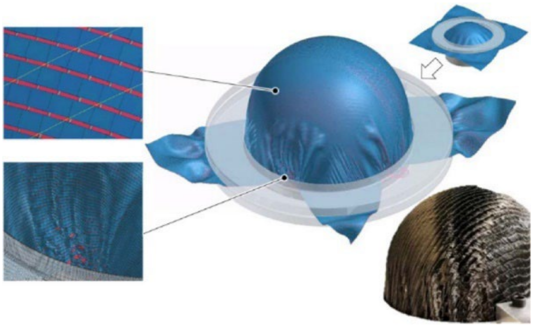
# Composite Forming Simulation Using Mesoscale Material Model



**KAZUKI NOMA**[*1] **KENTARO SHINDO**[*2]

*Using carbon fiber base materials such as non-crimp fabrics (NCFs) is becoming common especially in aircraft. Forming these materials into complex-shaped products causes defects such as fiber wrinkling. Although the forming conditions are generally adjusted for better quality, it is more effective to make the fiber base material itself more formable. Mitsubishi Heavy Industries, Ltd. is developing technology in which a mesoscale material model is used to simulate the forming process and predict the material's microscopic deformation behavior, with the aim of improving the simulation accuracy and adjusting the fabric architecture. This report presents the results of a comparison between the mesoscale NCF material model-based simulation of an elemental part forming process and the forming test, as well as the simulation assessment results of the impact of NCF fabric architecture on the formability.*

## 1. Introduction

As a low-cost forming method for composite material structures, the forming technology using NCFs, which are composed of carbon fibers, is being studied and developed mainly in Europe. Such technology has recently been applied to large structures such as aircraft. As shown in **Figure 1**, an NCF is formed as one structural sheet by stitching several differently oriented layers of carbon fiber tows together. When compared to woven fabrics, NCFs are especially characterized by their superior strength due to their maintained straightness of fibers.

| No. | Constituent |
|---|---|
| 1 | Stitch |
| 2 | Carbon fiber tow, −45° |
| 3 | Carbon fiber tow, +45° |
| 4 | Stitch |

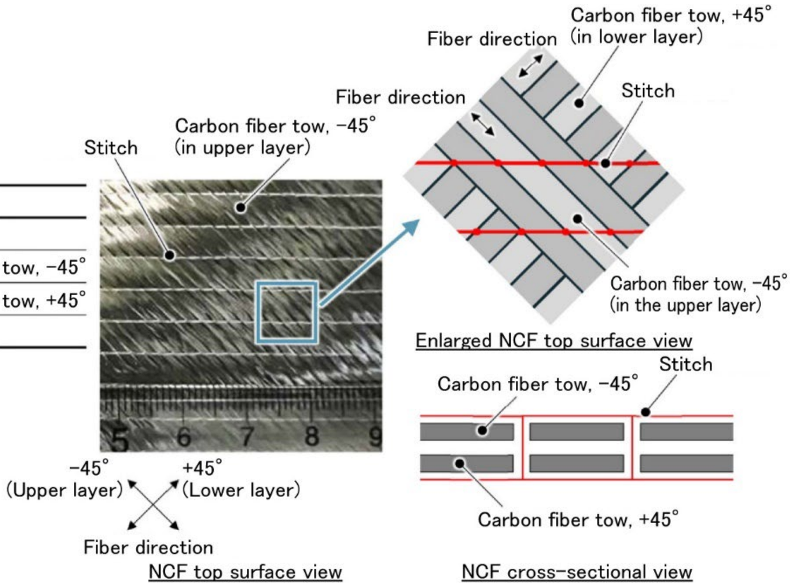


**Figure 1 Configuration of NCF discussed in this report**
The material (NCF) in this report is configurated by the constituents listed in the table above. Two layers of carbon fiber tows, which are arranged in the directions of -45° and +45°, are stitched together.

