# Composite Forming/Compression Molding Simulation with Introduction to J-Composites

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## Abstract

JSOL Corporation has developed J-Composites® [1], a set of tools, which works in cooperation with LS-DYNA®, to facilitate the complex manufacturing process and process-chain simulation of fiber reinforced composite materials. The J-Composites series consists of "Form Modeler", a tool to set up a press forming analysis model, and "Fiber Mapper", a tool to map a resin flow simulation result on to a structural mesh. Additionally, "Compression Molding", a tool for compression molding simulation is in development. This paper introduces those capabilities of J-Composites/Form Modeler and J-Composites/Compression Molding and demonstrates composite processing simulations.

JSOL Corporation 开发了 J-Composites®[1]，这套工具可与 LS-DYNA®合作，以促进纤维增强复合材料的复杂制造过程和工艺链仿真模拟。 J-Composites 系列由用于建立冲压成形分析模型的工具 " Form Modeler" 、以及于将树脂流动模拟结果映射到结构网格的工具 " Fiber Mapper"所组成。 另外，用于模拟长纤维增强材之压缩成型的工具 "压缩成型" 则正在开发中。 本文介绍 J-Composites / Form Modeler·以及 J-Composites / Compression Molding 的功能，并演示复合工艺之仿真案例。

## Introduction of J-Composites/Form Modeler

### Main Strategy to Describe Bending Behavior to Accurately Predict Wrinkles

Shell elements are usually used in sheet metal forming simulation. The out-of-plane bending stiffness of a continuous material such as metal can be directly deduced from in-plane properties. However, composite forming simulation using shell elements shows that the derived bending stiffness is unrealistically high compared to experimental bending stiffness. In order to describe the very low out-of-plane bending stiffness at macroscopic scale, it is possible to use the extremely small transverse shear stiffness in a Reissner-Mindlin shell where transverse shear deformation is capable. However it is very difficult to measure the transverse shear property of a textile reinforcement by experimental approach. Thus we propose the shell-membrane model in order to consider the bending stiffness that is independently free from any in-plane properties [2, 3].

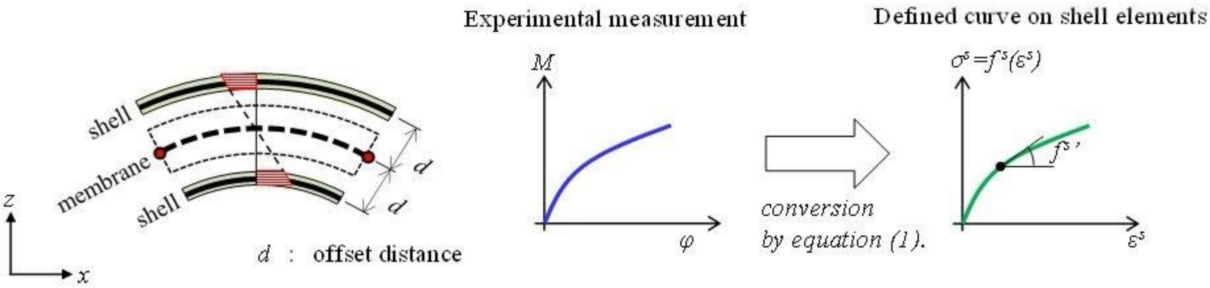



*Fig.13:* Shell-membrane model considering out-of-plane properties decoupled from in-plane properties.

As shown in Fig. 1 (b), bending properties with nonlinearity obtained by bending experiments and torsion experiment can also be expressed by using Eq. (1). Even if it is extended to a model that takes non-linear characteristics into consideration, in this model, it is assumed that the out-of-plane moment is decoupled from the in-plane stress

$$f_x^{s\,\prime} = \frac{\Delta M_y}{\Delta\phi_y}\frac{48}{t(48d^2+t^2)},\quad f_y^{s\,\prime} = \frac{\Delta M_x}{\Delta\phi_x}\frac{48}{t(48d^2+t^2)},\quad f_{xy}^{s\,\prime} = 2\frac{\Delta M_{xy}}{\Delta\phi_{xy}}\frac{48}{t(48d^2+t^2)} \qquad (1)$$

