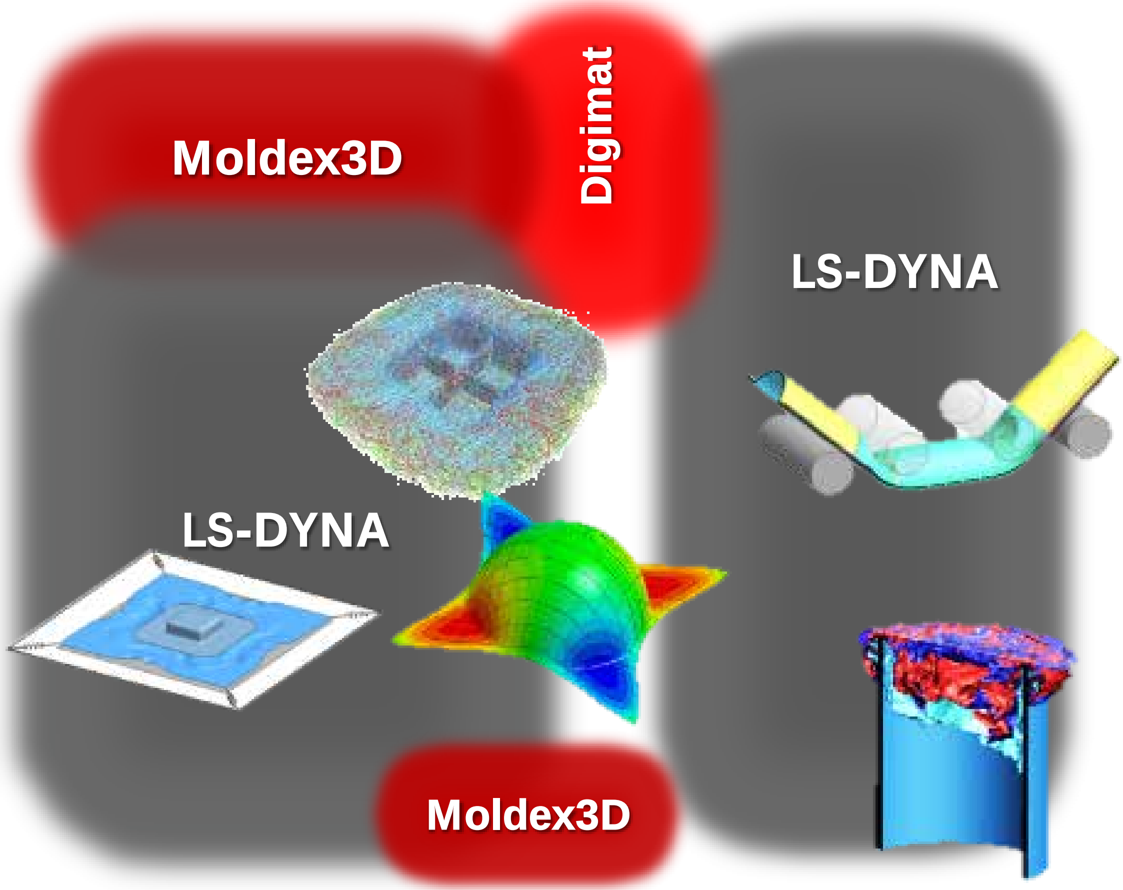


Portfolio
for Composite Simulation

Portfolio for Composite Simulation

FRP composites	Process	Process / Process chain simulations	Structure / Crash simulations
Short fiber - 2mm	Injection molding		
Long fiber 10-50mm	Compression molding		
Continuous fiber UD, Woven	Pre-preg forming		
	RTM preform → molding		



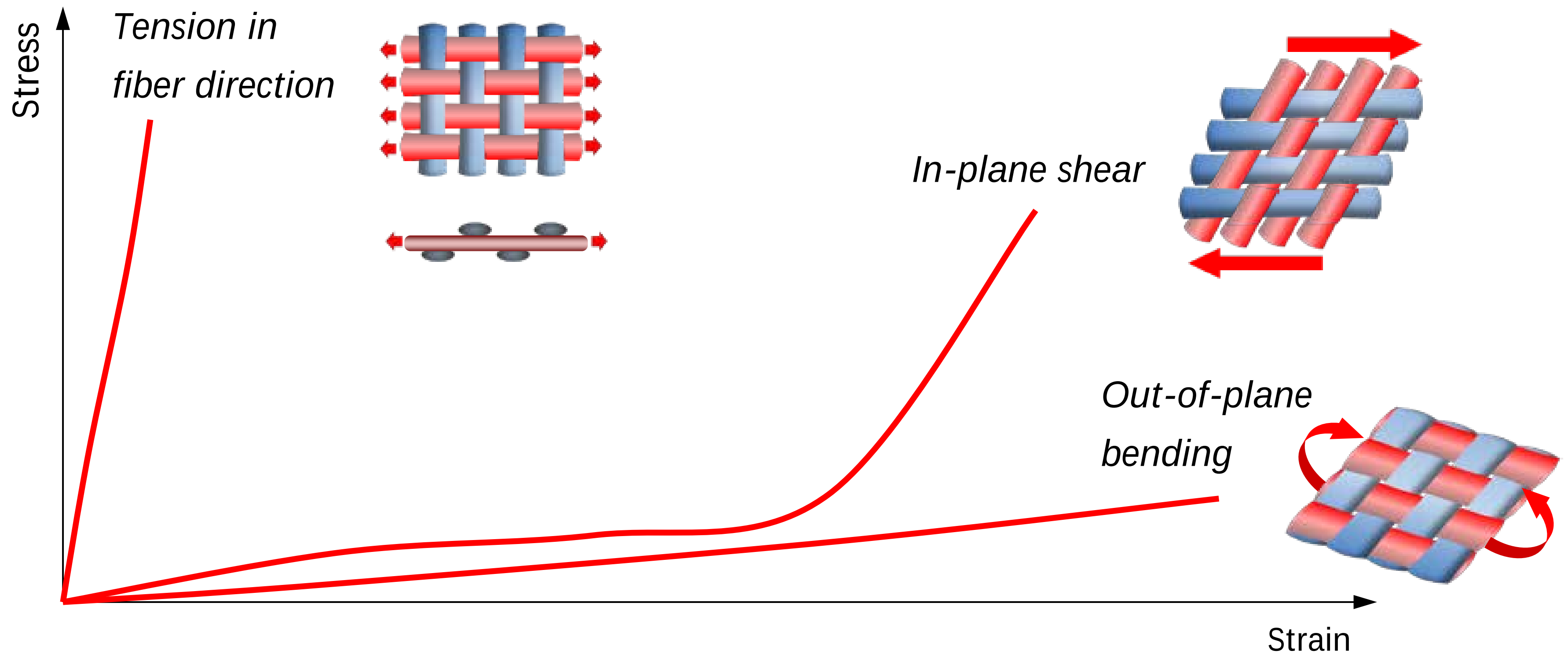
Because LS-DYNA can take into account large deformation and multi-physics, it is possible to simulate complicated composite behaviors during process.

Forming Simulation

of Continuous Fiber Reinforced Composites

Material Behavior

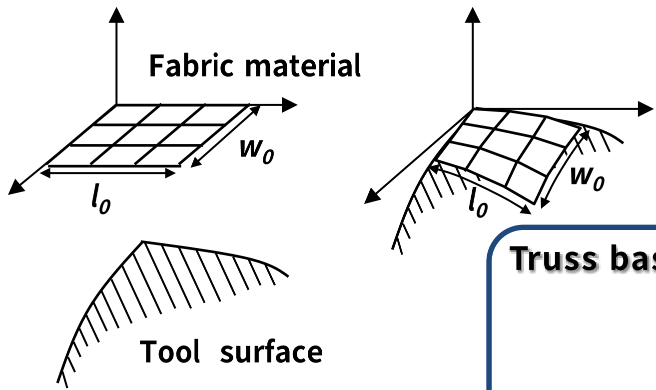
<u>Fabric reinforcement</u> and **<u>Pre-preg</u>**



Material model must consider the complex **anisotropy** and **nonlinearity** concerning both **“in-plane”** and **“out-of-plane”** properties.

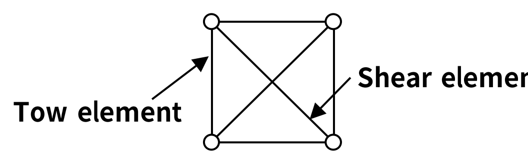
History of Macroscopic Models

Kinematic model Mack, et al., 1956



This model is based on the geo
approach of the fishnet type alg
This approach is fast but the m
behavior of the reinforcement a
boundary conditions are not co

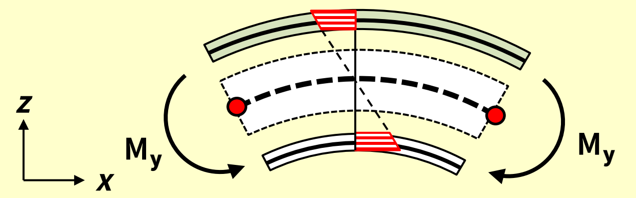
Truss based model Sharma, et al., 2



Some truss based models have been proposed to introduce the in-plane anisotropy and nonlinearity. This neglects the out-of-plane bending
considering it would give
simulation, especially co

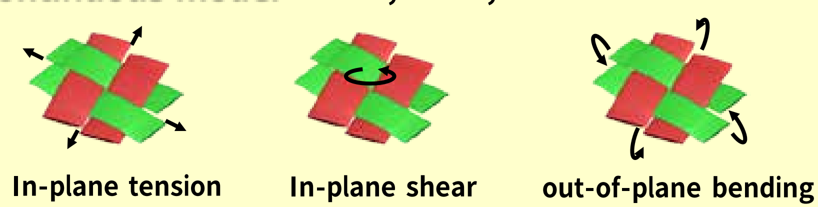
Shell-membrane hybrid model

Nishi, et al., 2013



Shell-membrane hybrid model can consider out-of-plane bending stiffness as well as in-plane anisotropic properties.

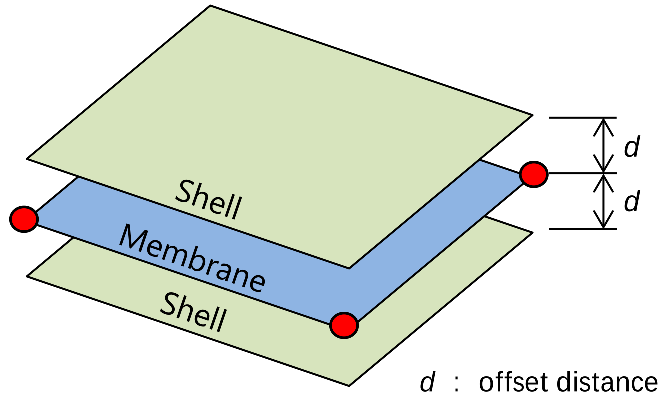
Continuous model Boisse, et al., 2011



Some FE models in recent studies can capture the bending stiffness as an independent virtual work separately from in-plane deformation.

Shell-Membrane Hybrid Model

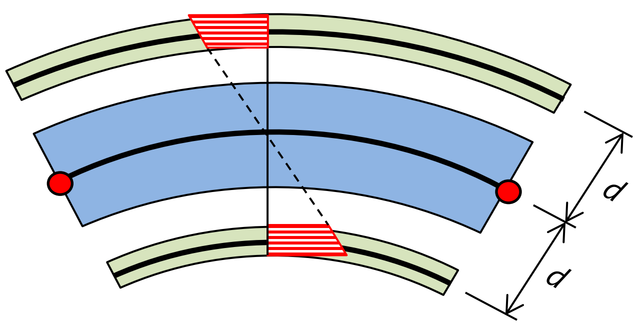
Considers in-plane and out-plane properties independently



Membrane element for in-plane property

*MAT_FABRIC (034)
*MAT_VISCOELASTIC_LOOSE_FABRIC (234)
***MAT_REINFORCED_THERMOPLASTIC (249)**

Strain distribution under bending

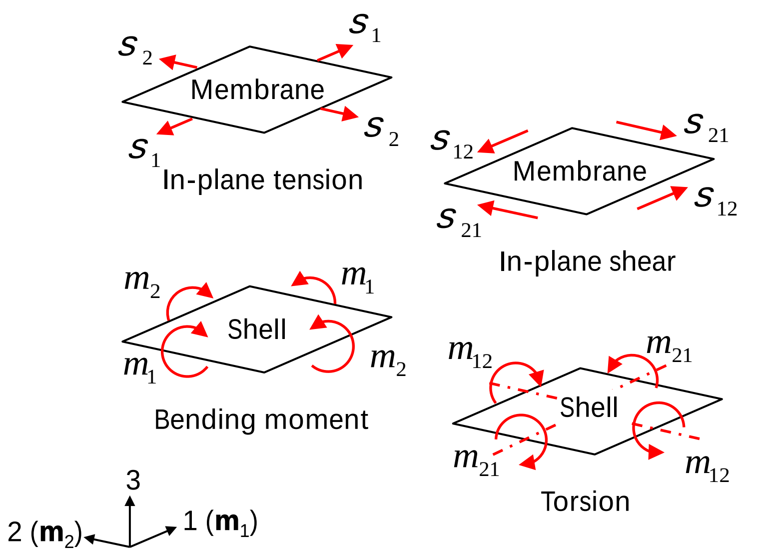


Shell element for bending stiffness with reference surface offset

*MAT_ORTHOTROPIC_ELASTIC (002)
***MAT_REINFORCED_THERMOPLASTIC (249)**

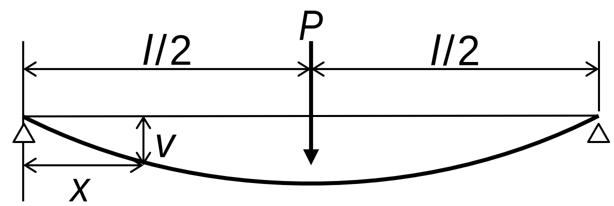
Shell-Membrane Hybrid Model

Constitutive Modeling

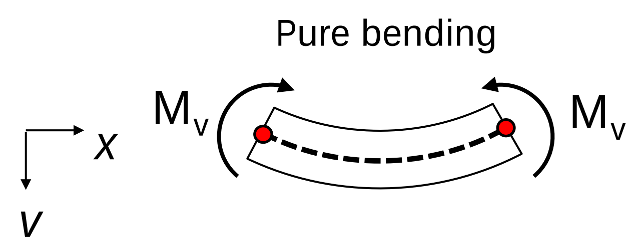


$$\begin{Bmatrix} \sigma_1 \\ \sigma_2 \\ \sigma_{12} \\ m_1 \\ m_2 \\ m_{12} \end{Bmatrix} = \begin{bmatrix} f_1 & 0 & 0 & 0 & 0 & 0 \\ & f_2 & 0 & 0 & 0 & 0 \\ & & g_{12} & 0 & 0 & 0 \\ & \text{sym.} & & EI_1 & 0 & 0 \\ & & & & EI_2 & 0 \\ & & & & & GI \end{bmatrix} \begin{Bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \gamma_{12} \\ \kappa_1 \\ \kappa_2 \\ \kappa_{12} \end{Bmatrix}$$

Kirchhoff-Love (Euler-Bernoulli)



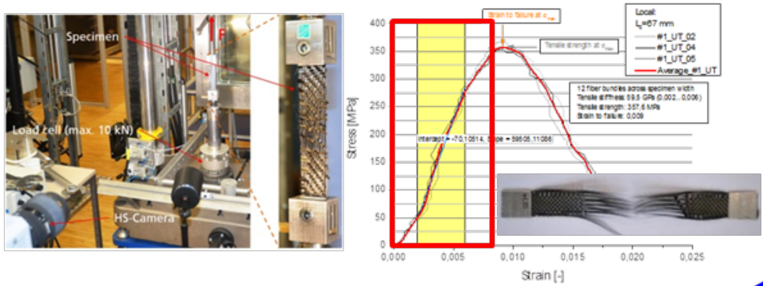
$$v(x) = \frac{P}{12EI} \cdot x \cdot \left(\frac{3}{4} l^2 - x^2 \right)$$