---

[*1] Manufacturing Technology Research Department, Research & Innovation Center

[*2] Chief Staff Researcher, Manufacturing Technology Research Department, Research & Innovation Center

Forming an NCF sheet into a complex-shaped product causes manufacturing defects such as fiber wrinkling, which affects the strength of the structure. Although the forming process and product shape are usually adjusted for a better quality outcome, it is more effective to make the NCF itself more formable. Forming simulation is used to investigate how to improve quality. However, a generally employed macroscale simulation, in which the material is modeled as a composite sheet level, has difficulty in predicting the microscopic deformation behavior of fibers during forming.

Therefore, our goal is to improve the prediction accuracy of in-plane and out-of-plane wrinkling during forming, by enabling the forming simulation with a mesoscale material model of fiber tows and stitch separately, which are the constituents of an NCF. If the microscopic deformation behavior of material can be predicted, the simulation accuracy will be improved and the fabric architecture of NCF can be optimized. Therefore, it is expected to improve the forming quality. In this paper, the mesoscale material model of NCF is constructed, and the results of comparative evaluation of forming simulation and test of elemental parts, and the results of evaluation of the effect of fabric architecture of NCF on formability by simulation are described.

## 2. Mesoscale material model

As shown in Figure 1, the NCF discussed in this report is comprised of two layers of carbon fiber tows arranged in the directions of +45° and -45° and the stitches that bind them together. ESI Group's Virtual Performance Solution was used as the simulation software.

As shown in **Figure 2**, all carbon fiber tows and stitches consisting of the NCF were modeled. Specifically, the former were modeled as three-dimensional (3D) solid elements, and the latter were as one-dimensional (1D) bar elements. It has thus become possible to take fiber tow opening/closing and sliding into account. The width and thickness of fiber tow, the tow-to-tow gap, and the stitch space were in agreement with the actual NCF used in the forming test. The in-plane gap between fiber tows was set at 0.1 mm, and the out-of-plane gap between two fiber-tow layers was also at 0.1 mm.

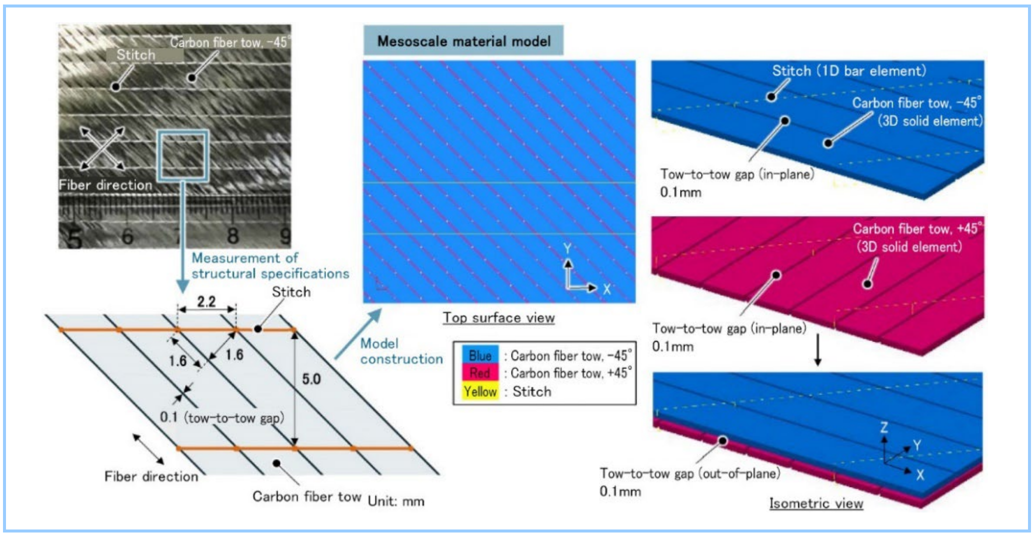


**Figure 2 Mesoscale NCF material model**
The structural specifications were determined by measuring the NCF used in the forming test, and the mesoscale material model was constructed accordingly. The fiber tows arranged in the directions of +45° and -45° were modeled as 3D solid elements, while the stitches were as 1D bar elements.

