The effect of pick-up point location on fibre angle devation in Non-Crimp Fabrics

de Zeeuw, C.M.; Peeters, D.M.J.; Bergsma, O.K.; Benedictus, R.

Publication date
2022

Document Version
Final published version

Published in
Proceedings of the 20th European Conference on Composite Materials: Composites Meet Sustainability

Citation (APA)
de Zeeuw, C. M., Peeters, D. M. J., Bergsma, O. K., & Benedictus, R. (2022). The effect of pick-up point location on fibre angle devation in Non-Crimp Fabrics. In A. P. Vassilopoulos, & V. Michaud (Eds.), *Proceedings of the 20th European Conference on Composite Materials: Composites Meet Sustainability: Vol 2 – Manufacturing* (pp. 226-233). EPFL Lausanne, Composite Construction Laboratory.

THE EFFECT OF PICK-UP POINT LOCATION ON FIBRE ANGLE DEVIATIONS IN NON-CRIMP FABRICS

Chantal, de Zeeuw [a,c], Daniël, Peeters[b,c], Otto, Bergsma[a], Rinze, Benedictus[a,c]

a: Structural Integrity and Composites Group, Faculty of Aerospace Engineering, Delft University of Technology, Delft, Netherlands – Email address corresponding author: C.M.deZeeuw@tudelft.nl

b: Aerospace Structures and Computational Mechanics, Faculty of Aerospace Engineering, Delft University of Technology, Delft, Netherlands

c: SAM|XL, Delft University of Technology Campus, Delft, Netherlands

Abstract: *The automated handling of non-crimp fabrics using pick-and-place processes will subject the fabrics to forces due to e.g. gravity and movement. These forces can result in undesired fiber angle deviations. The current work looks at predicting and preventing in-plane shear induced fiber angle deviations by studying the positioning of pick-up points. Experimental work shows that the layers of non-crimp fabrics should be expected to deform as individual layers unless they are fixed using an external mechanism. This is to be taken into account when choosing the gripping mechanism for the pick-up points to avoid unexpected behavior. The experimental work is also used for the preliminary validation of a numerical model based on deflections. Results from the current work are a basis for further research on the influence of pick-up point location on the fibre angle deviations in non-crimp fabrics.*

Keywords: Pick-and-place; automation; fabrics/textiles; non-crimp fabrics

1. Introduction

For pick-and-place processes to become widely implemented in industry a consistent product quality needs to be achieved. One important quality criterion is the fiber angle deviations in the reinforcement. Handling a reinforcement will subject it to forces due to e.g. gravity and movement. These forces can result in in-plane shear and subsequently in fiber angle deviations.

In the state of the art the positioning of individual pick-up points is typically either not discussed or is based on the mold where the fabric is to be draped on – not on the effect of the handling on the fabric. In the work where the positioning of pick-up points is studied the positioning is based on the deflection of the fabric or the minimization of strain energy, e.g. [1-4]. These parameters do however not give a clear indication of the influence of pick-up point location on the quality of the reinforcement.

This work is a step towards predicting and preventing in-plane shear induced fiber angle deviations by studying the positioning of pick-up points. Finite Element Simulations validated through experimental work will be used to study the influence of pick-up point location on the in-plane shear strain for a bi-axial Non Crimp Fabric [NCF]. In de Zeeuw et al. [5] tolerances have been set for the fiber angle deviations, additionally the relationship between in-plane shear strain and fiber angle deviations has been demonstrated for the NCF used in the current and

  doi:10.5075/epfl-298799_978-2-9701614-0-0

future work. The results from the current work will be used in future work to validate the results from the simulations.

In de Zeeuw et al. [6] pick-up point strategies for the handling of single and multiple layers of reinforcement are discussed. The current work studies whether an NCF can be considered as a single layer or should be treated as multiple layers when it comes to the selection of gripping mechanisms for pick-up points.

This paper presents the initial steps taken to study the effect of pick-up point location on plane shear induced fiber angle deviations in non-crimp fabrics. First, Section 2 presents the materials that are used. This is followed by the experimental and numerical methods in Section 3. The results are presented in Section 4 and discussed in Section 5. Finally, the conclusions are presented in Section 6.

2. Materials

The current work uses an E-glass based Biaxial $\pm 45^o$ NCF with a chain stitch pattern produced by R&G Faserverbundwerkstoffe GmbH. The choice for a chain-stitch type NCF is based on a chain stitch giving a high form stability, making the fabric appropriate for automated handling [3]. The NCF has stabilizing tows in the 0 and 90 direction. Table 1 presents the details for the NCF selected for the present work.