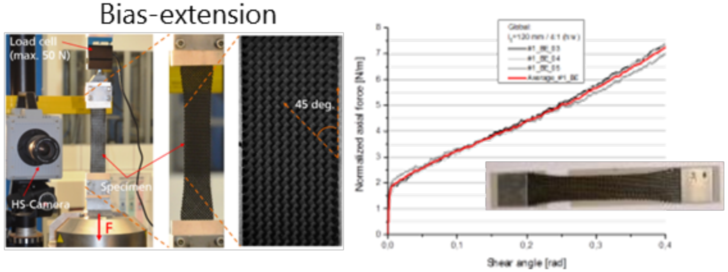
Case Study 1: dry textile (3K plain woven)

Material Parameter Identification

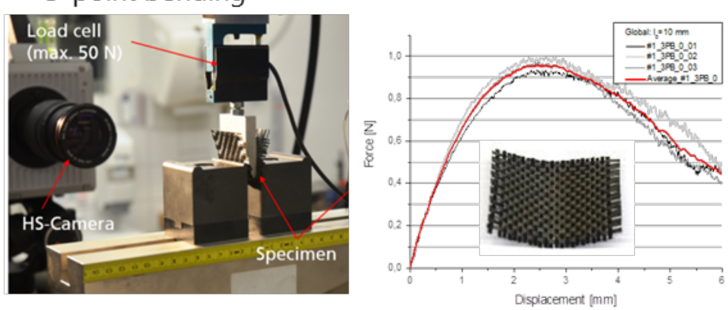
Uniaxial tension



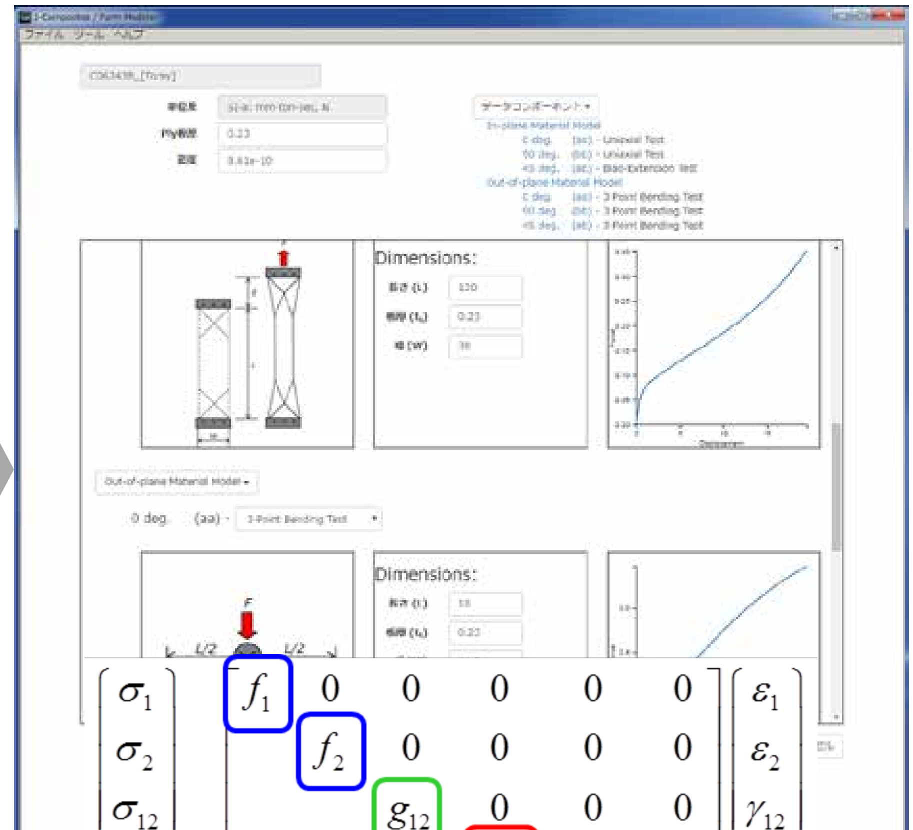
Bias-extension



3-point bending



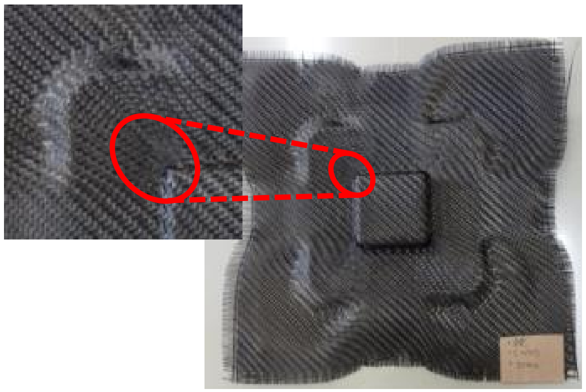
J-Composites



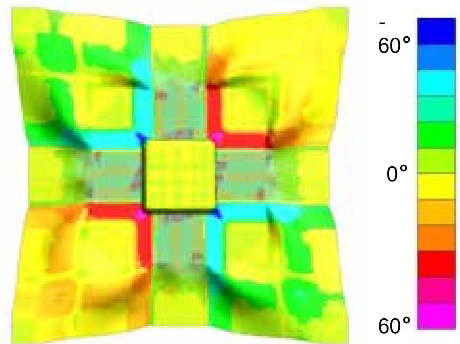
$$
\begin{Bmatrix} \sigma_1 \\ \sigma_2 \\ \sigma_{12} \\ m_1 \\ m_2 \\ m_{12} \end{Bmatrix} =
\begin{bmatrix} f_1 & 0 & 0 & 0 & 0 & 0 \\ & f_2 & 0 & 0 & 0 & 0 \\ & & g_{12} & 0 & 0 & 0 \\ & & & EI_1 & 0 & 0 \\ & \text{sym.} & & & EI_2 & 0 \\ & & & & & GI \end{bmatrix}
\begin{Bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \gamma_{12} \\ \kappa_1 \\ \kappa_2 \\ \kappa_{12} \end{Bmatrix}
$$

Case Study 1: dry textile (3K plain woven)

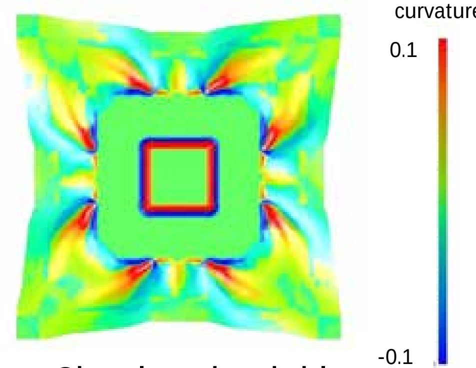
Forming Simulation



Forming experiment

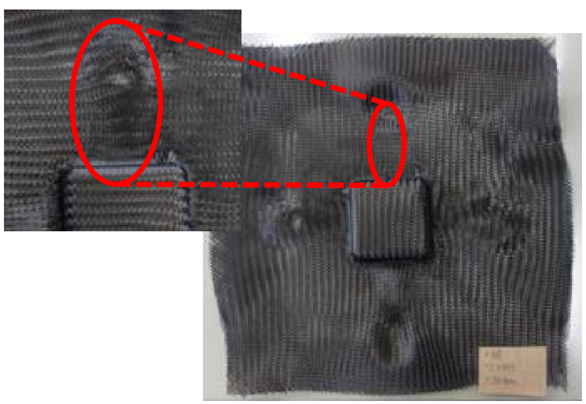


Simulated shear angle

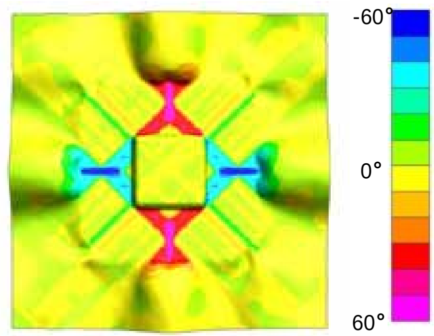


Simulated wrinkle

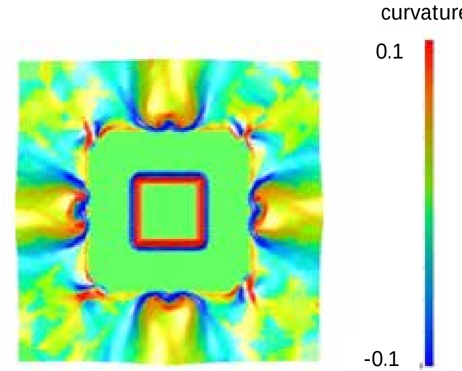
[0/90] fiber orientation



Forming experiment



Simulated shear angle



Simulated wrinkle

[+/-45] fiber orientation

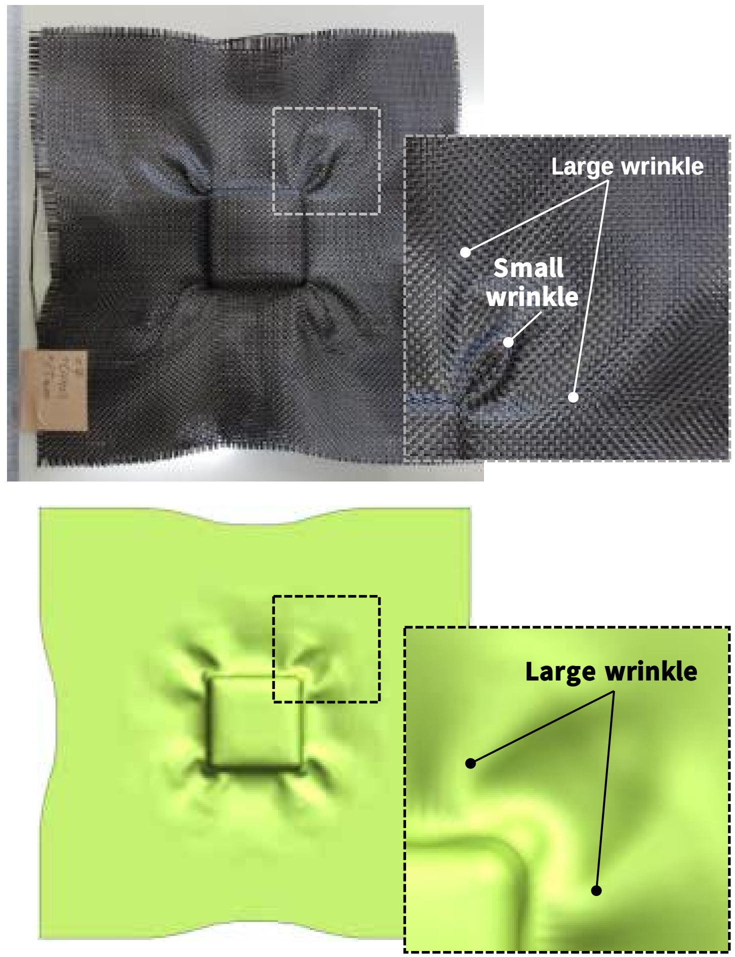
Simulated deformations are in good agreement with the experimental results for each fiber orientation.

Case Study 1: dry textile (3K plain woven)

wrinkle development / [0/90] fiber orientation

10mm remaining
closure travel

5mm remaining
closure travel

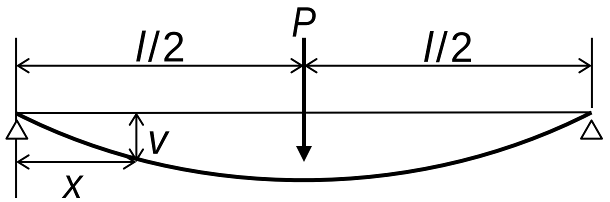


Full mold

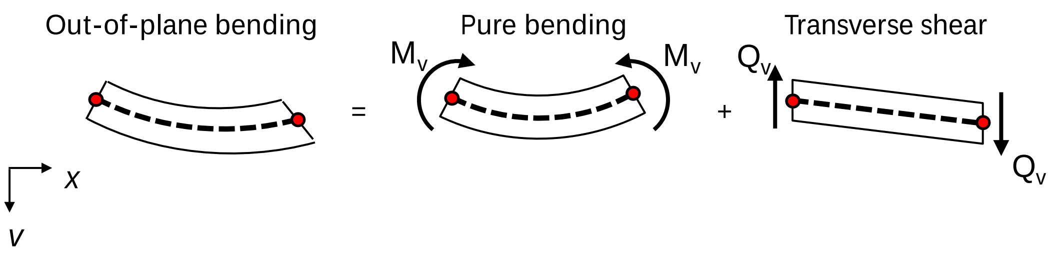
Case Study 1: dry textile (3K plain woven)

Reissner-Mindlin model

Reissner-Mindlin (Timoshenko)

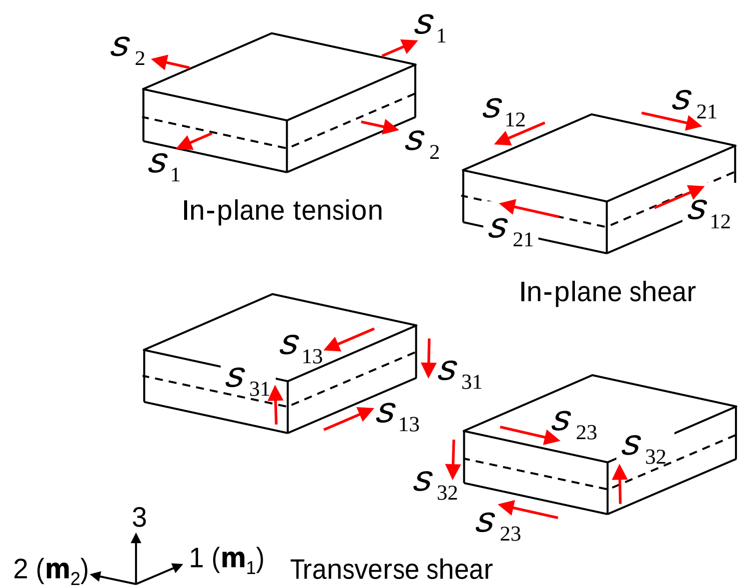


$$v(x) = v_b(x) + v_s(x) = \frac{P}{12EI} \cdot x \cdot \left(\frac{3}{4} l^2 - x^2 \right) + \frac{\alpha \cdot P \cdot x}{2G \cdot A}$$



Possibility for predicting a small wrinkle increases in the Reissner-Mindlin model.