## 3. Assessment of forming simulation accuracy of elemental parts

### 3.1 Simulation conditions

In order to evaluate the validity of the developed material model and the derived values of material properties, a forming simulation into a hemispherical mold was performed. The hemisphere is an appropriate model to evaluate the validity of the simulation because it has complex deformation modes with multiple deformations during forming, such as tension, shear, bending, and compression. **Figure 3** shows the simulation model. The forming process involves placing an NCF sheet (400 mm × 400 mm) on a hemispherical mold (200 mm in diameter and 150 mm in height), sandwiching the sheet between ring-shaped blank holders from upwards/downwards, and moving the holders down along the mold.

The simulation necessitated inputting the physical properties for each of the modeled carbon fiber tows and stitches, rather than those for a sheet unit of NCF. For carbon fiber tows, the inputs include Young's modulus, shear modulus, and friction coefficient. The Young's modulus value in the fiber direction, E1, was taken from a fiber catalog. Because of their difficulty in measuring, the other Young's modulus values, E2 and E3, and the shear modulus value were determined in such a way that the results of the bending/compression tests agreed with their reproduced simulations. The friction coefficient value between fiber tows was taken from similar literature(1). With regard to the stitches (bar elements), the Young's modulus value was adjusted in such a way that the results of the picture frame test agreed with the load-displacement curve of the reproduced simulation(2).

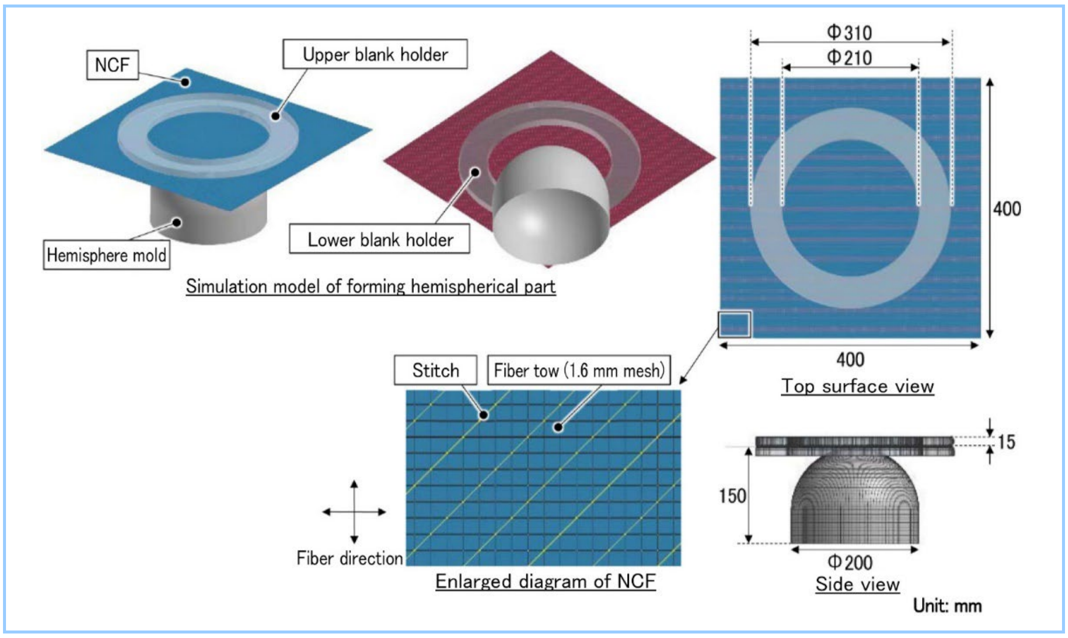


**Figure 3 Simulation model of forming hemispherical part**

### 3.2 Simulation results

**Figure 4** gives the simulation results. The predicted behaviors are the occurrence of different degrees of tow-to-tow gap opening and noticeable out-of-plane wrinkles of fibers that become redundant, especially in the lower part of the hemisphere. Moreover, the reproduced details show that the top fiber-tow layer is detached from the layer underneath because fibers are pulled at the bottom edge of the hemisphere sandwiched between the blank holders. This indicates the effectiveness of our mesoscale model, as it can predict the material's microscopic deformation behavior that cannot be reproduced by the conventional macroscale material model.

