FORMABILITY EVALUATION OF NON-CRIMP CARBON FABRICS

K.Tanaka[1,a], K.Kanazawa[2], S.Enoki[3], T.Katayama[1,b], K.Kurashiki[4]

[1] *Professor, Dept. of Biomedical Eng., Doshisha Univ. (Japan)*
[2] *Graduate Student, Dept. of Mechanical Eng., Doshisha Univ. (Japan)*
[3] *Associate Professor, Dept. of Mechanical Eng., Nara National College of Technology (Japan)*
[4] *Doshisha Univ. (Japan)*
[a] *ktanaka@mail.doshisha.ac.jp,* [b] *tkatayam@mail.doshisha.ac.jp.*

Keywords: Non-Crimp Fabric (NCF), Non-contact 3D deformation measurement, Stitch, Stitching Parameter.

Abstract
The bias extension test based on the measurement of shear angle by non-contact 3D deformation measurement system was conducted to evaluate the drape performance of the NCF. The measurement results proposed the formability evaluation index. Moreover, the draping test onto hemisphere geometry was conducted. And the availability of formability evaluation index calculated by the bias extension test was verified. The NCF stitched pattern used were tricot and chain, and stitched tension were of tight, normal and loose. The results obtained are follows. The tricot stitch NCF with normal tension was highest maximum shear angle. In the draping test onto hemisphere geometry, the Tricot stitch NCF has high maximum shear angle. Maximum shear angle of draping formability index calculated from the bias extension test is possible to evaluate the formability of the NCF.

1 Introduction
Non-crimp fabrics (NCF) have attracted much attention of the automotive industry and their usage is growing rapidly [1]. This structure leads to an advantageous combination of high material properties, low cost processing, and excellent drape performance, thus it is also suitable for moulding composite materials of complex shapes [2]. Common problems in the fabricating process of three-dimensional shells of complex curvature include unwanted features such as wrinkle or tears. The problems depend on the geometry of the mould surface and the type of fabric. Furthermore, during draping and forming of a fabric, there are local variations of fibre orientation, fibre volume fraction and possibly fabric thickness which are going to affect processability and the mechanical properties of the final product. Though, it is reported that NCF possesses excellent drape performance compared to woven fabrics. But, there is not a clear criteria of a drape evaluation. And, the influence of stitch type and stitch tension exert on the drape characteristic of NCF is not clarified. Until now, the picture frame test [3-5] and the bias extension test [6-9] have been proposed as the drape evaluation to the textile preform like woven fabrics. Especially, the bias extension test has been considered to be an alternative to the picture frame test. The reasons are as follows. The bias extension test can be carried out easily, the influence of the boundary condition to the result is small and bias extension test obtain high reproducibility results. However, for the traditional bias extension test, measurement of shear angle is based on the pin-jointed net (PJN)

approximation [10]. The fibers sliding and the effect of the stitching parameters of NCF were could not consider in PJN. Therefore, the development of a new measuring method of the shear angle which considers the fiber sliding and the calculation of formability evaluation index are needed. In this study, the bias extension test based on measurement of shear angle by non-contact 3D deformation measurement system was conducted to evaluate the drapability of NCF, and proposed the formability evaluation index. Moreover, the draping test onto a hemisphere curved geometry molding was conducted and the availability of formability evaluation index calculated by the bias extension test was verified.

2 Formability Evaluation of Non-Crimp Carbon Fabrics

2.1 Bias extension test

2.1.1 Material

Bidirectional carbon fiber non-crimp fabrics are used in this study. The specimen size is 50mm×150mm in this study. The directions of carbon fiber bundles are 0°/90°. The areal density of the fiber bundles is 300g/m^2. The stitching yarn is polyester sewing thread. The stitching pattern is tricot stitch and chain stitch. The tricot stitch tensions are Normal, Tight and Loose. The specimens denoted as Table.1. Chain stitch NCF has the deformation characteristic of two directions. Therefore, the specimens were cut as shown in Fig.1. The specimens named CN0 and CN90. Woven fabric(WF) is used for comparison.

Specimens		Stitch type	Tension of stitching	Thickness[mm]	Area density[g/m^2]
NCF	TL	Tricot	Loose	0.4	300
	TN		Normal		
	TT		Tight		
	CN	Chain	Normal		
Woven fabric(Plain) WF		-	-	0.25	200

Table 1. Specimens condition.