Constitutive Modeling

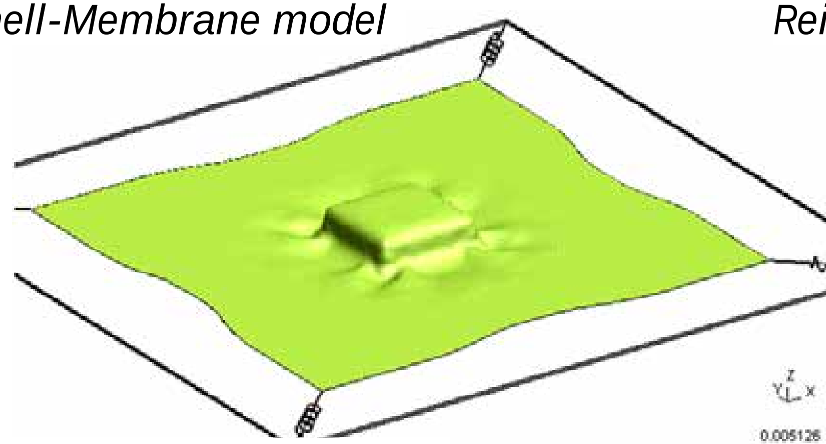


$$\begin{Bmatrix} \sigma_1 \\ \sigma_2 \\ \sigma_{12} \\ \sigma_{23} \\ \sigma_{31} \end{Bmatrix} = \begin{bmatrix} f_1 & 0 & 0 & 0 & 0 \\ & f_2 & 0 & 0 & 0 \\ & & g_{12} & 0 & 0 \\ & \text{sym.} & & G_{23} & 0 \\ & & & & G_{31} \end{bmatrix} \begin{Bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \gamma_{12} \\ \gamma_{23} \\ \gamma_{31} \end{Bmatrix}$$

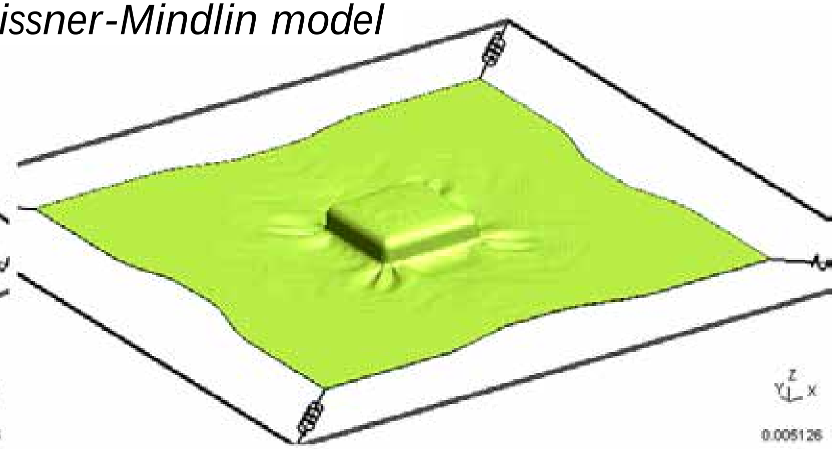
Case Study 1: dry textile (3K plain woven)

Forming Simulation by Reissner-Mindlin model

Shell-Membrane model



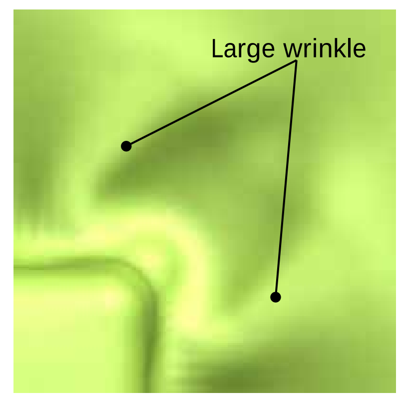
Reissner-Mindlin model



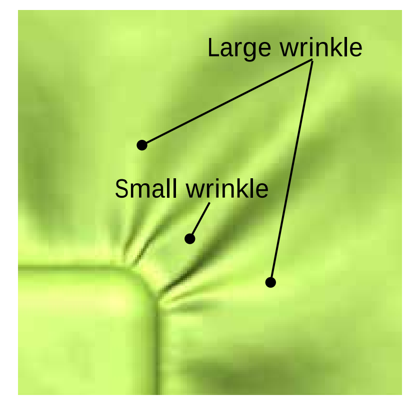
Wrinkles during the forming

Experiment

Shell-Membrane model



Reissner-Mindlin model

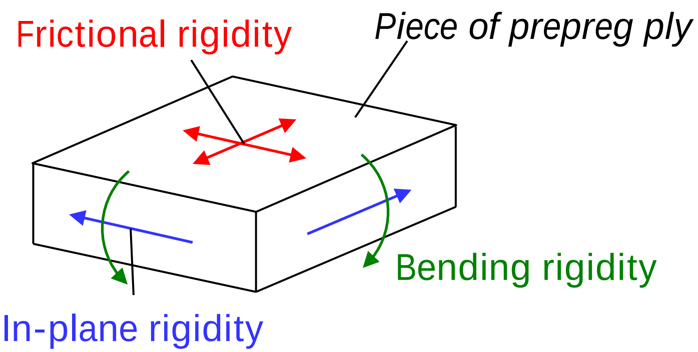


Considering the transverse shear deformation increase the possibility to predict the small wrinkles

Case Study 2: UD Thermoset Pre-preg

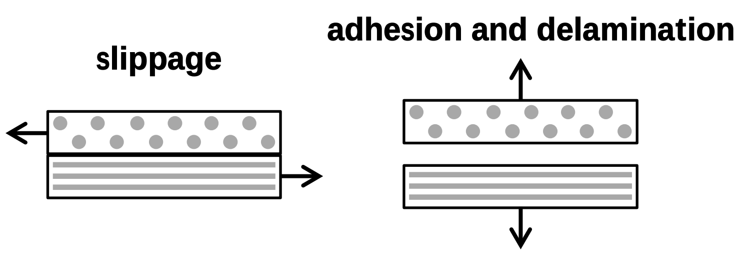
New Contact Option for Pre-preg

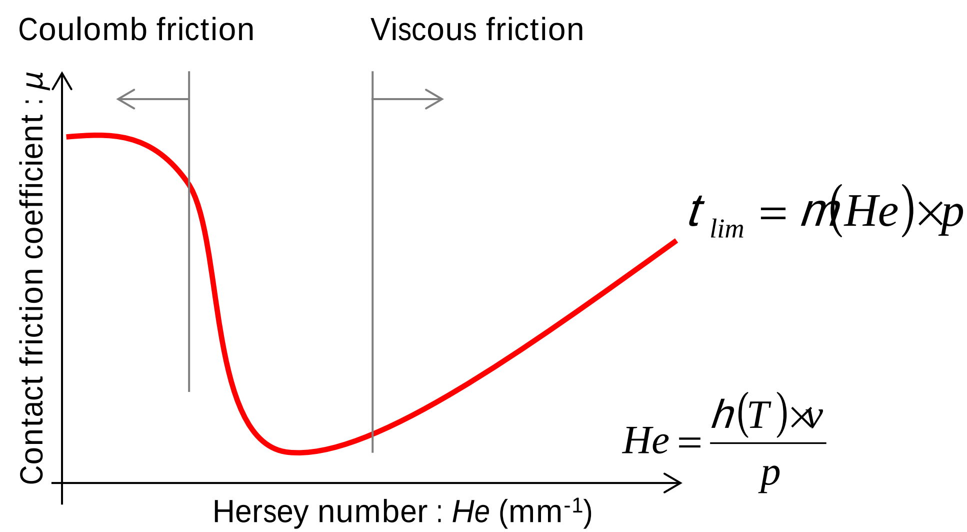
Situation of a prepreg during forming



_**COMPOSITE** (or LUBRICATION) option

- Adhesion/delamination in normal direction
- Friction model



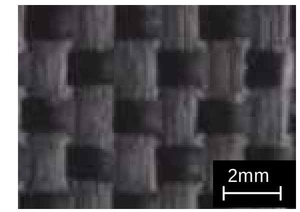


Case Study 3: Thermoplastic Pre-preg

Thermo-physical Parameter Identification

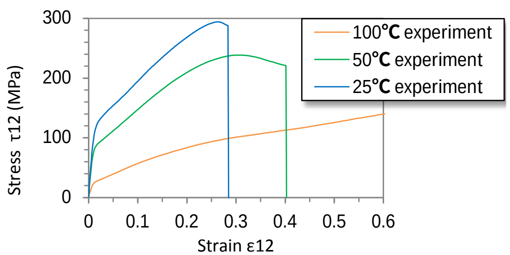
thermoplastic pre-preg

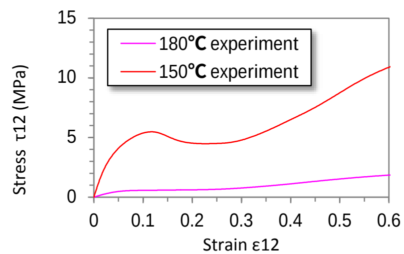
- 3K plain woven CF/PMMA



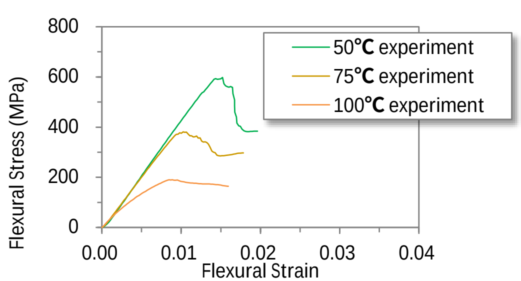
Temperature dependent properties

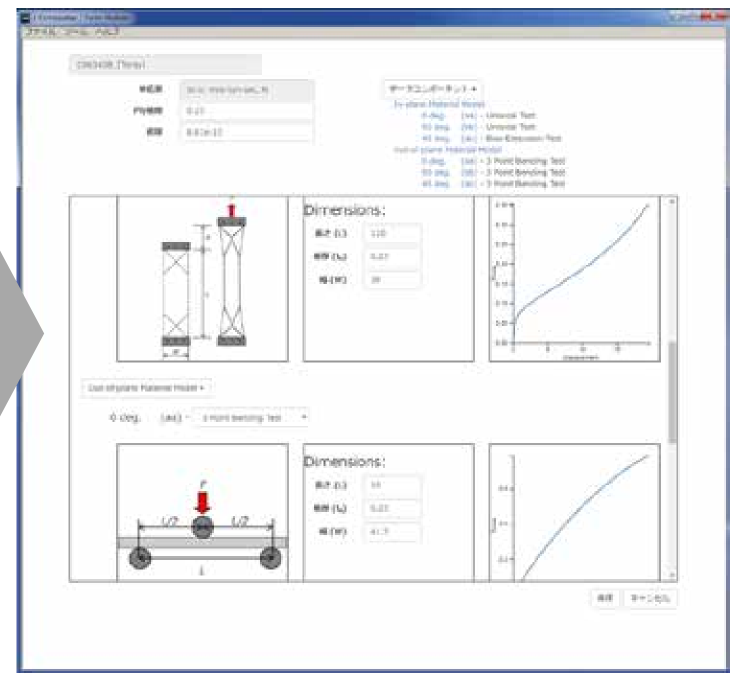
- In-plane shear (bias-extension)





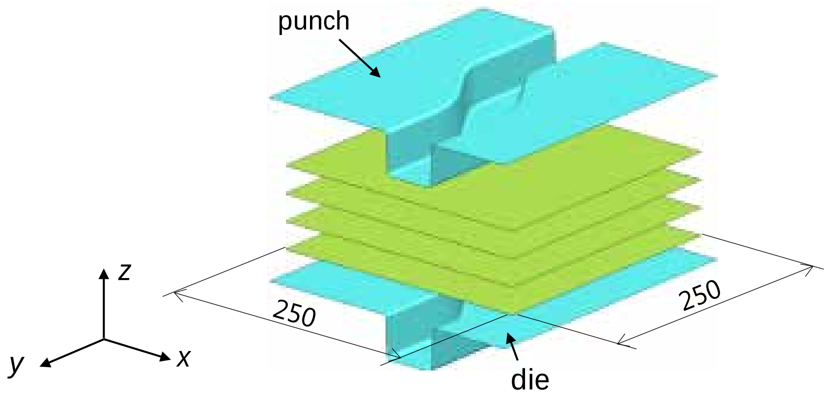
- Out-of-plane bending (3-point bend)





Case Study 3: Thermoplastic Prepreg

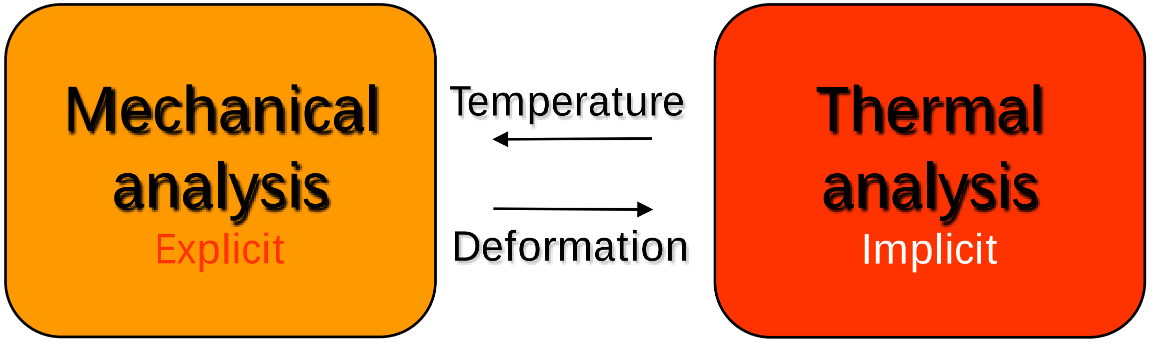
S-rail Thermoforming Simulation



Initial temperature
- blank sheet : 185℃
- tools : 25℃

S-rail tool

Non-isothermal forming simulation

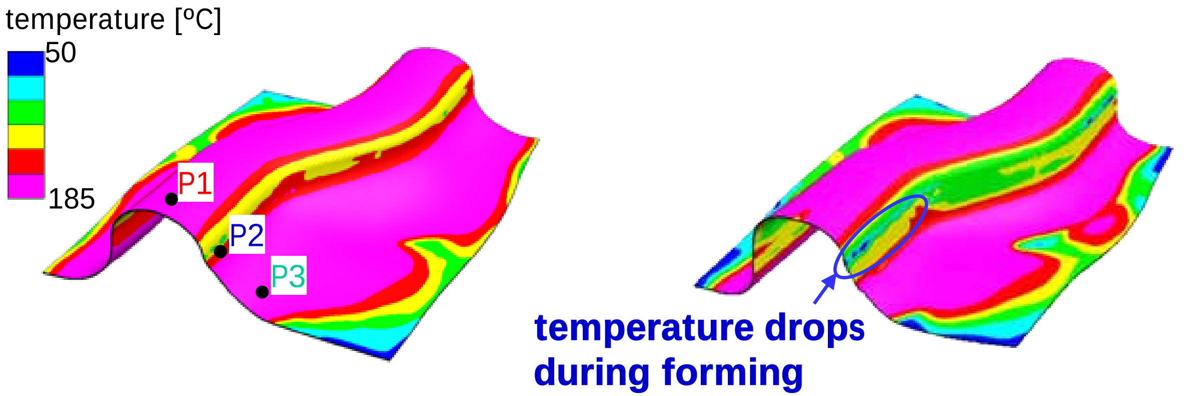


thermal-mechanical coupling analysis

Case Study 3: Thermoplastic Prepreg

S-rail Thermoforming Simulation

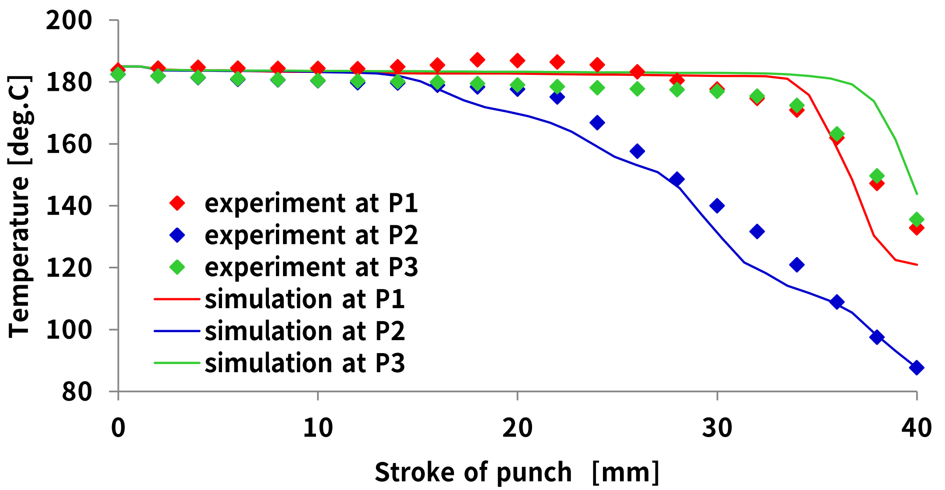
Temperature distribution and positions of thermocouples