## New Features in J-Composites / Form Modeler Version 2.0

In version 2.0 of Form Modeler, new features, including the enhancement of the material database, automated model creation for thermal-mechanical coupling analysis and one-step quick simulation, and other UI usability improvements are announced. Shown in Table 1, 11 material grades with data from dry fabric, thermoset, and thermoplastic prepregs are registered and available as standard database. The data was collected through experimentation or cited from public papers. Because thermal mechanical coupling analysis is now supported, the UI of Material DB was also updated for users to be able to input thermal and temperature-dependent mechanical properties easily.

| *Grade Name* | *Manufacturer* | *Matrix* | *Fiber* | *Pattern* |
|---|---|---|---|---|
| Cetex®_8HSatin | TenCate | PPS | Glass | 8 Harness-Satin |
| Cetex®_TC1200 | TenCate | PEEK | Carbon | UD |
| Cycom®HTS-977-2 | Cytec | Epoxy | Carbon | UD |
| HexForce®_G1151 | Hexcel | - | Carbon | 3X formable weave |
| HexPly®_T700-M21 | Hexcel | Epoxy | Carbon | UD |
| Pipreg®_5HSatin | Porcher | PEEK | Carbon | 5 Harness-Satin |
| PYROFIL$_{TM}$_TR3110 360GMP | Mitsubishi Chemical | Epoxy | Carbon | Plain weave |
| Tepex®dynalite_102-RG600 | Bond-Laminate | PA6 | Glass | Twill weave |
| Tepex®dynalite_202-C200 | Bond-Laminate | PA6 | Carbon | Twill weave |
| TORAYCA®_C06343B | Toray | - | Carbon | Plain weave |
| TORAYCA®_C06347B | Toray | - | Carbon | Twill weave |

Table 4: *Standard Material Database List in Version 2.0*

Fig.2 shows a GUI of input for temperature-dependent data of 3-point bending test for thermal-mechanical coupling analysis. After setting the temperature-dependent mechanical data, thermal properties, molding temperature, and scale factor for processing speed, the model ready for analysis will be generated automatically.

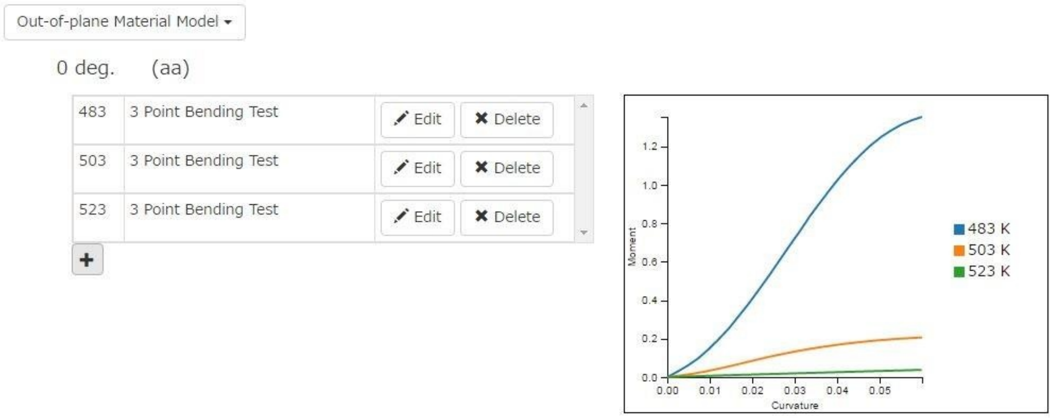



*Fig.14:* GUI for the input of temperature dependent mechanical properies

As a new function in LS-DYNA R11, One-step analysis for composites can be accomplished by setting up the related keywords ***DEFINE_FIBERS** and ***CONTROL_FORMING_ONESTEP**, which is extended from metal forming [4]. Skipping the tedious keyword setup, users just need to specify an FEM model of the final geometry, the material, and initial fiber orientation via the GUI shown as Fig. 3, and then the model ready for analysis will be generated automatically.