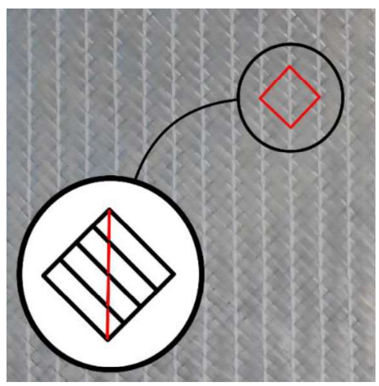

Figure 1. Stitch pattern of NCF

Table 1: Specifications of selected fabric as provided by manufacturer

Fabric type:	Biaxial $\pm 45^o$ NCF
Weight:	430 g/m^2
Fibres:	100% E-glass (300 tex)
Stitch:	Chain stitch
Finishing:	Silane treated

Table 2 presents the homogenized elastic properties that have been determined in de Zeeuw et al. [5] for the bi-axial NCF used in this work.

Table 2: Homogenized elastic properties as determined in de Zeeuw et al. [5]

E_{11} [MPa]	E_{22} [MPa]	E_{33} [MPa]	μ_{12} [-]	μ_{13} [-]	μ_{23} [-]	G_{12} [MPa]	G_{13} [MPa]	G_{23} [MPa]
196	196	0.16	0.5	0.5	0.5	2.39	0.24	0.24

3. Methods

During the experiments $\pm 45^o$ specimens of 300 x 300 mm and 550 x 550 mm are subjected to gravity while being suspended from a fixed pick-up point in each corner that's attached to a frame. Figure 2 shows one of these tests.

Figure 2. Frame with a 550 x 550 mm reinforcement suspended from the pick-up points

The in-plane positioning of the pick-up points is accurate op to 0.5 mm. The pick-up points with a diameter of 46 mm are attached to the reinforcements using double sided tape. From the moment the NCF is delivered on a roll to when the reinforcements are attached to the frame care is taken that they are always fully supported to avoid any preliminary in-plane shear or other deformations. Once the specimens are suspended from the frame the deflection is obtained through 3D scanning using a FARO 3D scanner.

Two different configurations are used for the specimens. This is done to determine whether an NCF can be treated as a single layer reinforcement or should be treated as multiple layers when selecting gripping strategies. In the first series the specimens are tested as is. For the second series a round piece of foil is adhered to the bottom side of the specimens at the location of the pick-up points using an silane modified polymer based adhesive. Care is taken that the adhesive fully penetrates the fabric to ensure the two layers of the NCF are fixed together.

Specimen dimensions are chosen with a pick-up point diameter of 50 mm in mind. For the 300 x 300 mm specimens this would result in a distance between the centers of two pick-up points of 250 mm. For the 550 x 550 mm specimens this distance would be twice as large, 500 mm. The 50 mm knobs that were ordered for the current work did however turn out to be 46 mm.

The numerical models are created using Abaqus/CAE 2021. The reinforcement is modeled as a shell using S4R elements with the material properties as defined in Table 2. A gravity load of 9.81 m/s^2 is applied. Figure 3 shows the partitions used for the current work. The lines across the diagonal are used to obtain the simulated deflection. This is later compared to the experimental work for an initial validation step based on deformation. The partitions for the pick-up points are used to apply the translational and rotational displacement boundary conditions observed for the pick-up points during the experiments. To facilitate modeling of the rotation of the pick-up point the material for these areas is modeled as a very rigid material instead of the properties presented in Table 2.

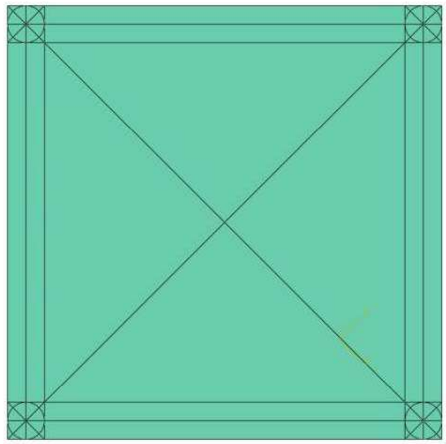

Figure 3. Partitions for the 550 x 550 mm numerical model

4. Results

Figure 4 shows a color map of the obtained point cloud for one of the 550 x 550 mm specimens from the first series. This first series did not include the adhesive gluing the layers together at the corners. The deflection pattern is not the one typically observed for $\pm 45^o$. In this figure the tows of the top layer lay in the direction indicated with a solid line. The tows of the bottom layer lay in the direction indicated with a dashed line.