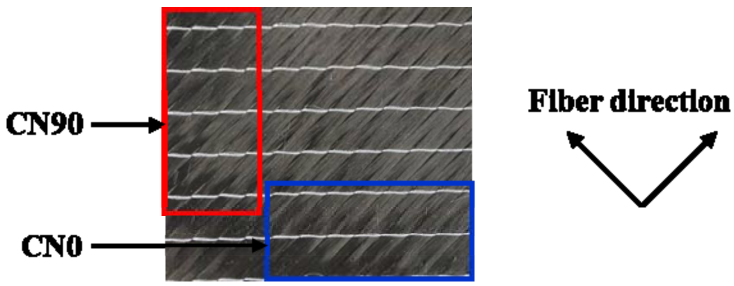


Figure 1. Cut direction of specimens.

2.1.2 Bias extension test

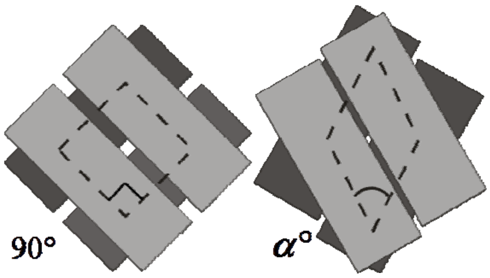
The set-up consists of specimens installed in the jaws of a tensile testing machine with the fibers in the warp and weft directions initially oriented at ±45°from the loading direction. During testing, the central portion of the specimen undergoes a pure interplay shear deformation, where the angle between the fibers decreases gradually until it reaches a locking angle at which the sheet theoretically undergoes an out of plane deformation to from a wrinkle. By recording the load vs. time data and by measuring the angle between the fibers at several time intervals during testing, the sheet viscosity in the fiber directions, the locking angle and the pre- and post-locking shear moduli can be determined. In this study, the bias extension test were conducted by universal testing machine (Autograph AG-100kNX, Shimadzu Co.

Ltd.) and measurement of shear angles of carbon fiber bundles was conducted by non-contact 3D deformation measurement system (ARAMIS®).

2.1.3 Shear angle measure

A camera (ARAMIS®) installed outside the test machine which was used to record the shear angles. In order to measure by non-contact 3D deformation measurement system, the specimen surface was made random pattern which was produced by an air spray paint mixed with calcium carbonate and ethanol. Fig.2 shows schematic drawing of specimen in new bias extension test. The recordings were then used to measure the angle (α) between the warp and weft directions of the specimen during testing. The shear angle θ_{ARAMIS} calculated from Eq.(1) with measured angle (α).

$$\theta_{ARAMIS} = 90° - \alpha \tag{1}$$

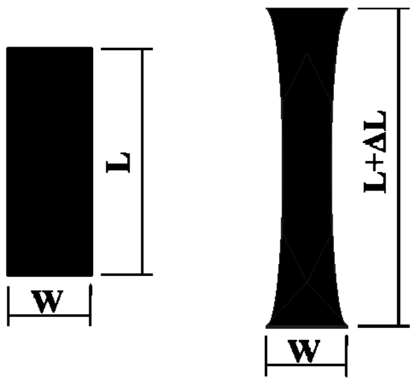


(a)Initial (b)Deformed

Figure 2. Schematic drawing of specimen in new bias extension test.

On the other hand, the shear angle $\theta_{Kinetic}$ that had been measured from the crosshead displacement of the testing machine was calculated from Eq. (2). Fig.3 shows schematic drawing of specimen in traditional bias extension test. The L shows the long side length of the rectangle, the W shows the short side width and ΔL shows the crosshead displacement.

$$\theta_{Kinetic} = 90° - 2\cos^{-1}\left(\frac{L - W + \Delta L}{\sqrt{2}(L - W)}\right) \tag{2}$$



(a)Initial (b)Deformed

Figure 3. Schematic drawing of specimen in traditional bias extension test.