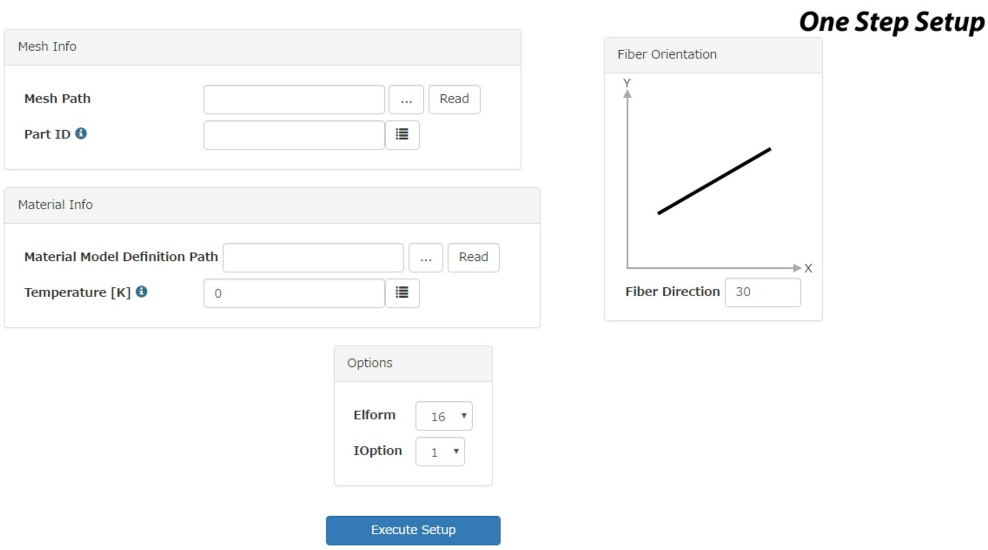
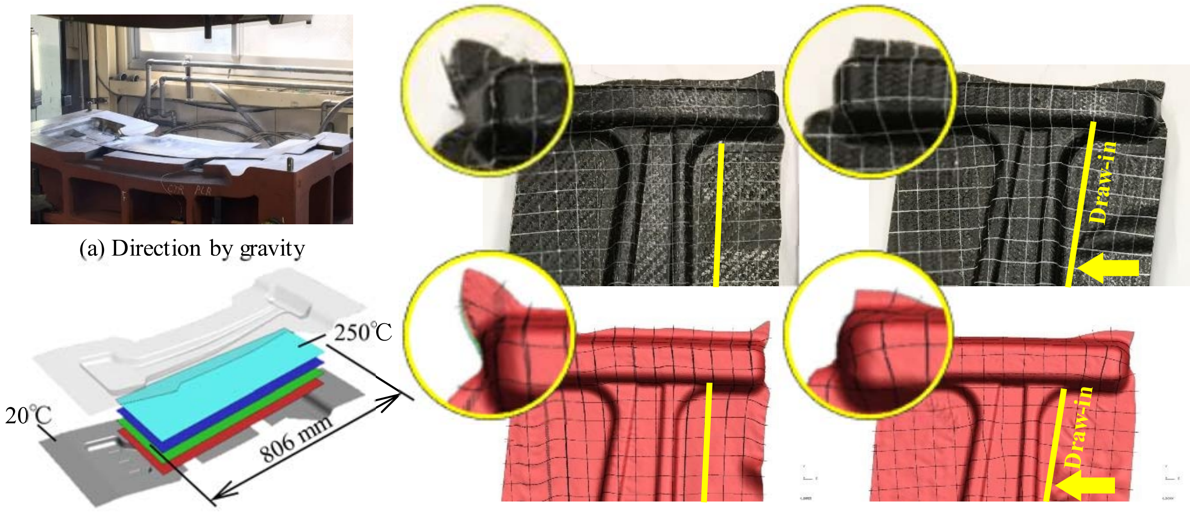