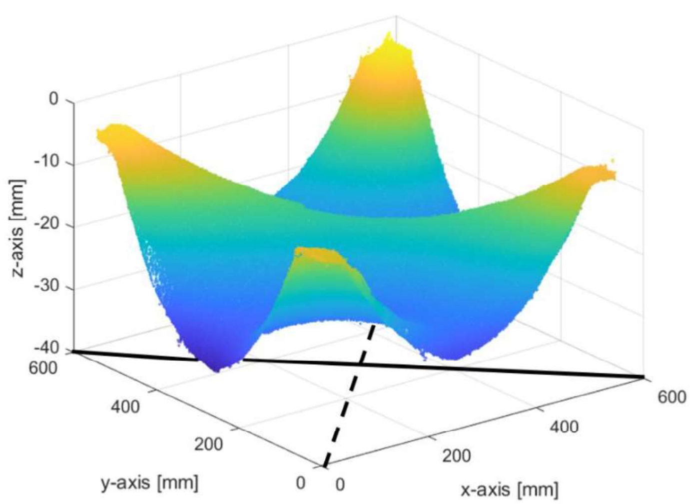

Figure 4. Point cloud with color map for one of the specimens from series 1.

Figure 5 shows the deformation result for one of the 550 x 550 mm specimens from the second series. The second series did include the adhesive gluing the layers together at the corners. For these specimens the deflection pattern is as expected for a $\pm 45^o$ fabric. These specimens show a smaller deflection than the specimens without adhesive applied at the corners.

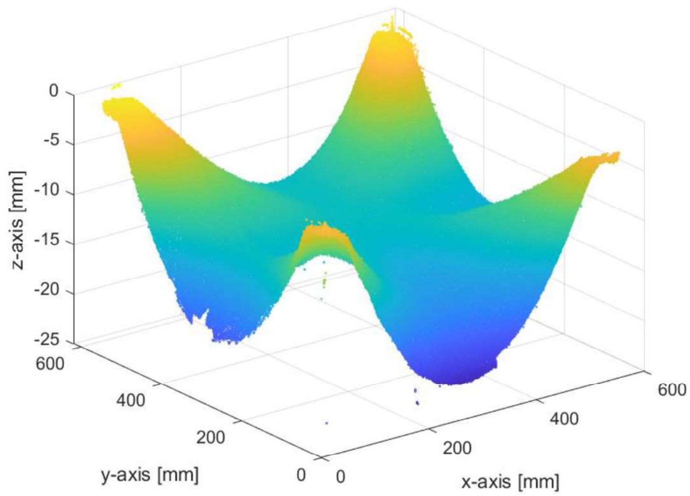

Figure 5. Point cloud with color map for one of the specimens for series 2.

The results show that the method chosen to grip the reinforcement is important for the behavior during handling. For the first series as shown in Figure 4 the double sided tape results in a firm connection between the pick-up point and the upper layer of the reinforcement. Within the NCF the two layers are held together by the stitches. The bottom layer is free to slide, the stitches do not prevent movement along the tows. With the tows of the bottom layer not being fixed they are unable to resist the gravity load and slide, resulting in the pattern as seen in Figure 4.

An initial validation step is done using the deformation results from the series 2 experiments. This is done by comparing the deflections along the diagonal of the numerical and experimental results. Figure 6 and 7 show this comparison for respectively the 300 x 300 mm specimens and the 550 x 500 mm specimens. The experimental results showed that there were small off-sets in the y-direction for the different pick-up points. These off-sets have been included in the numerical models.