Stroke 20mm

Stroke 30mm

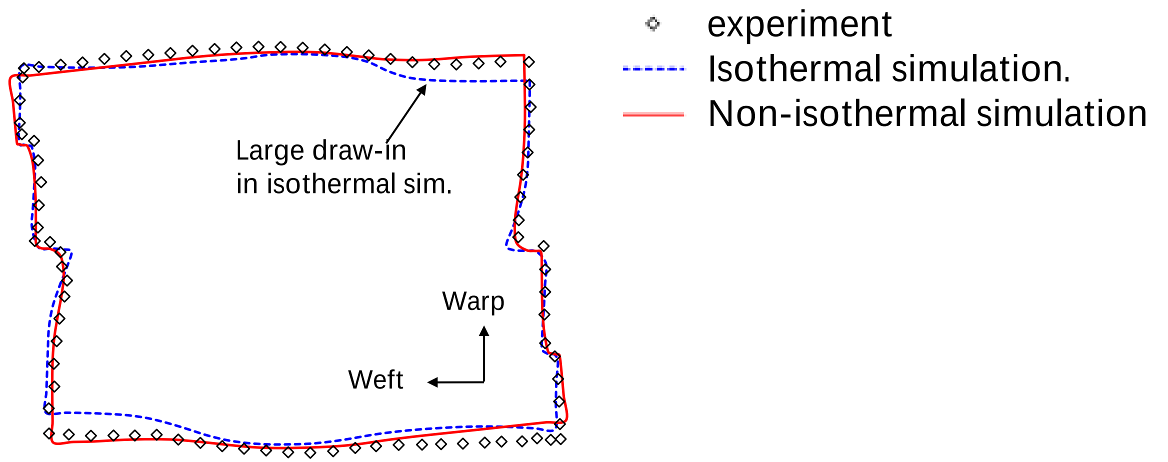
Comparison of temperature histories within laminate



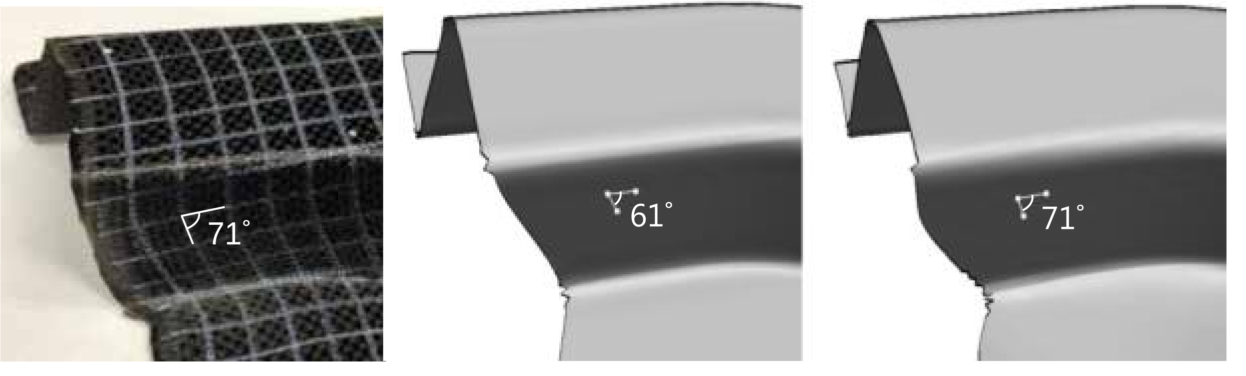
Case Study 3: Thermoplastic Prepreg

S-rail Thermoforming Simulation

Comparison of outline $[(0/90)]_4$



Comparison of shear angle of $[(0/90)]_4$

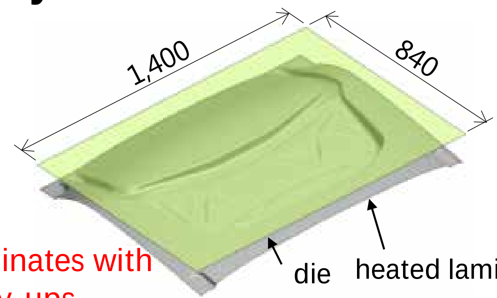


experiment | isothermal simulation | non-isothermal simulation

Case Study 3: Thermoplastic Prepreg

Forming Simulation of Automobile Backdoor

Self-gravity simulation

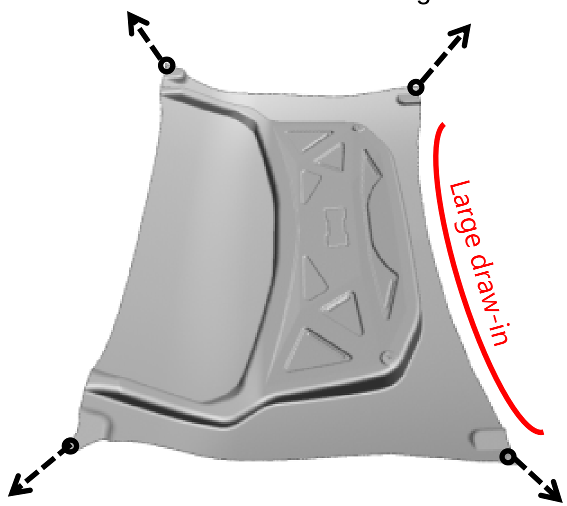


simple laminates with $[(0/90)]_4$ lay-ups

deflected shape of the heated laminate due to self-gravity

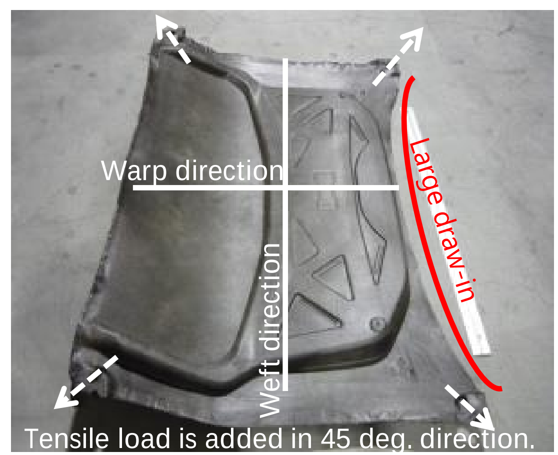
Forming simulation

Tensile load is added in 45 deg. direction.



Simulation

courtesy of ASANO Asano Co., Ltd.



Experiment

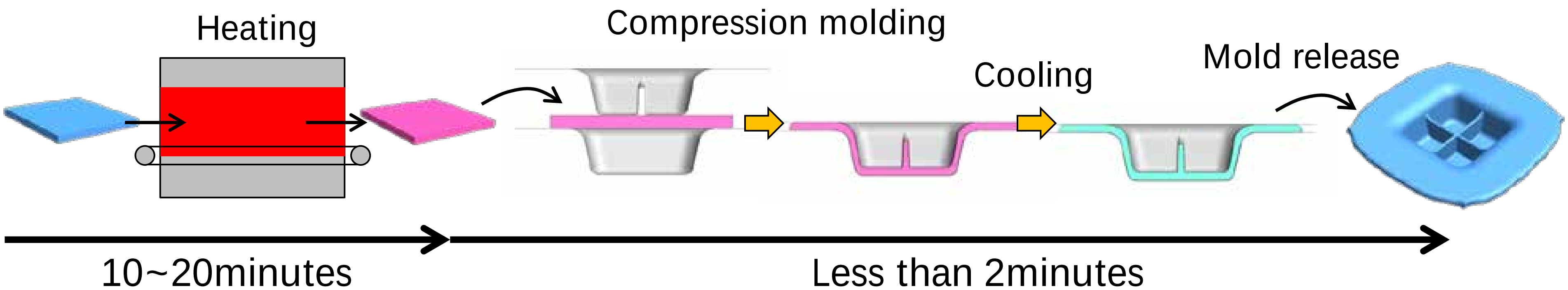
Compression Molding Simulation

of Discontinuous Fiber Reinforced Composites

Compression Molding of L-FRTP

Compression molding is one of the most efficient manufacturing processes to form L-FRTP in a short time.

Complex shapes can be formed.



Manufacturing process strongly affects mechanical strength.

- Unwanted fiber orientation
- Uneven distribution of fibers
- Formation of weld lines,
- Matrix rich region, etc.

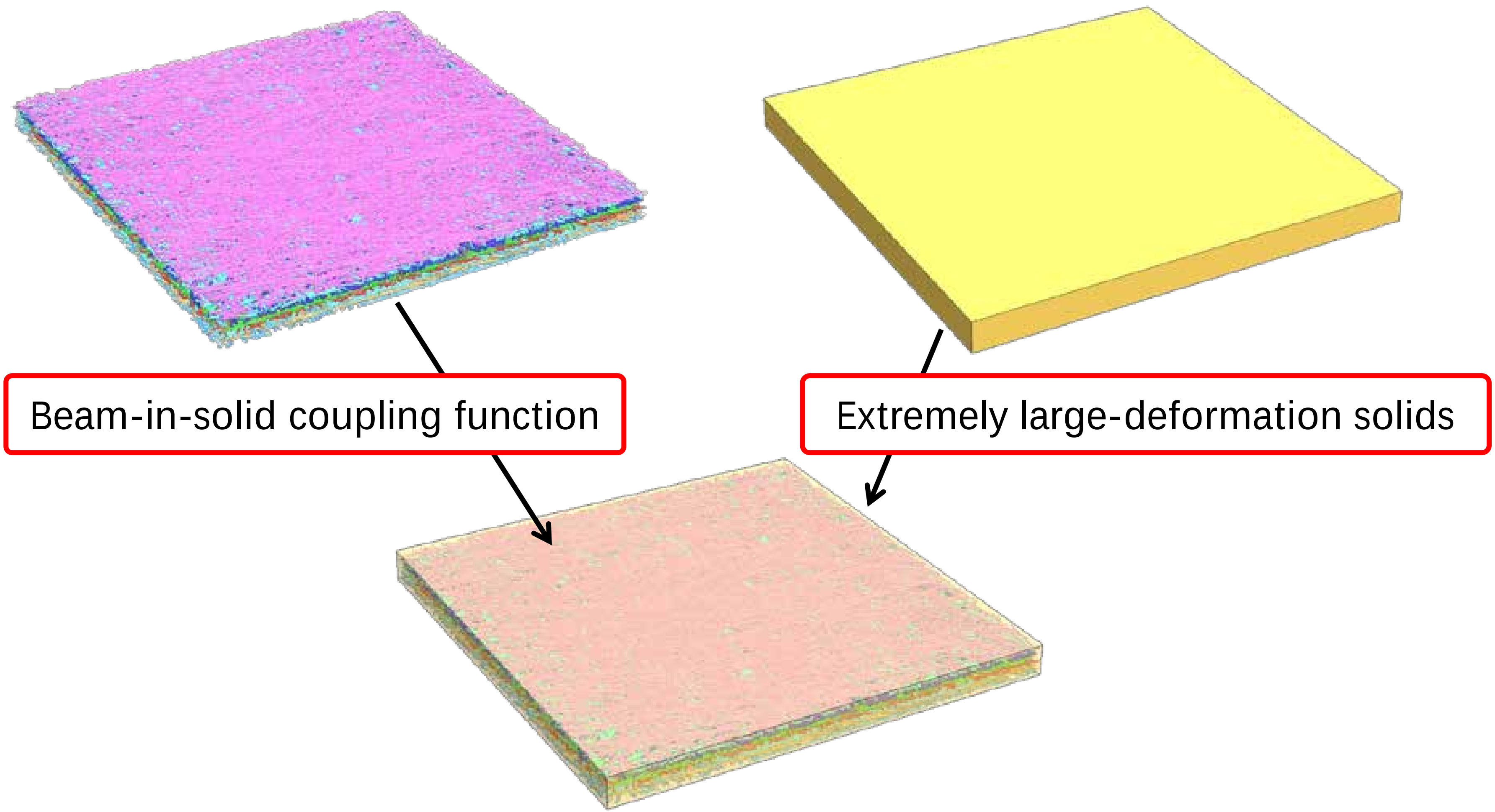
There *was* no high accuracy CAE method to predict compression molding.

Modelling Strategy

Coupling Model of L-FRTP

Long fibers (Beam elements)

Polymer matrix (Solid elements)

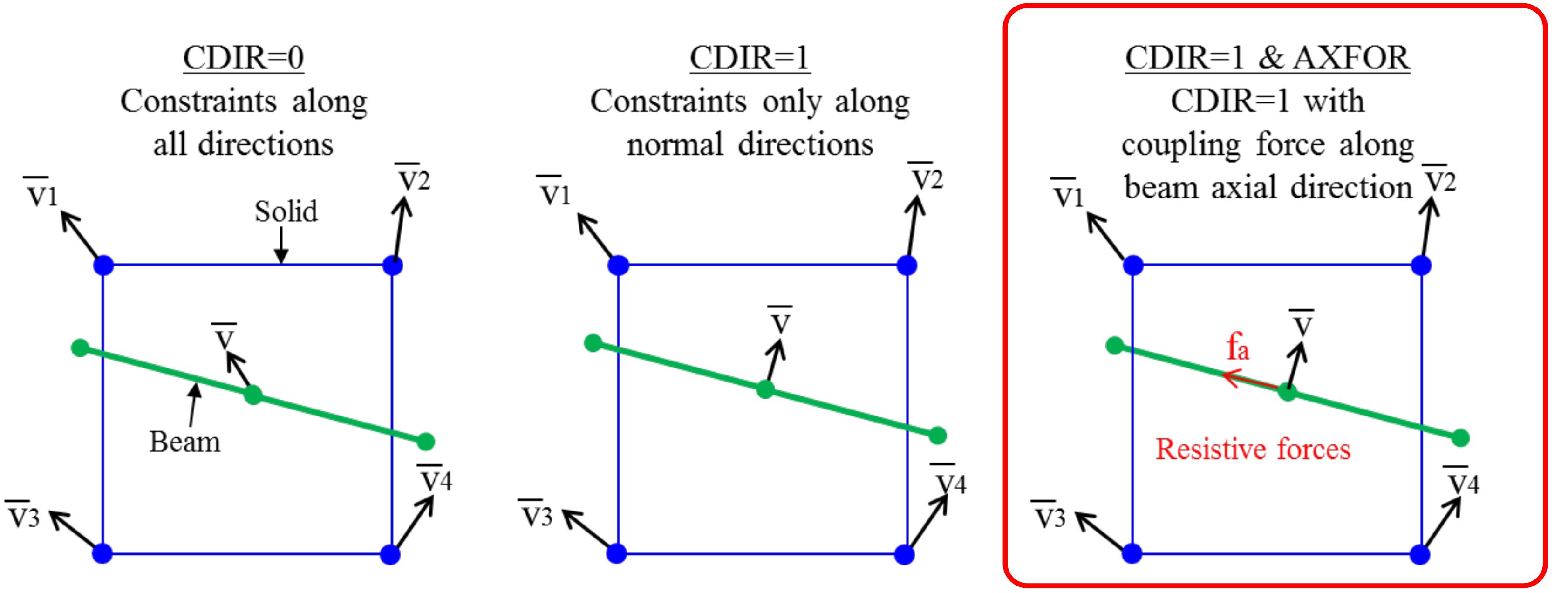


Modelling Strategy

Beam-in-solid Coupling Function

Beam in Solid Coupling Function

- Constraint method (velocity and acceleration coupling method)
- Tetrahedral and pentahedral solid elements supported.
- Some coupling options available.