*Fig.15:* GUI for Composites Forming One-Step Simulation

## Composite Forming Example with J-Composites/Form Modeler and LS-DYNA

Automotive B-pillar forming simulation for simple laminates of Tepex dynalite 102-RG600 with $[(0/90)]_4$ and $[(45/-45)]_4$ lay-ups is performed by thermal-mechanical coupling analysis. The material model, which is included in the standard material database in J-Composites/Form Modeler, considers the temperature dependent mechanical properties. Fig. 4 shows the comparison of the deformation after forming of the automotive B-pillar of $[(0/90)]_4$ and $[(45/-45)]_4$ lay-ups to the experiments. Simulated outline for both fiber orientations show good agreement with the experimental deformations.




(a) Direction by gravity
(b) Model set-up
(c) [0/90] fiber orientation
(d) [+/-45] fiber orientation

*Fig.16:* Thermoforming Simulation of Automotive B-pillar considering change in temperature and mechanical properties of glass reinforced thermoplastic during forming process.

## Introduction of J-Composites/Compression Molding

## New Capabilities used in Compression Molding Simulation

Beam and solid elements are coupled by ***CONSTRAINED_BEAM_IN_SOLID** (CBIS), which has been implemented since LS-DYNA R8 [5]. CBIS constrains both accelerations and velocities between beam and solid elements (constraint based method). CBIS has a coupling option which applies only in the beam normal direction, thereby releasing constraint in the beam axial direction. As an additional function, an axial coupling force function has also been implemented. The beam and solid axial debonding processes can be modelled with a user-subroutine giving the axial shear force based on the slip between beam nodes and solid elements.

In May 2016 the idea was conceived in JSOL Corporation (JSOL) to combine the new axial beam coupling function in CBIS with 3D adaptive EFG to simulate compression molding of long fiber reinforced plastics. In this method CBIS continues to constrain the beam elements to the tetrahedral solid elements even during the re-meshing process. Livermore Software Technology Corporation (LSTC) improved the code to enable the simultaneous use of these two functions with the aid of JSOL's testing and feedback. Fig.5 shows the modelling method using the beam-in-solid coupling function. This new function was implemented in LS-DYNA R10 [6].

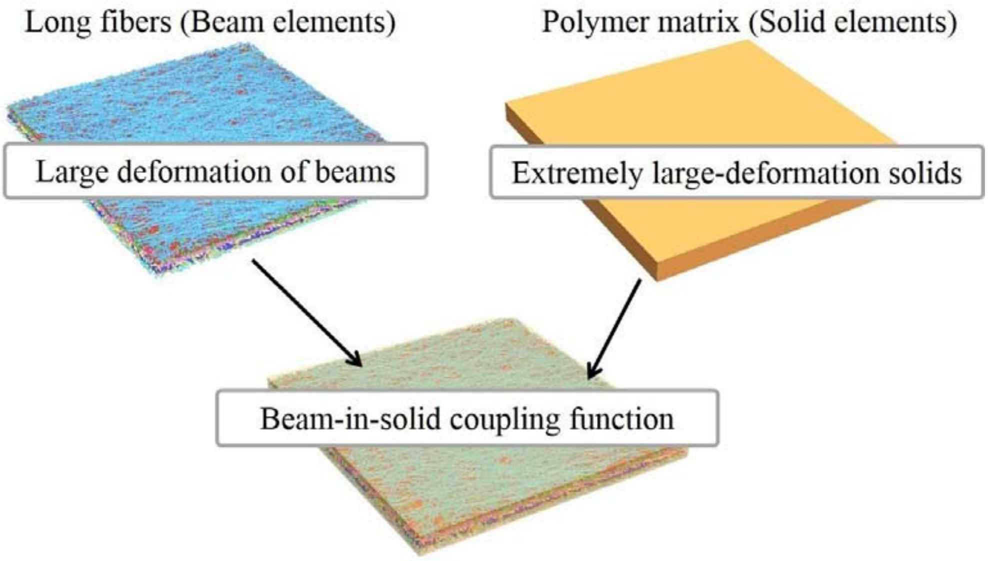



*Fig.17:* Long fibers modelled by beam elements and polymer matrix by solid elements

S. Hayashi et al. [7] applied these new simulation technologies to a compression molding of long glass fiber reinforced thermoplastics (Tepex® flowcore from Bond-Laminates GmbH) and compared results for complex shaped part. Fig.6 (left) shows deformations mid-way through the compression molding test of the long glass fiber reinforced thermoplastic sheet. Large wrinkles occur around the edge of the sheet. The simulation result seen in Fig.6 (right) shows good agreement to the test.