2.2 Result and discussion

2.2.1 Influence that difference of measuring method of shear angle exerts on shear angle measurement results

Fig.4 shows the mean shear angle – crosshead displacement curves of Kinetic and ARAMIS. θ_{ARAMIS} is calculated from Eq. (1). $\theta_{Kinetic}$ is calculated from Eq. (2). Fig.5 shows the shear angle which calculated from non-contact 3D deformation measurement system (ARAMIS®). *a, b* and *c* of Fig.2 corresponds to *a, b* and *c* of Fig.3. Difference between the shear angle of Kinetic and the shear angle of ARAMIS increases with the expansion of deformation from Fig.4. The traditional bias extension test(Kinetic) considers that red dotted line area of Fig.3 is not deformed. However, in fact, red dotted line area of Fig.3 is deformed. Therefore, the shear angle measured by non-contact 3D deformation measurement system (ARAMIS®) is effective.

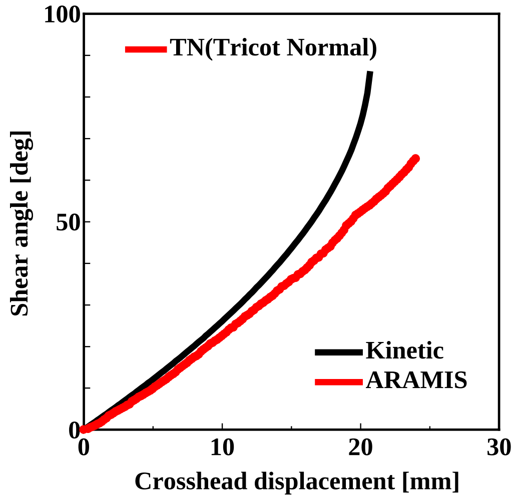


Figure 4. Relationship between shear angle and crosshead displacement.

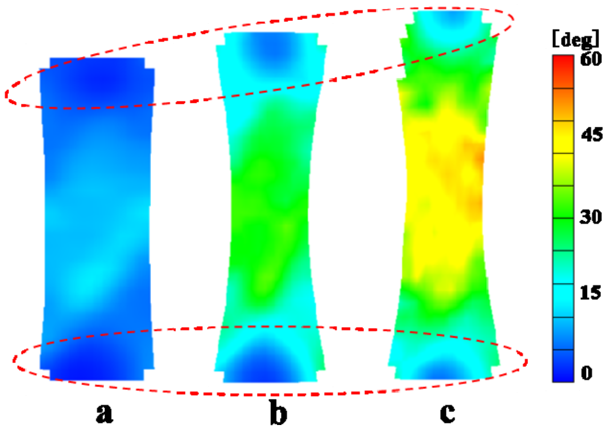


Figure 5. Contour of shear angle in the TN obtained of new bias extension test.

2.2.2 Proposal of the formability evaluation index

Fig.6 shows relationship between the shear angle and normalized force.

The change in shear deformation behavior starts from a dotted line position in Fig.6. The defect is caused by the contact of the fiber bundle and the restraint of the stitching yarn since the dotted line. Therefore, the angle of the change in behavior starting point was assumed to be formability evaluation index. Formability evaluation index is called maximum shear angle in this study. Fig.7 shows maximum shear angle of each specimens.

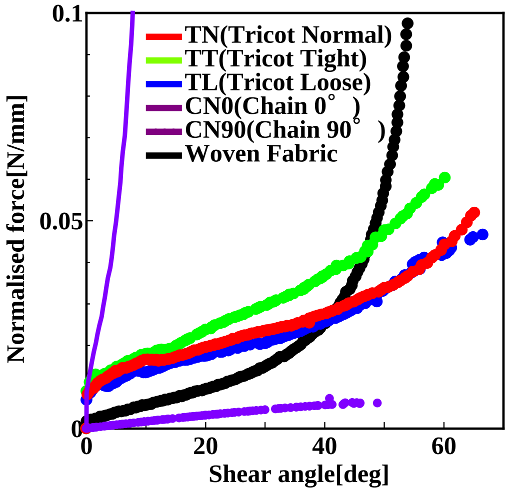


Figure 6. Relationship between shear angle and normalized force.