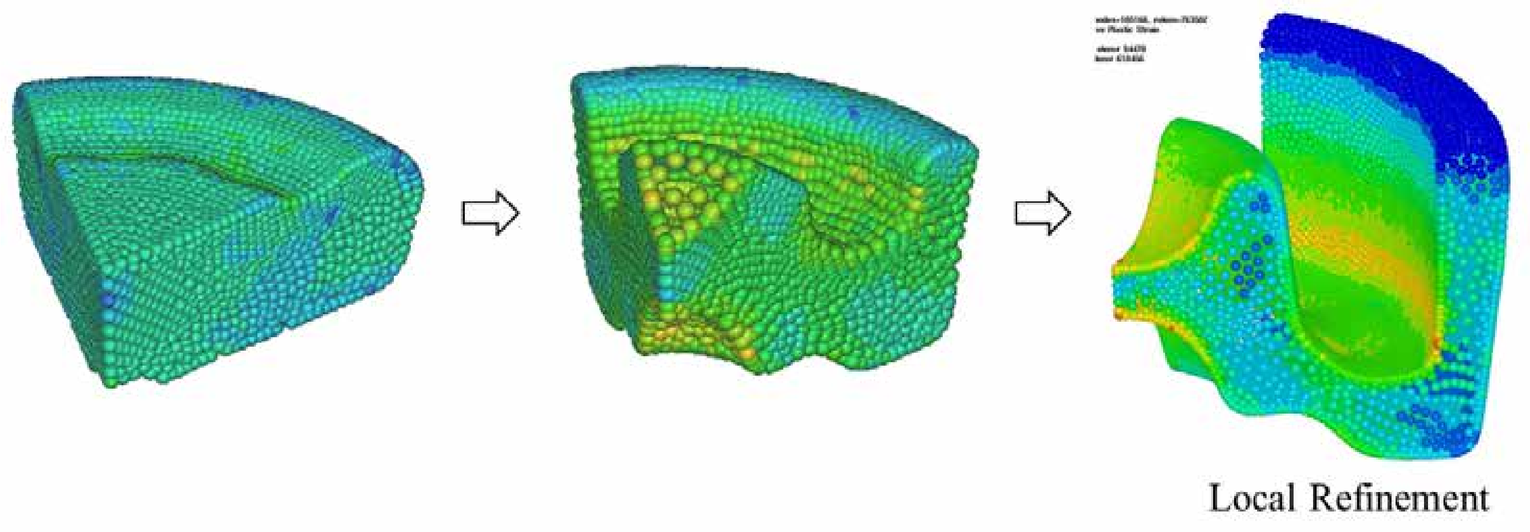


Modelling Strategy

Extremely Large Deformation Solid

3D adaptive EFG

- R-adaptive remeshing capability based on a Mesh-free Galerkin Method
- Extremely large deformation metal forming simulation
- Some useful functions available; local mesh-refinement, interactive adaptive method, monotonic mesh resizing and a pressure smoothing scheme.
- Thermal conductivity-structural coupling simulation for hot forging.

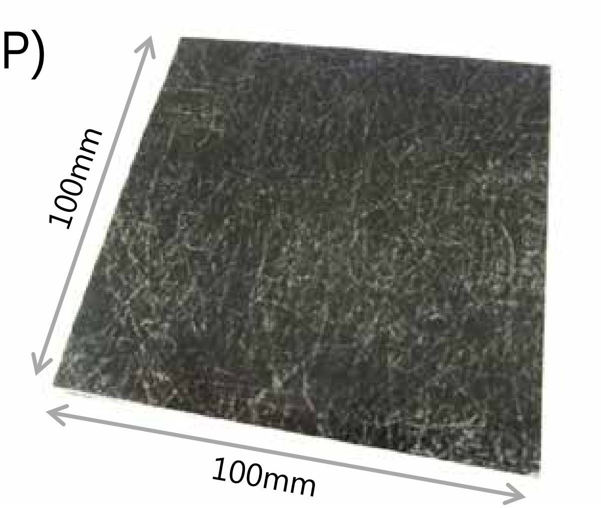


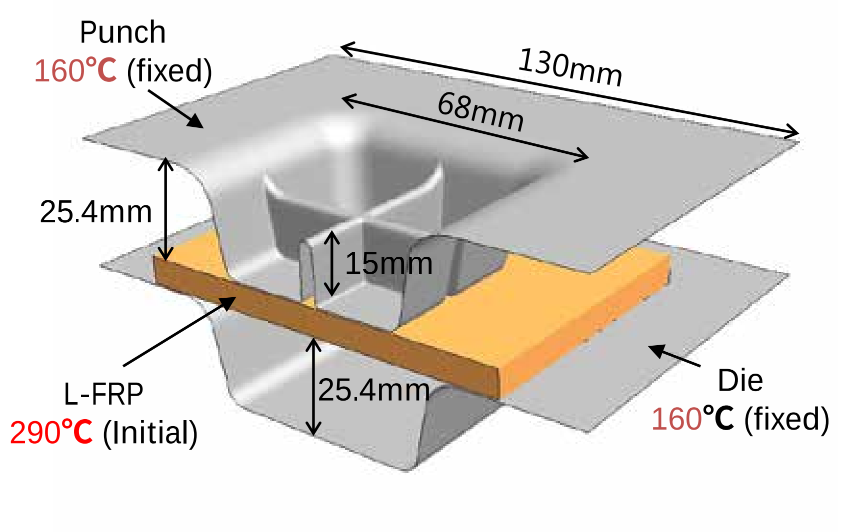
Compression Molding Simulation

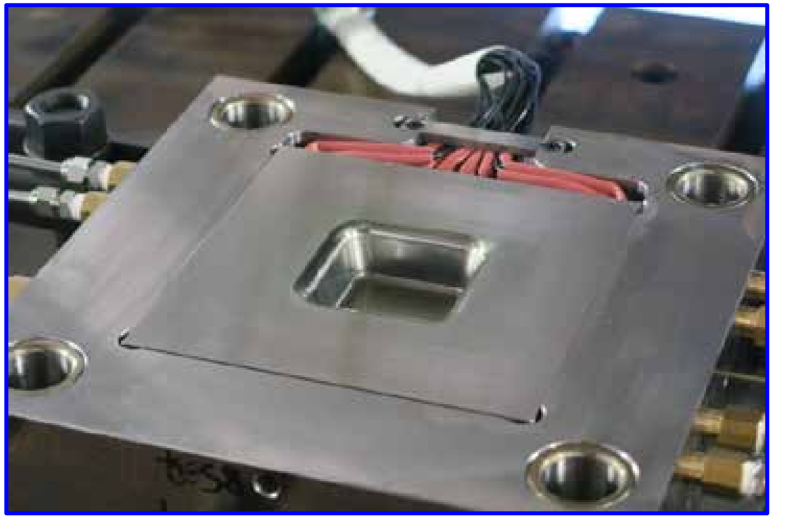
Cross-ribbed Component

Long Glass Fiber Reinforced ThermoPlastics (L-GFRTP)

- Tepex® flowcore (Bond-Laminates GmbH)
    - Glass fiber length: 30-50mm
    - Fiber orientation: 2D random
    - Volume fraction: 47%
    - Matrix: Polyamide Nylon6 (PA6)