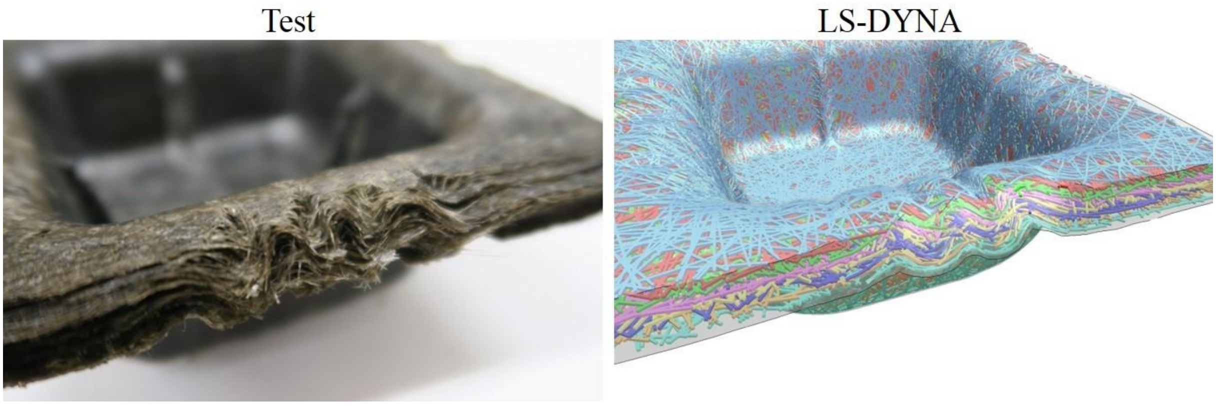



*Fig.18:* Charge wrinkling mid-way through the punching process

## Simple Compression Test to Identify Macroscopic Mechanical properties

Simple compression tests were performed to measure macroscopic mechanical properties of Randomly-Oriented Strand (ROS) thermoplastic composites (Flexcarbon® from Suncorona Oda Co., Ltd.). The ROS thermoplastic composites comprise many strands in 2D random orientation. Each strand is a chopped piece of unidirectional (UD) prepreg composite tape made up of carbon fiber / thermoplastic epoxy resin with fiber volume fraction (Vf) 40%. One strand is 25mm long and 12mm wide.

Fig.7 shows a simple compression test using a disc-shaped test specimen in diameter 75mm and thickness 6mm of the ROS thermoplastic composites. The simple compression tests were performed at low velocity 0.1 mm/sec inside a high temperature chamber, each at constant temperature of 125, 150, 175 and 200 degrees. The melting temperature of the thermoplastic epoxy resin was 100 degrees. A lubricant was applied to the loading surfaces to reduce friction against the test specimen.