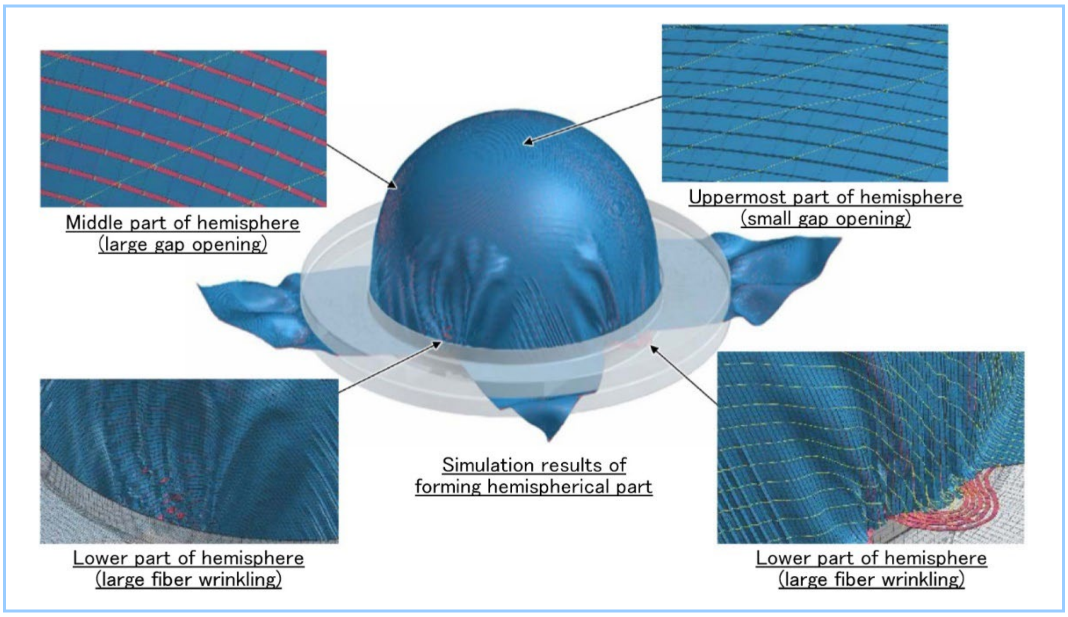


**Figure 4 Simulation results of forming hemispherical part**

### 3.3 Comparison of simulation and forming test result

To assess the simulation accuracy, a forming test was conducted under the same forming conditions as the simulation, which is shown in **Figure 5**. The hemispherical mold was installed in the lower part of the strength test machine. The upper/lower blank holders sandwiching the NCF and the crosshead in the upper part of the test machine were fixed in place. The blank holders were moved down at a constant speed to form the NCF into a hemispherical shape.

As shown in **Figure 6**, there is a correlation between the simulation and test results, in terms of the positions of occurrence of major wrinkles and their wrinkling shapes when viewed from Positions A to D. The validity of the simulation model and material property values has thus been confirmed. Moreover, the out-of-plane wrinkle heights were measured by a 3D scanner in the test, to compare with the simulation results. As the height of a wrinkle greatly differed depending on where it was measured, the hemisphere was divided into three measurement zones: upper, lower central, and lower outer. The averages in the respective zones were used for comparison; the error fell within the range of 0.1-28%. It can therefore be considered that the overall accuracy in the prediction of wrinkle height is good enough.