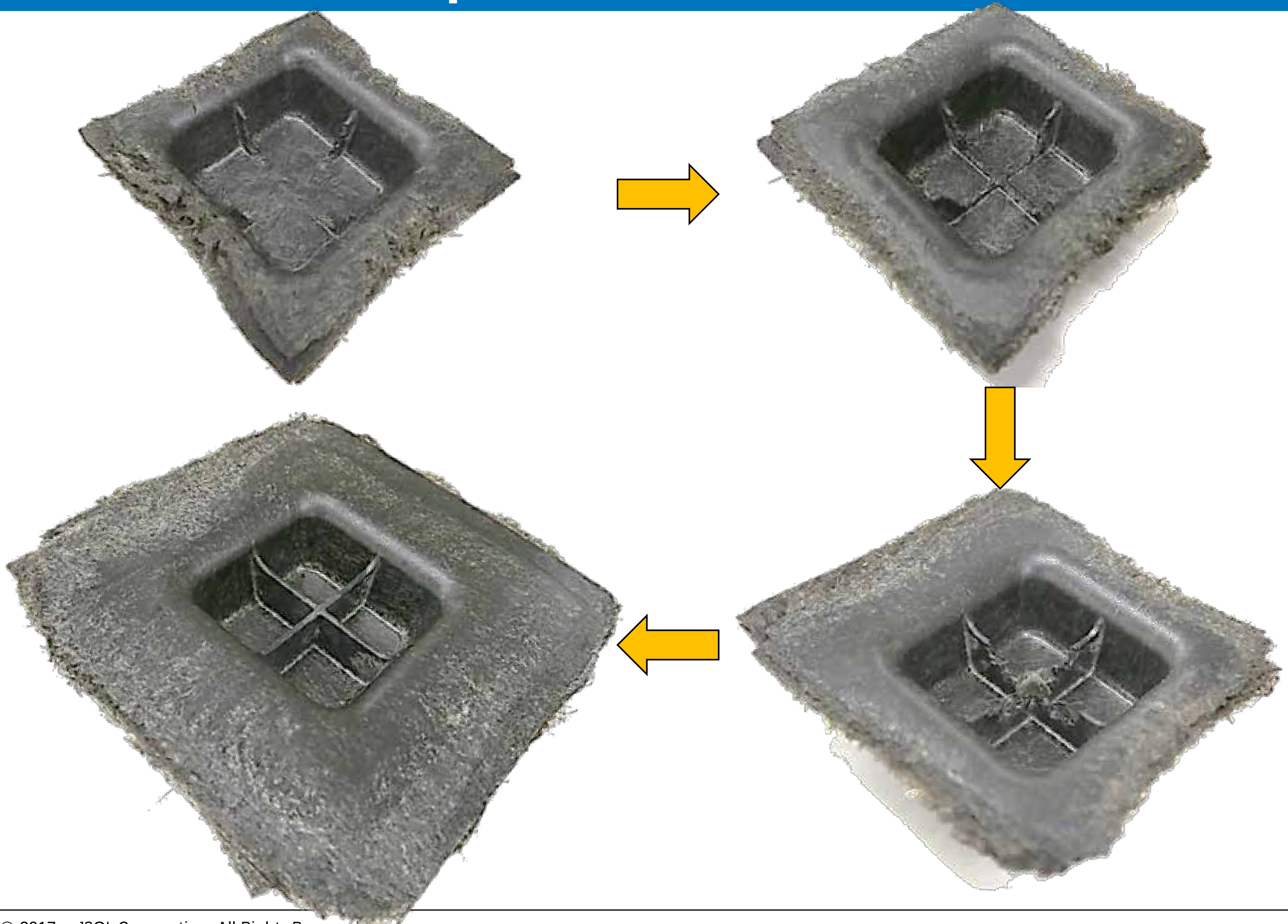






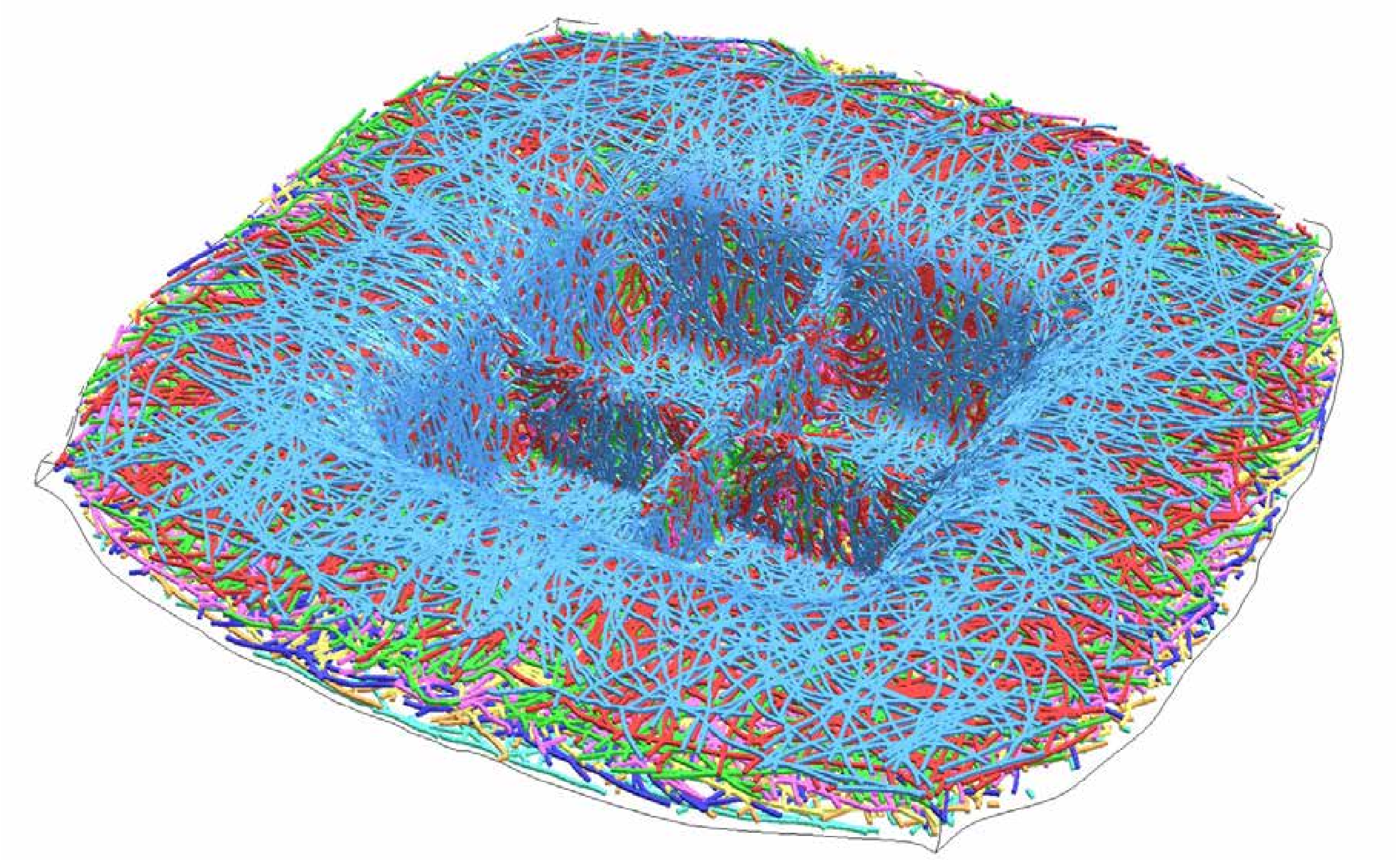
Compression Molding Simulation

Cross-ribbed Component



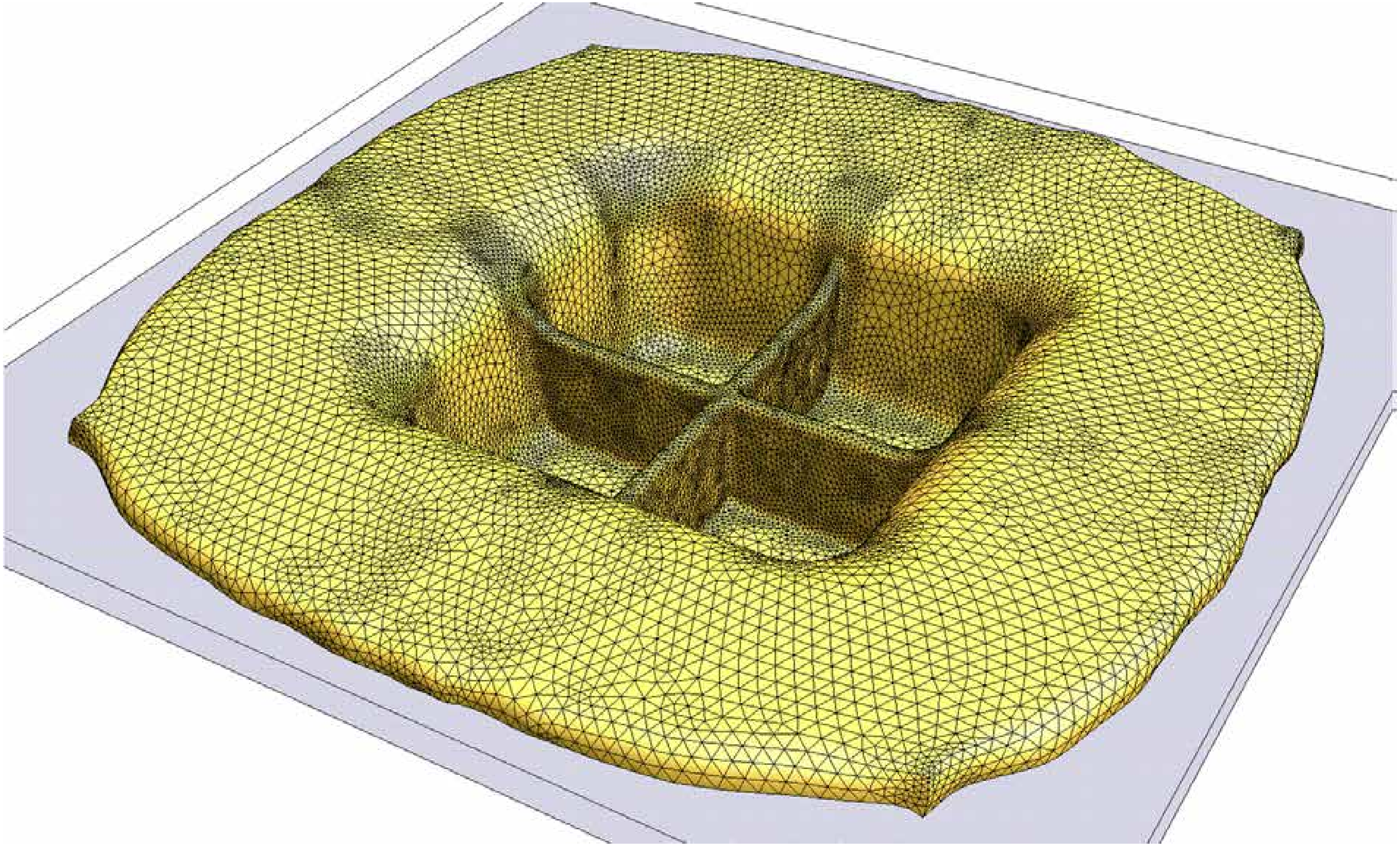
Compression Molding Simulation

Deformation Behavior of Beam Elements



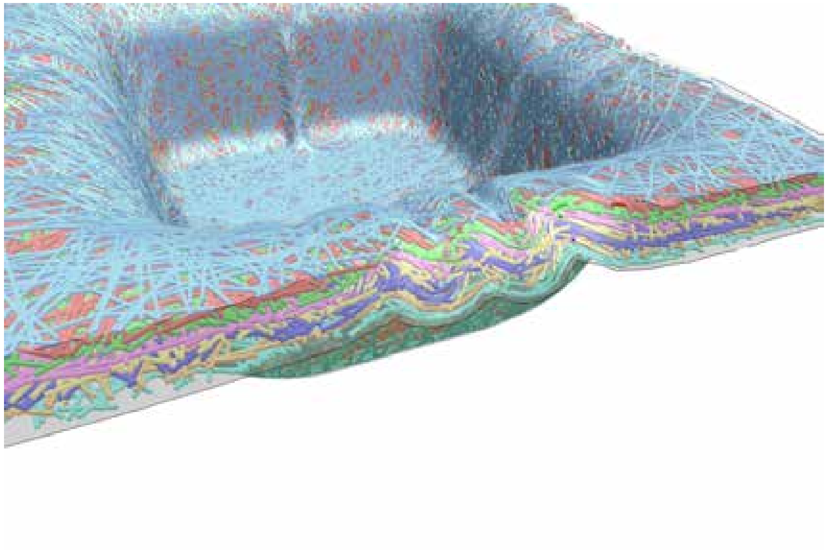
Compression Molding Simulation

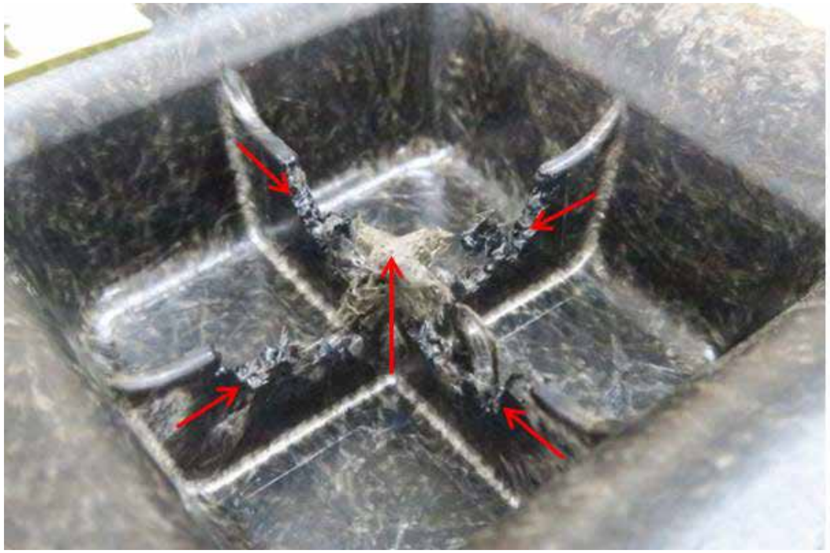
Remeshing Behavior of 3D Adaptive EFG

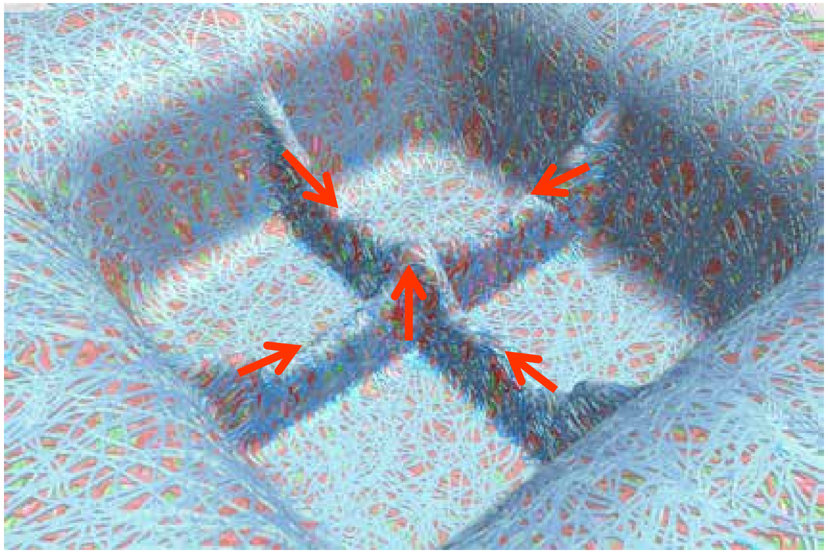


Compression Molding Simulation

Comparison of experiment and LS-DYNA Results

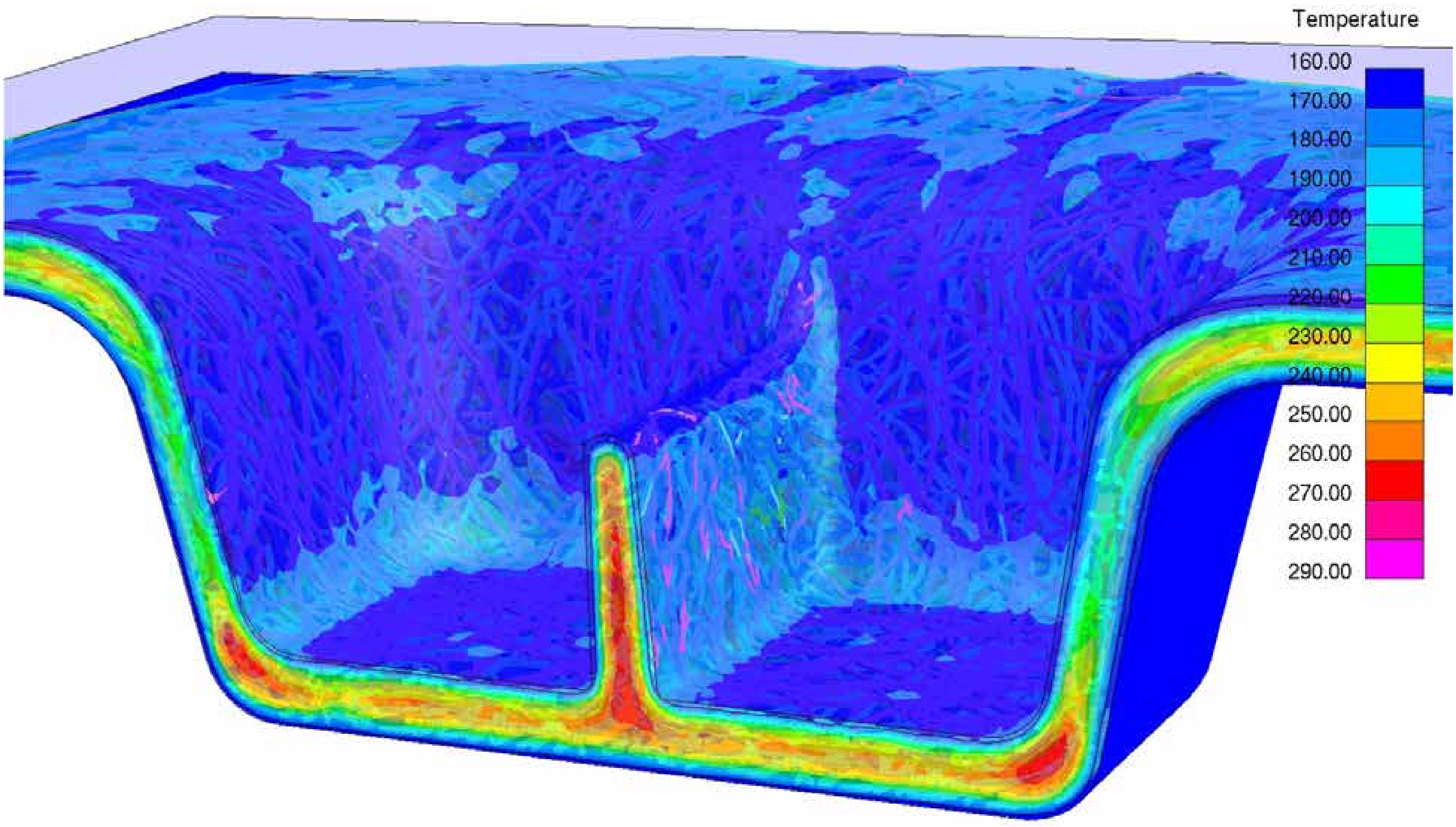






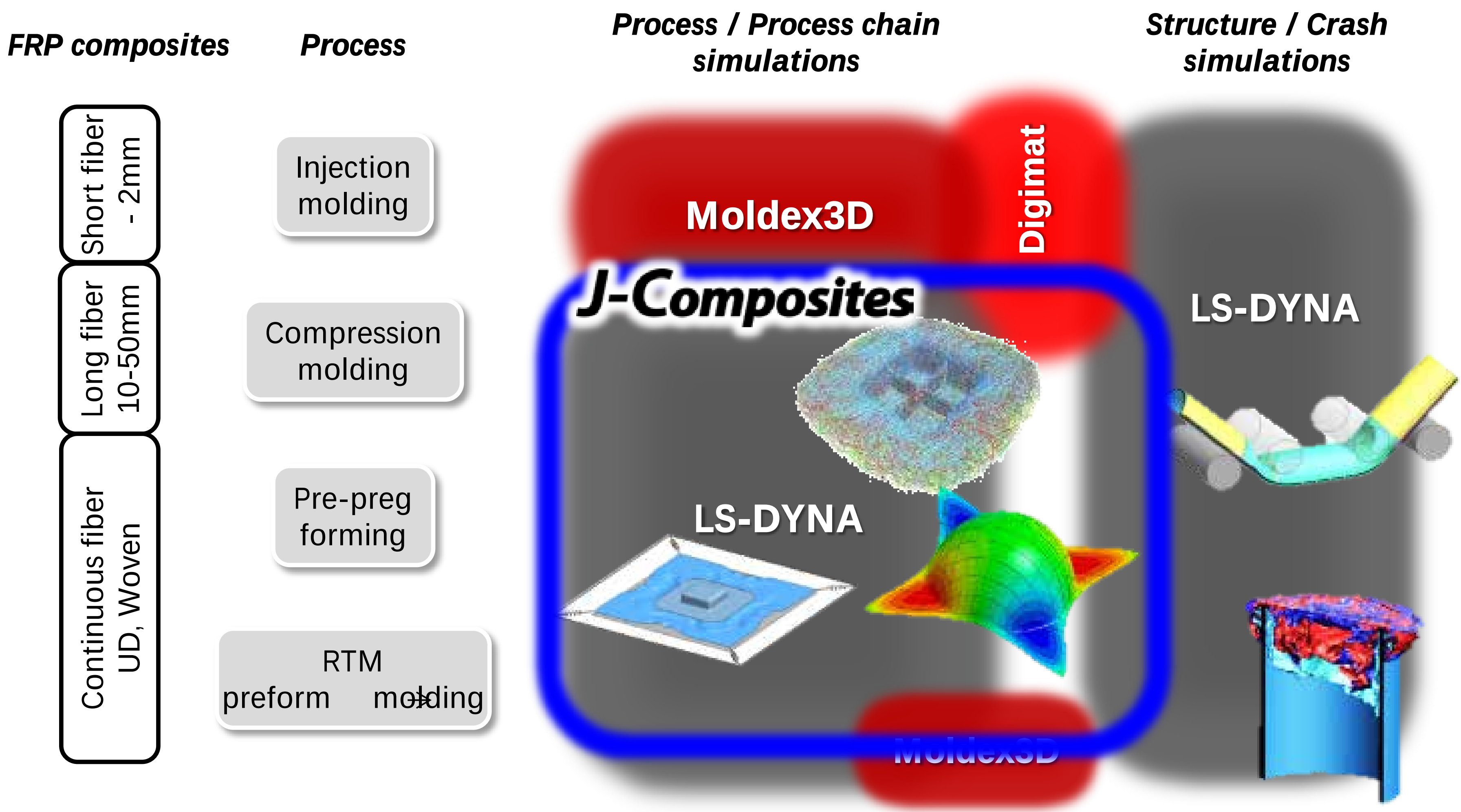
Compression Molding Simulation

Thermal-mechanical Coupling Simulation



Introduction to *J-Composites®*

Portfolio with *J-Composites*®

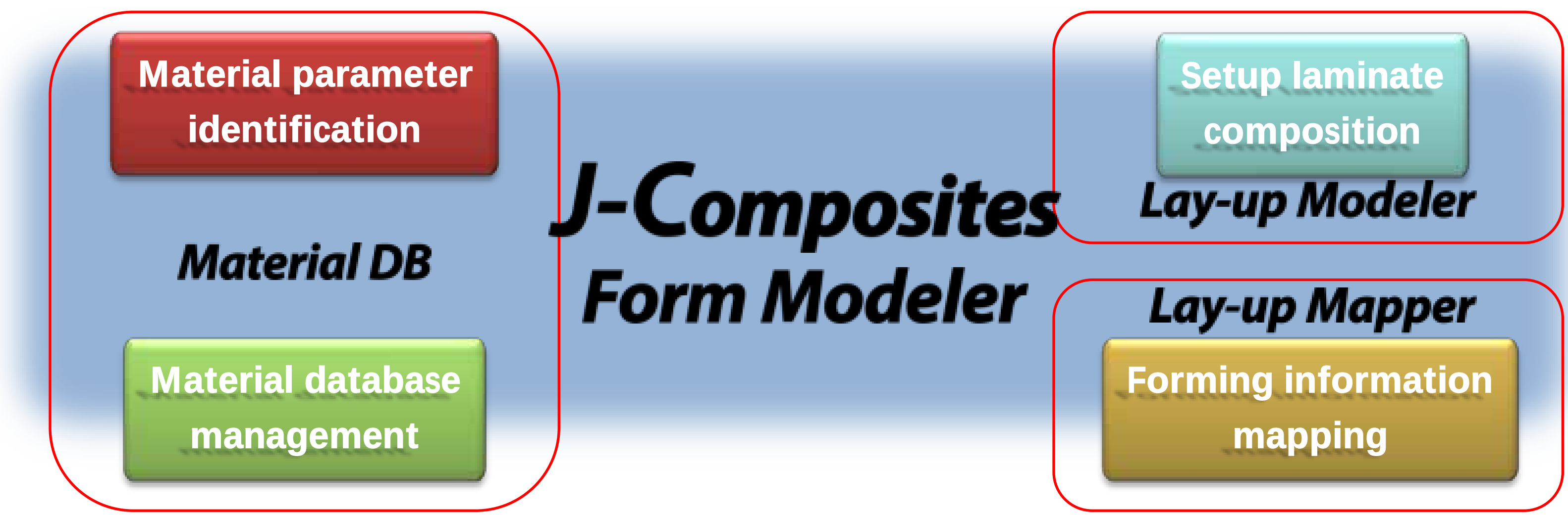


JSOL has promoted the development of J-Composites as a modeling tool series to help LS-DYNA users easily conduct composite process simulations.