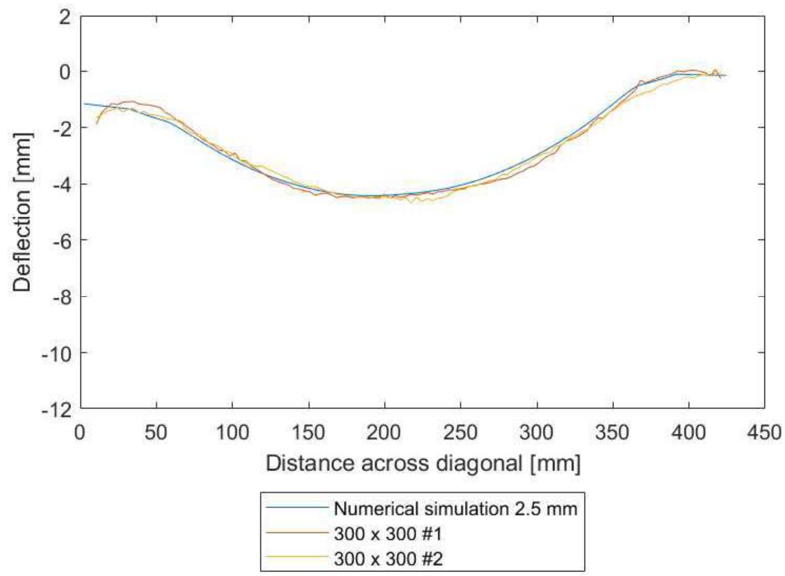

Figure 6. Comparison between numerical and experimental results for dimensions of 300x300

The results show that the numerical model is better able to predict the behavior of the 300 x 300 mm specimens than for the 550 x 550 mm specimens. For the 300 x 300 mm specimens the numerical results lay within 8% from the mean experimental results. For the 550 x 550 mm specimens this is 18.5%. The numerical model is shown to overestimate the deflection.

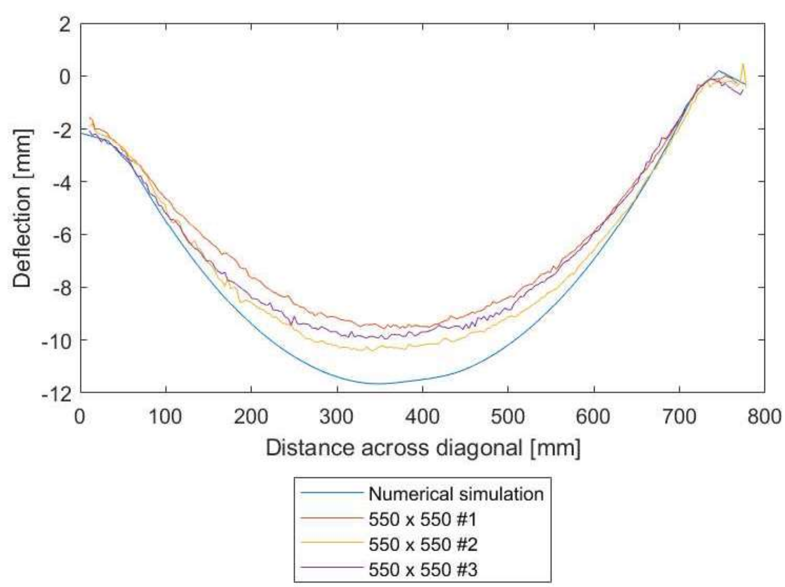

Figure 7. Comparison between numerical and experimental results for dimensions of 550x550

The actual values of interest for the current work are not the displacements but the in-plane shear strains. These in-plane shear strains are directly related to the fiber angle deviations.

Figure 8 shows the simulated in-plane shear strains for a 550 x 550 mm specimen. For the in-plane shear strains the regions closer to the pick-up points are of interest while for deflections the maximum values will be roughly in the center of the reinforcement.

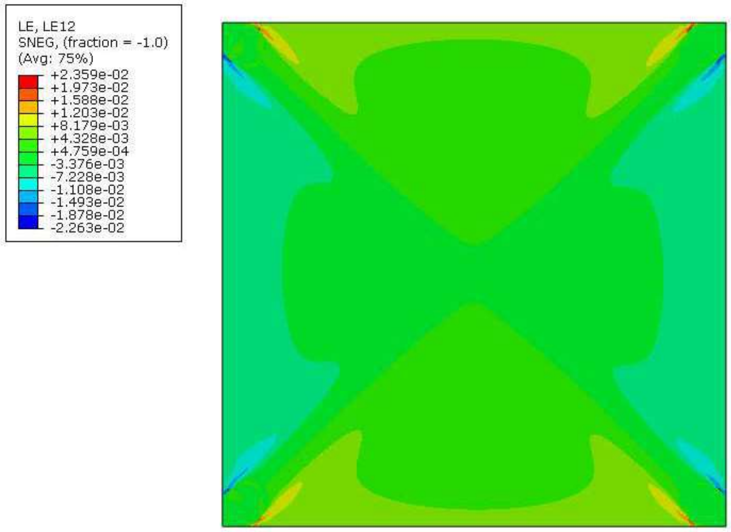

Figure 8. Simulated in-plane shear strains for 550 x 550 mm non-crimp fabric reinforcement