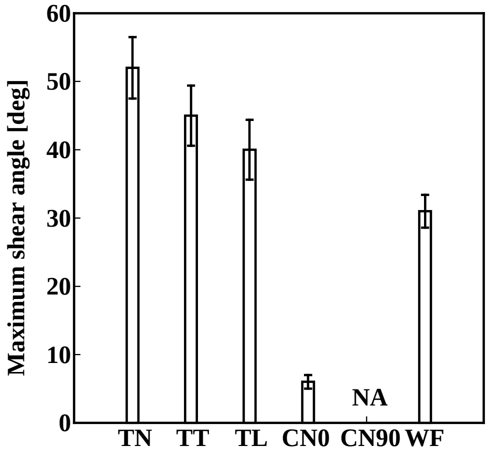


Figure 7. Maximum shear angle of each specimen.

2.2.3 Effect of stitch parameter

TN (NCF, tricot, normal tension) of the maximum shear angle is the largest from Fig.7. There was difference of the maximum shear angle from the difference of stitch tension. It is not easy to slip fiber bundle in TT(NCF, tricot, tight tension), because stitch tension is strong. On the other hand, it is too easy to slip fiber bundle in TL(NCF, tricot, loose tension), because stitch tension is loose. The balance of fiber bundle slipping to the loading direction is the best in TN. Therefore, TN of the maximum shear angle is the largest of each specimen.

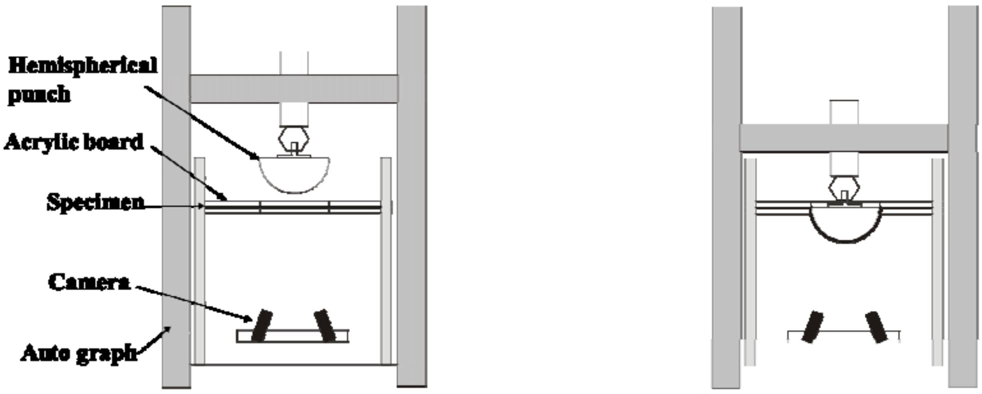
3 The availability of formability evaluation index

3.1 Material

Bidirectional carbon fiber non-crimp fabrics (Benny-Toyama Co. Ltd., Japan) were used in this study. Specimen size is 300mm × 300mm. The directions of carbon fiber bundles are 0°/90°. The areal density of the fiber bundles is 300g/m^2. The stitching yarn is polyester sewing thread. The stitching pattern is tricot stitch and chain stitch. The tricot stitch tensions are Normal, Tight and Loose. The specimens denoted as Table.1.

3.2 Draping test for 3D shapes

Fig.8 shows schematic view of draping tests in this study. The draping tests were conducted by universal testing machine (Autograph AG-100kNX, Shimadzu Co. Ltd.) and measurement of shear angles of carbon fiber bundles was conducted by non-contact 3D deformation measurement system (ARAMIS®). The displacement rate was set for 10mm/min. We conducted the draping tests by hemisphere punch shapes. Diameters of the hemisphere punch shape are 50mm. Each blank holder for the hemisphere punches has 52mm diameter hole. In order to measure by non-contact deformation analysis, the square specimen(300mm×300mm in size) made random pattern which was produced by an air spray paint mixed with calcium carbonate and ethanol. During test, the state of deformation was measured by non-contact 3D deformation measurement system (ARAMIS®).



(a)Initial (b)Deformed

Figure 8. Schematic drawing of the draping test machine.

3.3 The available of formability evaluation index

Maximum shear angle is defined by angle that did not result in defect. Maximum shear angle was measured from the last image that became impossible to analyze by defect. Fig.9 shows maximum shear angle of these specimens by hemisphere punch shape. A significant difference was not seen between the maximum shear angle measured by the hemisphere jig and the maximum shear angle measured by the bias extension test from Fig.7 and Fig.9. Therefore, the maximum shear angle is effective as formability evaluation index.