J-Composites® / Form Modeler®

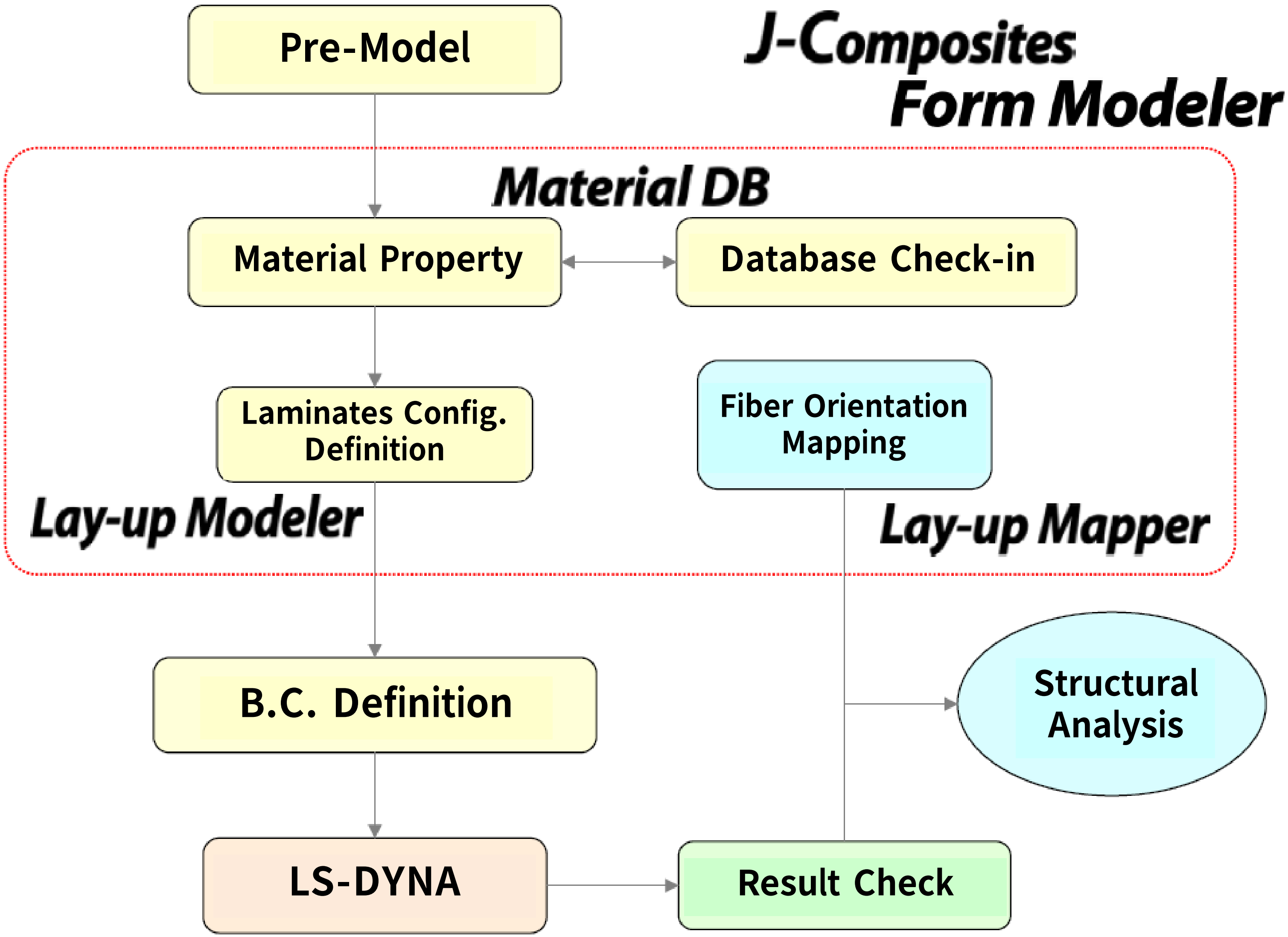
modeling tool for continuous fiber reinforced composite

Textile	×	Dry (w/o plastic)
UD		Thermoset
NCF		Thermoplastic



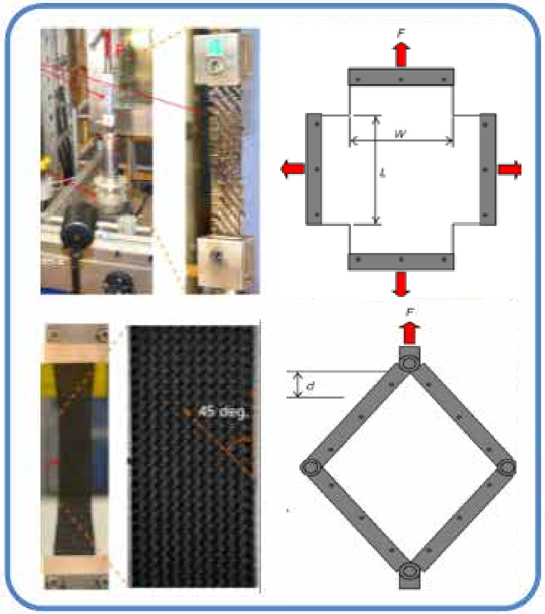
J-Composites® / Form Modeler®

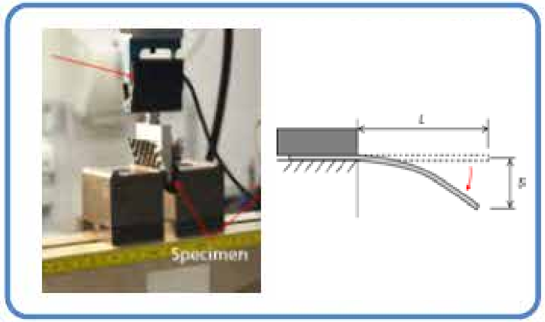
Workflow

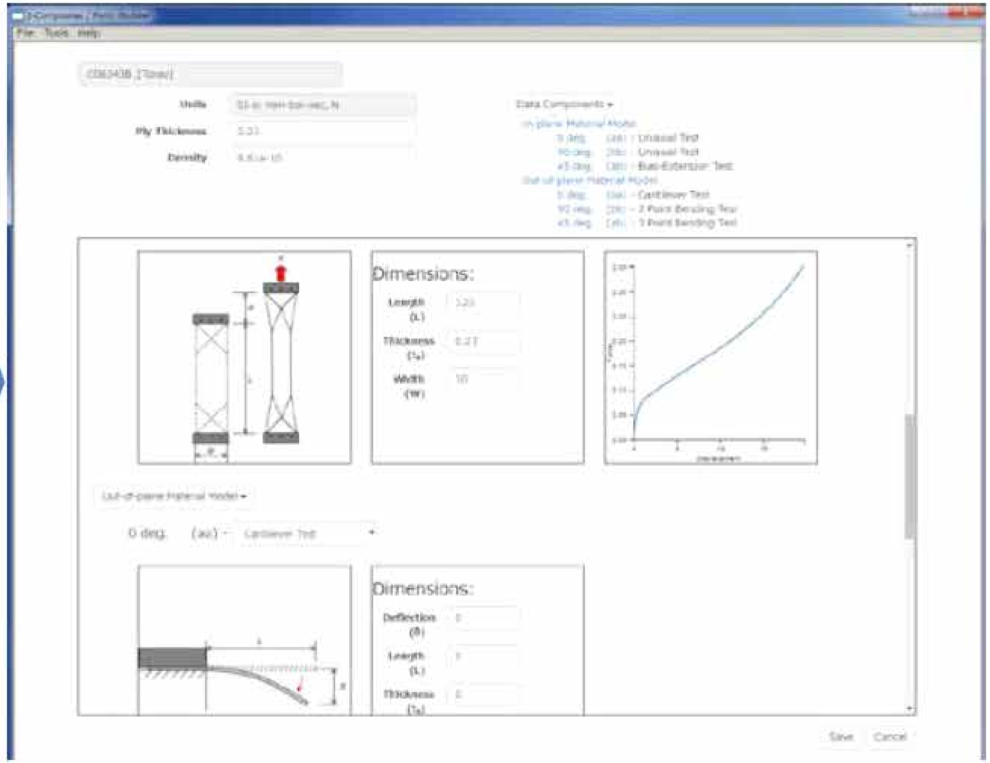


J-Composites® / Form Modeler®

Material DB: Outline

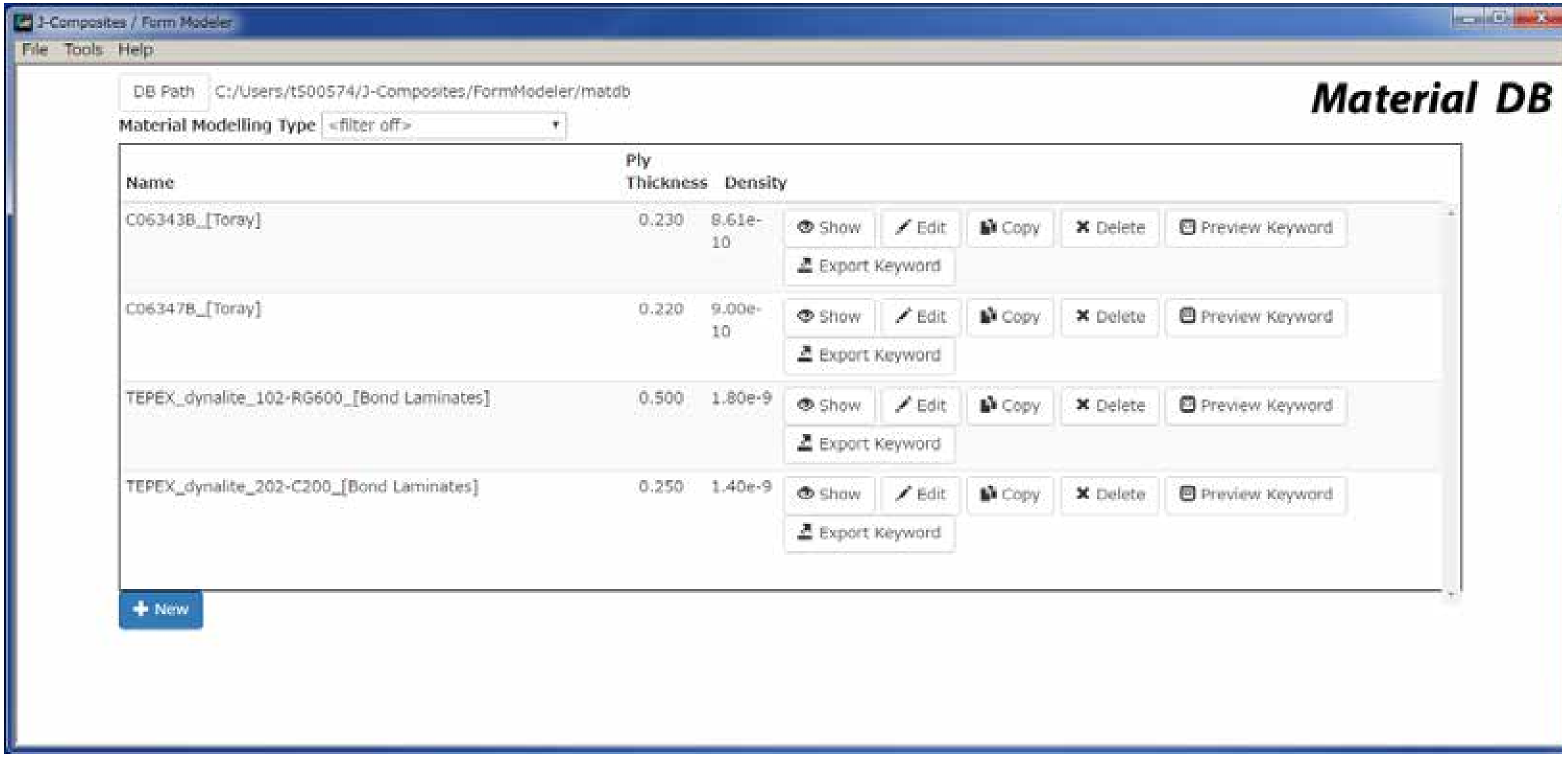






Material Fitting performed automatically by inputting experimental data.
Material database check-in available.