5. Discussion

The current work shows that when handling a dry non-crimp fabric it is important that both layers are supported and that the stitches should not solely be relied on to ensure the bottom layer stays in place. When handling multiple layers of reinforcement needle grippers are the only gripping technology discussed in Zeeuw et al. [6] that can reliably pick up all layers. The bi-axial NCF of the current work consists of only two layers, still gripping technologies will need to be evaluated before they are implemented to ensure all layers are gripped.

The FEM model assumes that the two layers of the NCF cannot act independently. It can therefore not predict the behavior observed for the first series of experiments. An initial validation based on the displacement measured has been performed. The results show that the model is able to give a reasonable prediction for the deflections along the diagonal. The simulated result is more accurate for the 300 x 300 mm specimens than for the 550 x 550 mm specimens. For practical reasons it is more desirable for the simulations to overestimate the deflections than to underestimate them. When designing the pick-and-place process an overestimate in the deflections will ensure there is always enough clearance between reinforcements and other surfaces.

It is suggested that the differences between experimental and numerical results are a side effect of the way the material is modeled. The numerical model does not consider the individual tows and stitches but uses homogenized elastic properties. A biaxial NCF has a variety of mesoscopic fabric deformation mechanisms [8]. A representative volume element [RVE] is used to obtain homogenized elastic properties based on displacements in the 1, 2 and 3 directions. The deformation mechanisms that occur when a reinforcement is picked up at four corners will however be more complex than those that occur in the RVE.

The area of interest of the work is not the deflection of the reinforcements during handling but the in-plane shear strains and the fiber angle deviations. The deflections give an indication of the ability of the model to predict the behavior of the reinforcement. However, the deflections are not necessarily directly linked to the in-plane shear strains. A small difference in the in-plane shear strains near the pick-up points could for example result in a significantly larger deflection in the middle of the fabric. The model will need to be validated based on in-plane shear strains in future.

6. Conclusions

The current work presents the initial steps taken to study the influence of pick-up point positioning on in-plane shear induced fiber angle deviations. The experimental work found that for dry NCFs it cannot be assumed that the whole NCF will behave as a homogeneous material during handling. The results show that if a gripping technology is used that just grips the top layer, the bottom layer will be free to slide. To ensure predictable handling, gripping technologies will need to be chosen such that all layers are fixed.

The experimental results are used to take a preliminary look at the ability of the numerical model to simulate the behavior of bi-axial NCFs under gravity loading. The simulation is shown to give reasonable predictions for the deflections along the diagonal. The validation strategy used in the current work is however not the most appropriate one for validating the model. Further validation will be carried out based on in-plane shear strains.

7. References

1. Lankalapalli S, Eischen JW. Optimal pick-up locations for transport and handling of limp materials: Part I: One-dimensional strips. Textile Research Journal 2003; 787-796
2. Ragunathan S, Karunamoorthy L. Genetic algorithm-based optimal locations for handling fabric materials in garment automation. International Journal of Robotics and Automation 2006; 288:294
3. Lankalapalli S, Eischen JW. Optimal pick-up locations for transport and handling of limp materials: Part II: Two-dimensional parts. Textile Research Journal 2003; 867-874
4. Ballier FJ. Systematic gripper arrangement for a handling device in lightweight production processes. PhD Thesis 2019;
5. de Zeeuw CM, Peeters DMJ, Bergsma OK, Benedictus R. Setting bounds for in-plane shear induced fiber angle deviations in bi-axial non-crimp fabrics. Under review/Unpublished 2022; -:-
6. de Zeeuw CM, Peeters DMJ, Bergsma OK, Benedictus R. Strategies for swift automated pick-and-place operations of multiple large-sized layers of reinforcement-a critical review. Advanced Manufacturing: Polymer & Composites Science 2020; 57:71
7. Krieger H, Gries T, Stapleton SE. Design of tailored non-crimp fabrics based on stitching geometry. Applied Composite Materials 2018; 113:127
8. Creech G, Pickett AK. Meso-modeling of non-crimp fabric composites for coupled drape and failure analysis. Journal of material science 2006; 6725:2736