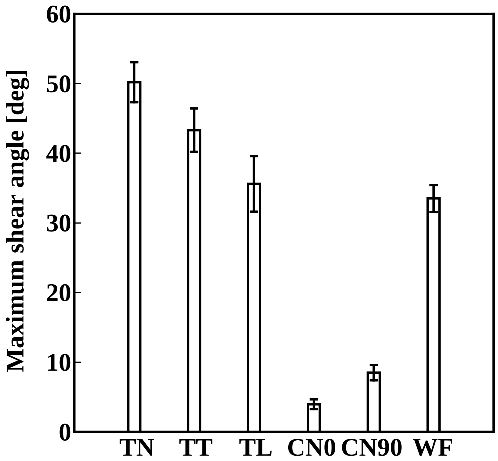


Figure 9. Maximum shear angle of each specimen in 3D shapes.

3.4 Compared to woven fabric

TN (NCF, tricot, normal tension) of the maximum shear angle is larger than WF (woven fabric) from Fig.9. The reasons are as follows. Contact area between each fiber bundle of WF is large. And, the friction between each fiber bundle grows by contact area. In the result, the movement of the fiber bundles is obstructed. Therefore, TN of the maximum shear angle is larger than WF.

4 Conclusions

(1) The tricot stitch NCF with normal tension was highest draping limit shear angle.
(2) In the draping test onto hemisphere geometry, the Tricot stitch NCF has high draping limit shear angle, and availability compared to woven fabric.
(3) The draping limit shear angle of draping formability calculated from the bias extension test is possible to evaluate the formability of the NCF.

References

[1] Ozawa M., Satake H. Development of CFRP Body for LFA. *Jidoushagijyutu,* **Vol. 64**, pp. 52-57,(2009).

[2] Truong T.C., Vettori M., Lomov S., Verpoest I. Carbon composites based on multi-axial multi-ply stitched performs. Part 4: Mechanical properties of composites and damage observation, *Composites: Part A,* **Vol. 36**, pp. 1207-1221, (2005).

[3] Boisse P., Zouari B., Daniel J.L. Importance of in-plane shear rigidity in finite element analysis of woven fabric composite preforming, *Composite: Part A*, **Vol. 37**, pp. 2201-2212, (2006).

[4] Lomov S.V., Barburski M., Stoilova Tz., Verpoest I., Akkerman R., Loendersloot R., Thije R.H.W. Carbon composites based on multi-axial multi-ply stitched performs. Part 3: Biaxial tension, picture frame and compression tests of the preform, *Composites: Part A*, **Vol. 36**, pp. 1188-1206, (2005).

[5] Launay J., Hivet G., Duong A.V., Boisse P. Experimental analysis of the influence of tensions on in plain shear befaviour of woven composite reinforcement, *Composites Science and Tecnology*, **Vol. 68**, pp. 506-515, (2008).

[6] Kong H., Mouritz A.P., Paton R. Tensile extension properties and deformation mechanisms of multiaxtial non-crimp fabrics, *Composite Structure*, **Vol. 66**, pp. 249-259, (2004).

[7] Potluri P., Perez Ciurezu D.A., Ramgulam R.B. Measurement of meso-scale shear deformations for modeling textile composites, *Composites: Part A*, **Vol. 37**, pp. 303-314, (2006).

[8] Creech G., Pickett A.K. Meso-modelling of Non-Crimp Fabrics composites for coupled drape failure analysis, *J Mater Science*, **Vol. 41**, pp. 6725-6736, (2006).

[9] Takano N., Zako M., Fujitsu R., Nishiyabu K. Study on large deformation characteristics of knitted fabric reinforced thermoplastic composites at forming temperature by digital image-based strain measurement technique, *Composites Science and Technology*, **Vol. 64**, pp. 2153-2163, (2004).

[10] Lebrun G., Bureau M.N., Denault J. Evaluation of bias-extension and picture-frame test methods for the measurement of intraply shear properties of PP/glass commingle fabrics *Composites Structures*, **Vol. 61**, pp. 341-352, (2003).