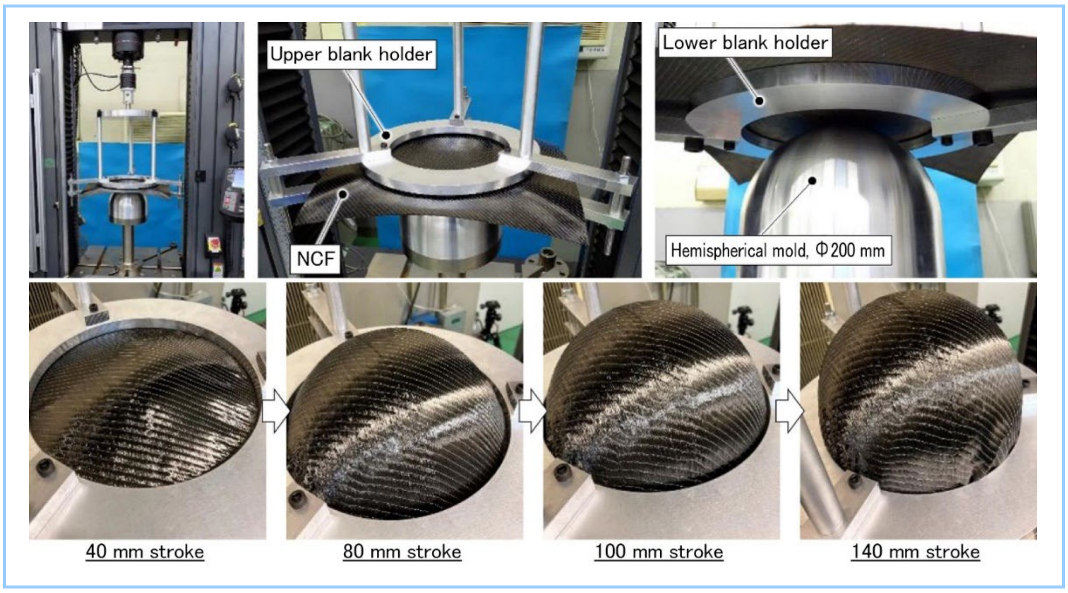


**Figure 5 Hemispherical part forming test**

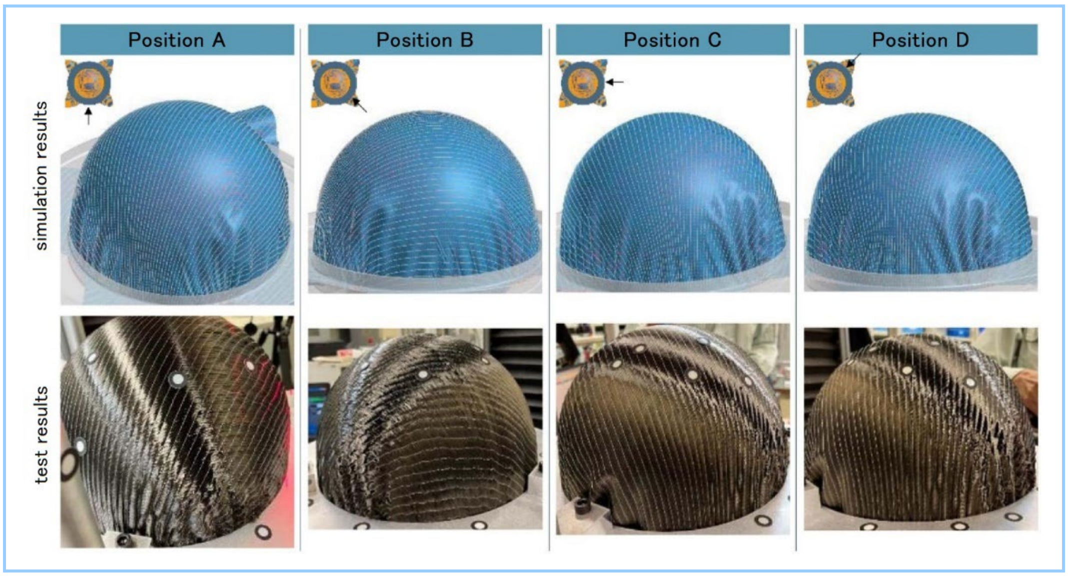


**Figure 6 Results of comparison between forming simulation and test**

## 4. Assessment of impact of NCF fabric architecture on formability

To optimize the fabric architecture of NCF for better forming quality, the hemispherical forming simulation was performed using three different material models (**Figure 7**). Based on the model of the NCF used for the assessment in the earlier section, two modified models were constructed for comparison purposes, that is, one with the stitching lines that are halved in number, and the other with the width of fiber tow (stitch pitch) doubled.