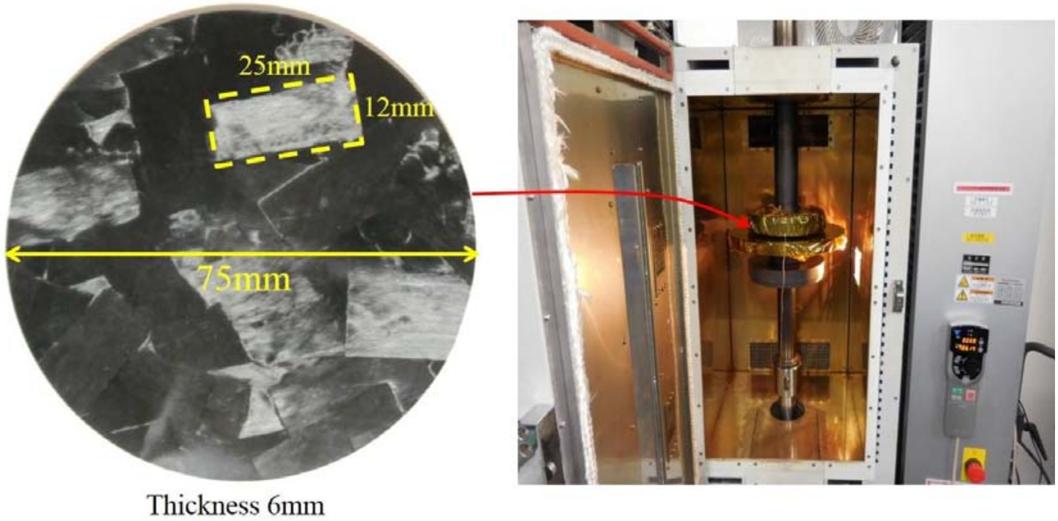



*Fig.19:* Test specimen and compression test machine with high temperature chamber

Fig.8 shows the final shapes of the test and the simulation formed by simple compression at temperature 200 degrees. Fig.9 shows contact forces of the simple compression tests at four different temperatures. The simulation results show good agreement to the tests.