Material DB: User Interface



Standard Database Material Grades

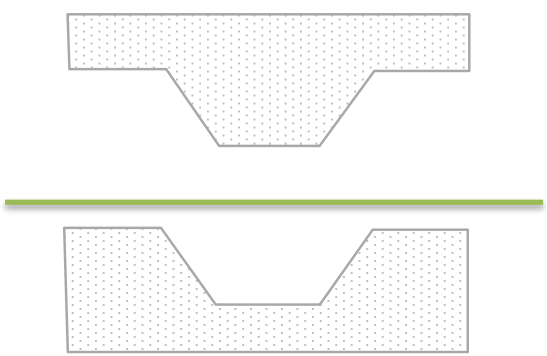
- Toreca C06343B (Toray)
- Toreca C06347B (Toray)
- TEPEX dynalite 102-RG600 (GF/PA6) (Bond Laminates)
- TEPEX dynalite 202-C200 (CF/PA6) (Bond Laminates)

Lay-up Modeler: Outline

Input

Pre-Model

- Molding tools
- 1 blank sheet



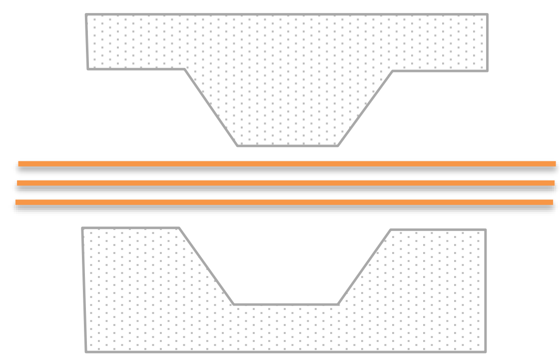
Output

Composites Model

- Molding tools
- Multi-ply sheets
- Laminates configuration defined
- Contact defined

Ply vs. tools

Ply vs. ply

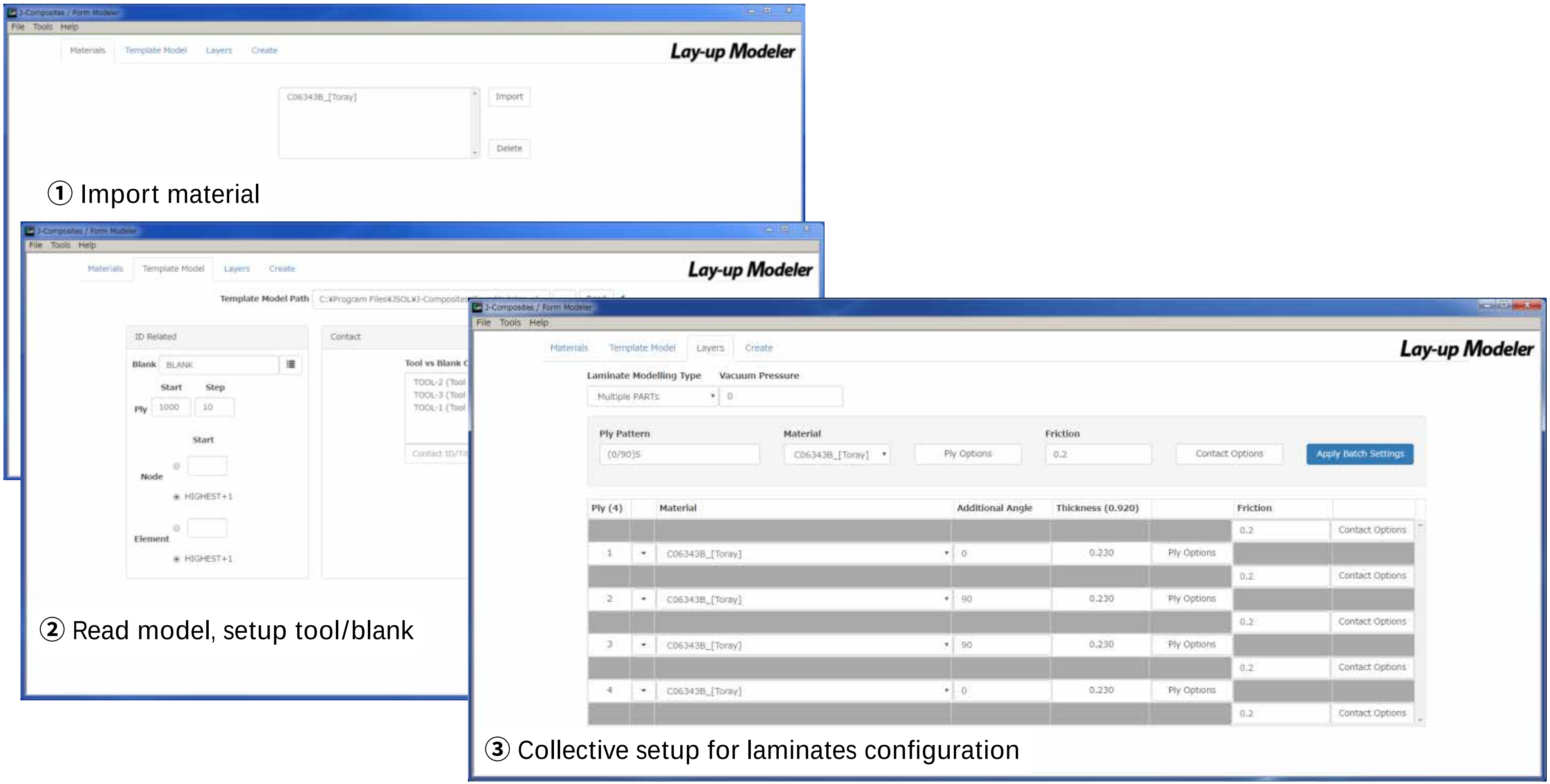


J-Composites® / Form Modeler®

Lay-up Modeler

Lay-up Modeler: User Interface

Automatic generation of LS-DYNA model for Composite Analysis



Lay-up Mapper: Outline

Input

Source result

- Forming analysis result
- Fiber orientation @dynain file

Target model

- For structural analysis

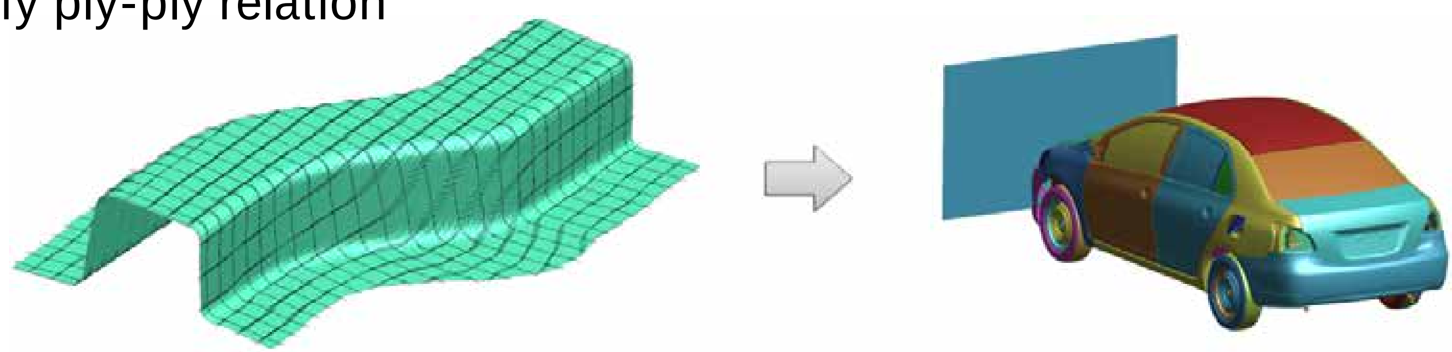
Output

Structural Model

- w/ fiber orientation inherited

Matching

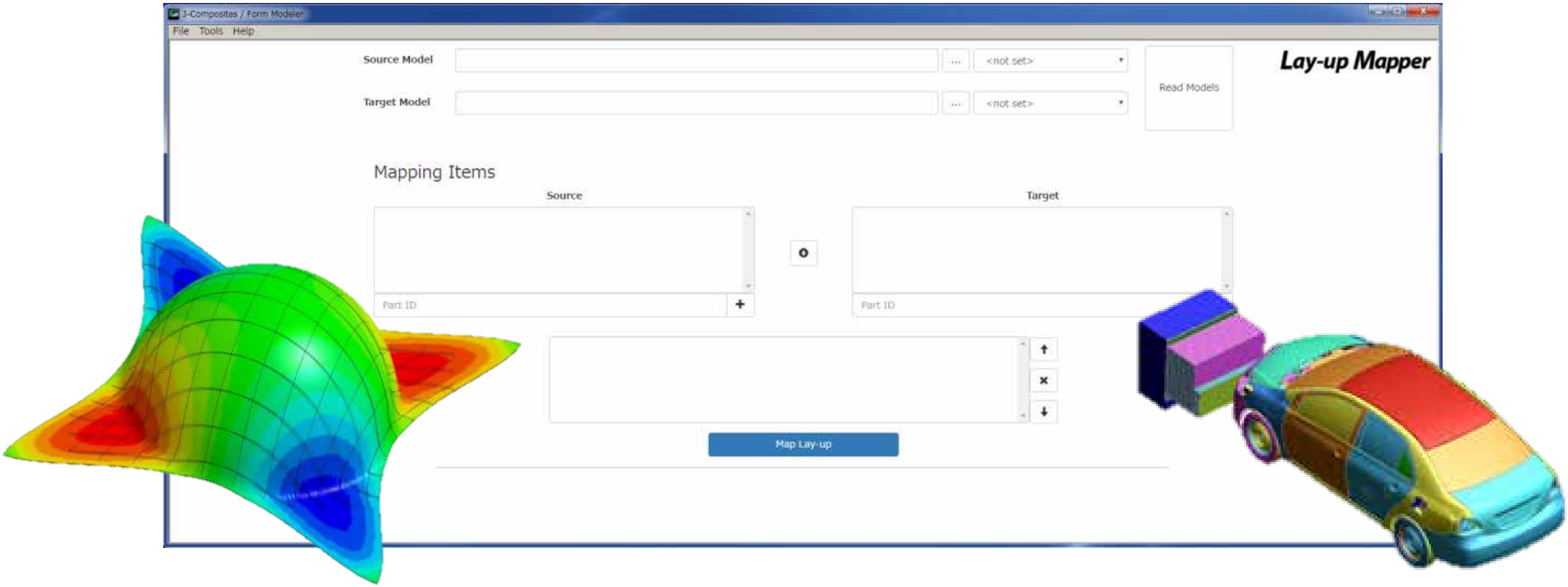
- Specify ply-ply relation



※Car body model from NCAC/GWU

Lay-up Mapper: User Interface

Mapping from forming analysis to structural analysis



※Car body model from NCAC/GWU

Forming Analysis

Shell-membrane model
*PART_COMPOSITE model

→

Structural/Crash Analysis

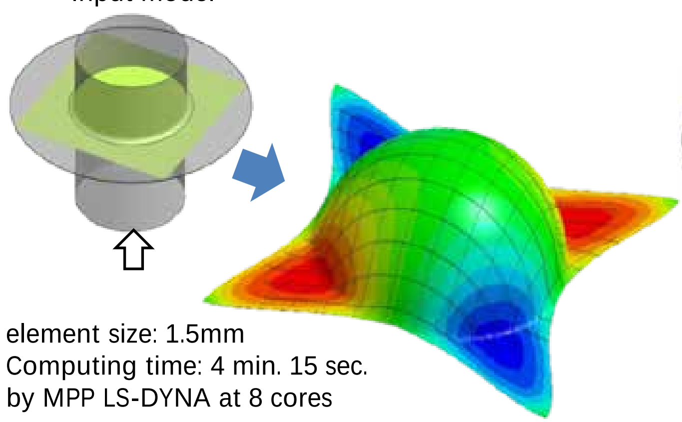
Shell-membrane model
*PART_COMPOSITE model
Solid model

J-Composites® / Form Modeler®

Form Modeler, Ver. 2.0

- **Enhancements to the standard material database**
  - CETEX® (TenCate), HexPly®,G1151® (Hexel), Cycom® (Cytec), HTS/977-2 (UD)
- System to automatically create the model for **thermal mechanical coupling** simulation
- System to automatically create the model for **one-step** inverse forming simulation

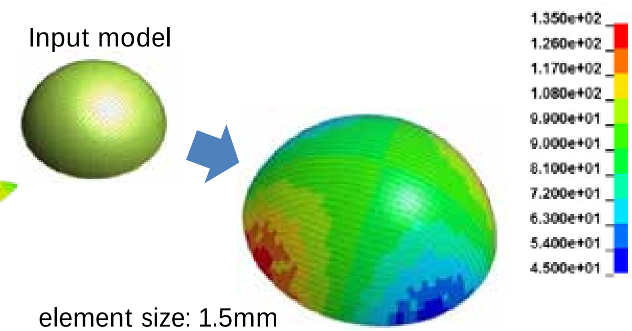
Input model



element size: 1.5mm
Computing time: 4 min. 15 sec.
by MPP LS-DYNA at 8 cores

Input model

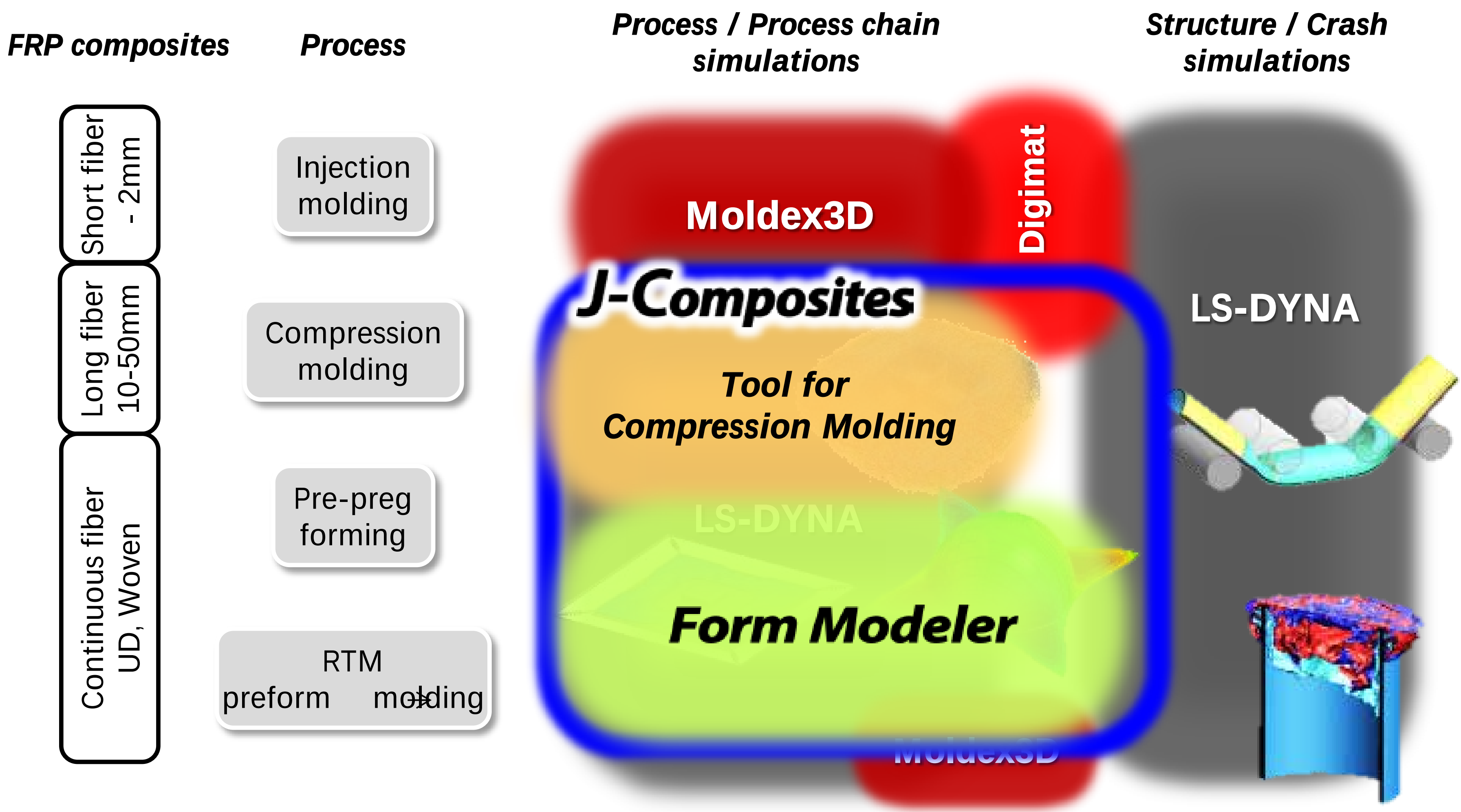
Shear angle



element size: 1.5mm
Computing time: 8 sec.
by SMP LS-DYNA at 1 core

- Usability improvements to the UI system
- New functionality according to customer requests

Portfolio with *J-Composites®*



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Summary

Forming Simulation

- Shell-Membrane hybrid model: easy to identify the material parameters with ***J-Composites/Form Modeler***.
- Through the case studies of dry textile, thermoset pre-preg and thermoplastic pre-preg, simulation with LS-DYNA can predict material deformation like fiber orientation and deformation, forming defects like wrinkles and temperature distribution, etc.

Compression Molding Simulation

- Proposed new simulation technology has great potential to simulate the material behavior and provides valuable information such as filling behavior and timing, fiber orientation and deformation, identification of weld line locations and matrix rich region and heat transfer and temperature distribution, etc.

J-Composites®

- JSOL is continuously developing ***J-Composites*** series in order to help LS-DYNA users quickly generate the model and conduct the reliable process simulations of composite materials.

Thank you for your attention!

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