When compared to the original model, the modified one with the halved number of stitching lines tends to facilitate in-plane deformation because of the weaker constraint of stitches on fibers, dispersing out-of-plane wrinkles in the lower part of the hemisphere. With regard to the other model with the doubled width of fiber tow, the doubled stitch pitch halves the number of fiber constraint points, widening the in-plane gap between fiber tows and reducing out-of-plane wrinkles. The simulation results indicate that the stitch pitch has a greater impact on the formability than the number of stitching lines, in the case of forming into a hemispherical shape.

Therefore, our mesoscale material model can be used to investigate how different fabric architectures change the formability. It can also be expected that the simulation is used to optimize the fabric architecture for actual parts.

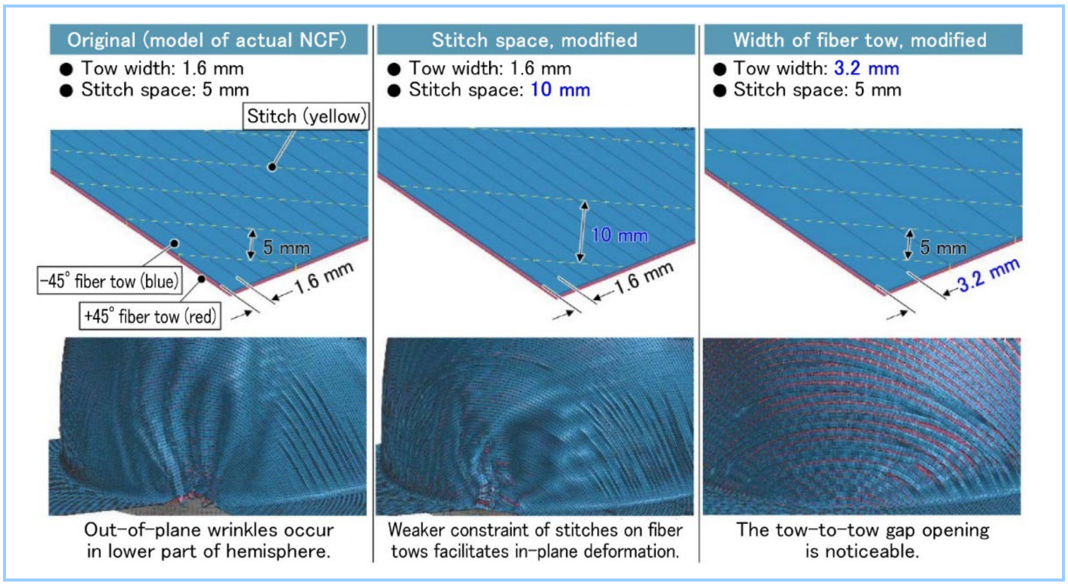


**Figure 7 Assessment of impact of NCF fabric architecture on formability**

## 5. Conclusion

In this report, a mesoscale material model was constructed using 3D solid elements for NCF fiber tows and 1D bar elements for stitches. The simulation of forming an elemental part was performed. As a result, the size of the fiber opening and the occurrence of the out-of-plane wrinkle were predicted, and the occurrence position and form of the main wrinkle agreed well with the test result. Moreover, the simulation was used to investigate how different NCF fabric architectures can change the formability. The results indicate that the simulation can be used to optimize the fabric architecture for actual parts. With a view to the practical application, we will further work on the development of simulation technology for large/multilayer parts.

## References

(1) J. Sirtautas et al., A mesoscopic model for coupled drape-infusion simulation of biaxial Non-Crimp Fabric, Composites: Part B, Vol.47 (2013), p.48-57

(2) K. NOMA et al., High-precision Forming Simulation for Composite Material Using Mesoscale Material Model, Mitsubishi Heavy Industries Technical Review Vol.61 No.1 (2024)