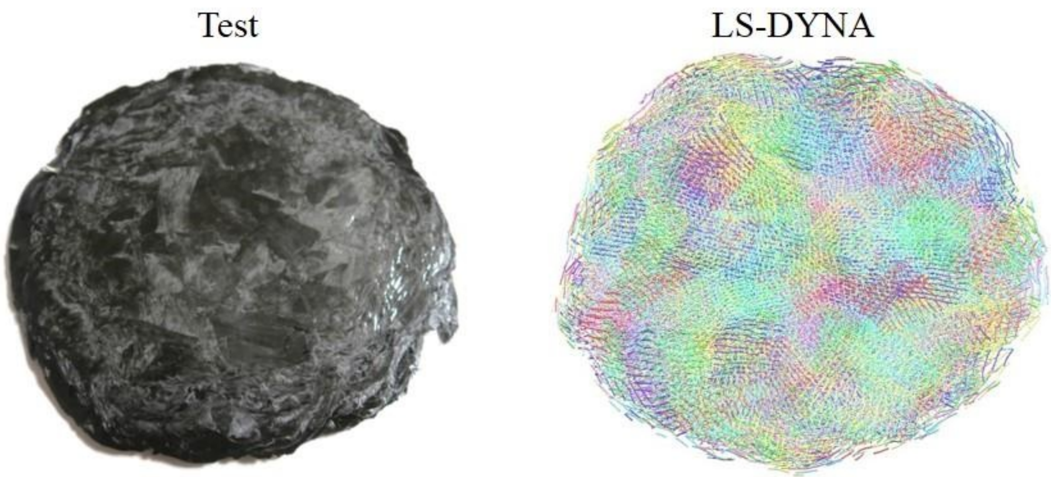



*Fig.20:* Final shapes formed by simple compression at temperature 200 degrees

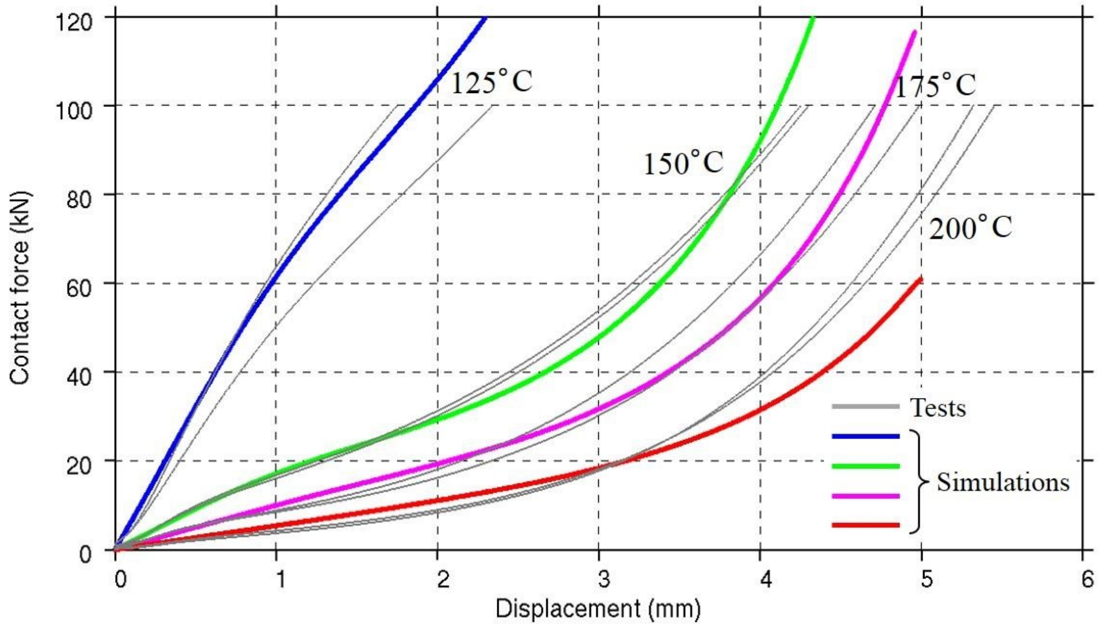



*Fig.21:* Contact forces at four different temperatures

## Compression Molding Test and Simulation to Form Cross-Ribbed Component

A compression molding test was performed to evaluate this new simulation technology. Fig.10 shows the ROS thermoplastic composite sheet (Flexcarbon® from Suncorona Oda Co., Ltd.) and the simulation model used in the compression molding. The sheet is square shape, 100mm x 100mm and thickness 8mm. The simulation model is made by the same modelling method as that developed in the simple compression simulation at temperature 200 degrees.

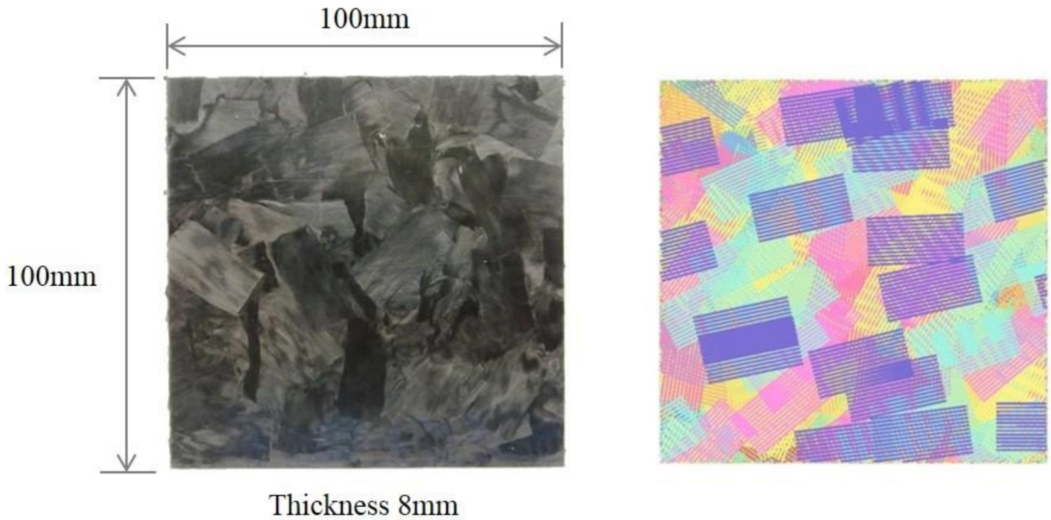



*Fig.22:* ROS thermoplastic sheet and simulation model

Fig.11 shows the punch and die used in the test and the simulation. The compression molding test was performed by a heat and cool molding method. The ROS thermoplastic composite sheet is heated in an oven until the temperature reaches 200 degrees. The punch and the die are also heated to the same temperature. The heated sheet is moved from the oven to the die and formed in several seconds at temperature 200 degrees. Then the formed sheet is solidified by gradually cooling the punch and the die to a temperature of 90 degrees over a period of several minutes. The molded sheet was then released from the molding system.

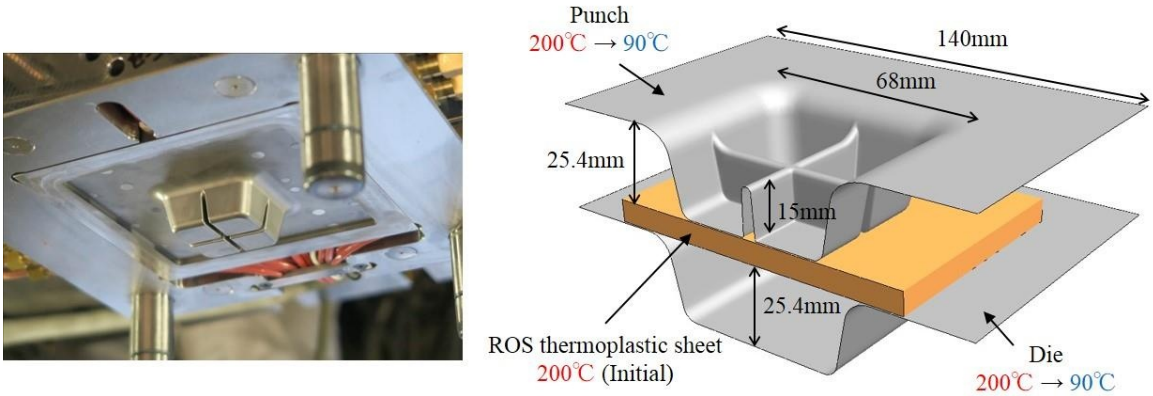



*Fig.23:* Compression molding to form cross-rib shaped component

Fig.12 shows the final forming shapes from the test and the simulation. The total footprint of expanded material is predicted to be the same as seen in the test.

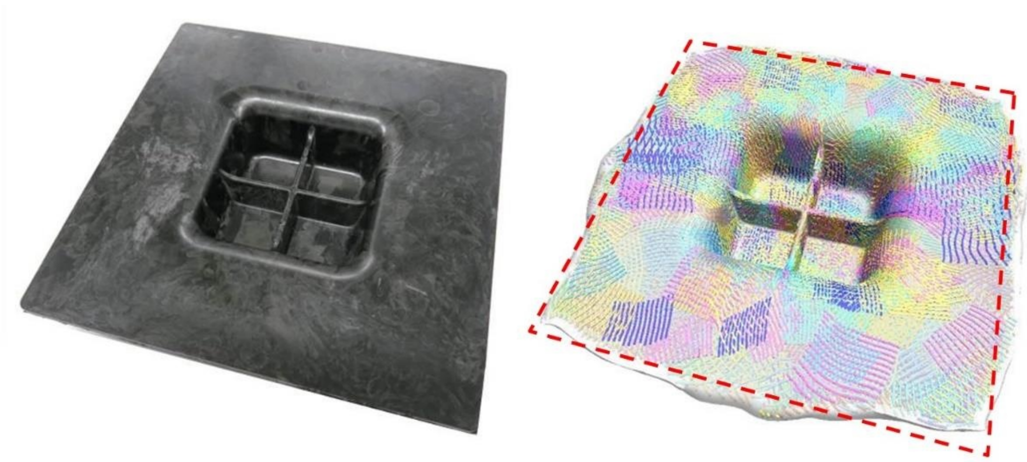


*Fig.24:* Final shapes formed by compression molding

## Summary

This paper has introduced J-Composites/Form Modeler & Compression Molding, and demonstrated case studies with LS-DYNA calculation to validate the prediction capability.
JSOL Corporation is devoted to developing new simulation tools to simulate forming/compression molding of FRP composites by using LS-DYNA in order to provide accurate and valuable analysis results.

## Literature

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