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ASSESSING THE MULTIAXIAL DEFORMATION RESPONSE OF UNIDIRECTIONAL NON-CRIMP FABRICS

M. Ghazimoradi[1]*, V. Carvelli[2], and J. Montesano[1]
[1] Composites Research Group, Department of Mechanical & Mechatronics Engineering, University of Waterloo, 200 University Ave. West, Waterloo N2L 3G1, Canada
[2] Department A.B.C., Politecnico di Milano, Piazza Leonardo Da Vinci 32, 20133 Milan, Italy

* Corresponding author (Mehdi.ghazimoradi@uwaterloo.ca)

ABSTRACT

In this study, the mixed-mode deformation response of a unidirectional non-crimp fabric (UD-NCF) was investigated. Multiaxial in-plane shear-biaxial tension tests were performed using a new multi-branched fabric specimen on a custom multi-axial loading device. Tests were performed with various ratios of deformation along three loading directions to impose combined tension and shear deformation on the fabric specimens. The different loading cases revealed a strong inter-dependency between shear and tensile deformation modes. Observation and measurement of local deformations provided important quantitative and qualitative information to deeply understand the interaction of typical meso- and macro-scale deformations, which can be leveraged during the forming process of liquid composite molded components to reduce shear-induced defects such as wrinkling.

INTRODUCTION

During the last decade, unidirectional non crimp fabrics (UD-NCFs) with unique tow and stitching architectures have been developed and used as reinforcements in high-performance composite materials fabricated by liquid composite molding processes. UD-NCFs have been widely applied in various industries such as aeronautic, automotive and wind energy due to their good drapability characteristics and ease of handling during processing. However, compared to other engineering fabrics, the deformation and formability characteristics of UD-NCFs have not been extensively investigated (see e.g. [1–3]).

As indicated in reported literature [4–11], many attempts have been made to investigate in-plane shear deformation of composite textile reinforcements, whereas limited studies have focused on characterizing shear-tension coupling experimentally [12,13]. Early investigations involved pre-tensioning the fabric specimens prior to placement in a picture frame rig using biaxial pre-tensioning devices [14]. Also, the shear pre-tension coupling properties of technical fabrics have been studied using picture frame testing devices to explore the influence of blank holder and clamping systems on wrinkling, and these studies indicated significant increases in shear stiffness with increasing pre-tension [15–18].

Characterizing the mixed-mode deformation of fabrics under controlled conditions can provide valuable insight on the mechanisms that influence the formation of defects during draping. Since shear and biaxial tension are the main deformation modes during fabric preforming processes, the goal of this experimental study was to propose a new specimen geometry to characterize the multiaxial deformation response, but not limited to, of a heavy-tow stitch bonded carbon fiber UD-NCF.

MATERIAL FEATURES

The UD-NCF assessed in this experimental investigation was PX35-UD300 (Zoltek Corp.). The heavy tow fabric was composed of aligned tows with 50K carbon fiber (CF) filaments and transversely oriented glass fiber (GF) yarns (34 dtex) placed approximately 3.5 mm apart below the CF tows.

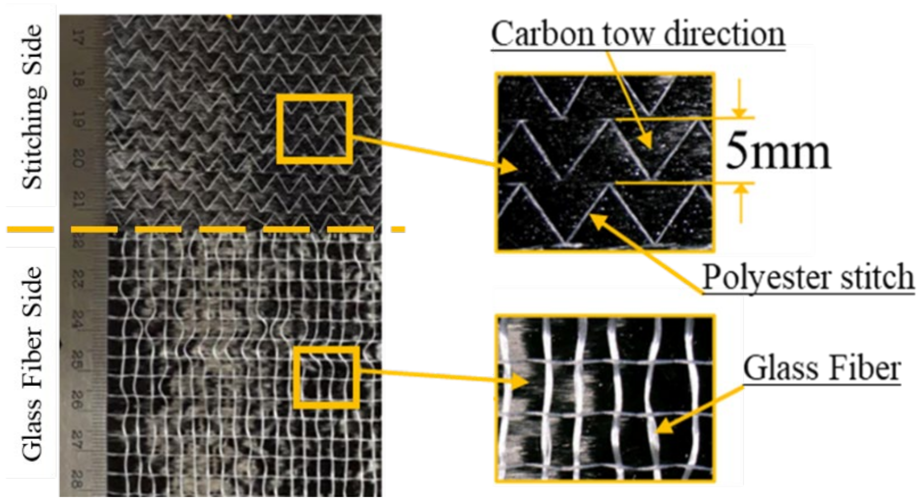
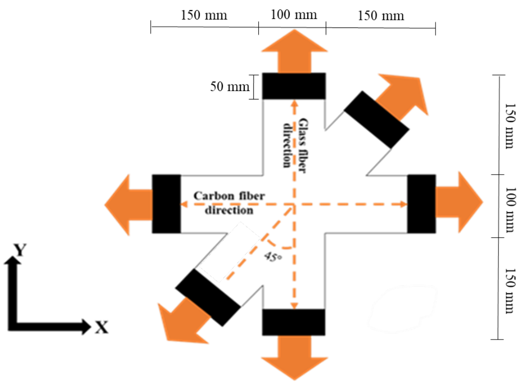


Figure 1. Images of Zoltek™ PX35-UD300 unidirectional non-crimp fabric.

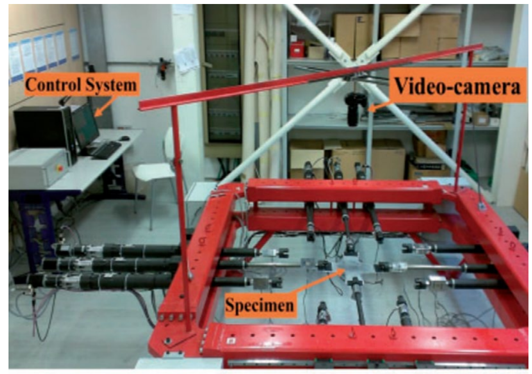
The CF tows and GF yarns were stitched together with a light polyester thread (76 dtex) using a tricot pattern along the CF tow direction (Figure 1). The total areal weight of the UD-NCF was 333 g/m^2.

EXPERIMENTAL TEST SETUP

Multiaxial in-plane shear-biaxial tension tests were performed at room temperature on multi-branched fabric specimens (Figure 2a) using a custom loading device equipped with 12 independent jacks (Figure 2b). The maximum displacement rate and stroke of the device were 240 mm/min and 512 mm respectively, with a displacement accuracy of 0.05 mm. Each jack comprised a load cell with a maximum capacity of 15 kN. Displacements were applied along the two orthogonal and diagonal directions of the branched specimen (Figure 2a). Digital image correlation (DIC) was used to measure the full field in-plane deformation of a 50 mm × 50 mm region at the specimen center. The oil-based paint technique detailed in [19] was used to speckle the specimen surface, with no decorrelation issues observe. Also, Vic 2D software was employed for full field displacement measurement using a step size of 5–11 pixels, a subset size of 31–55 pixels and strain filter size of 9.



(a)

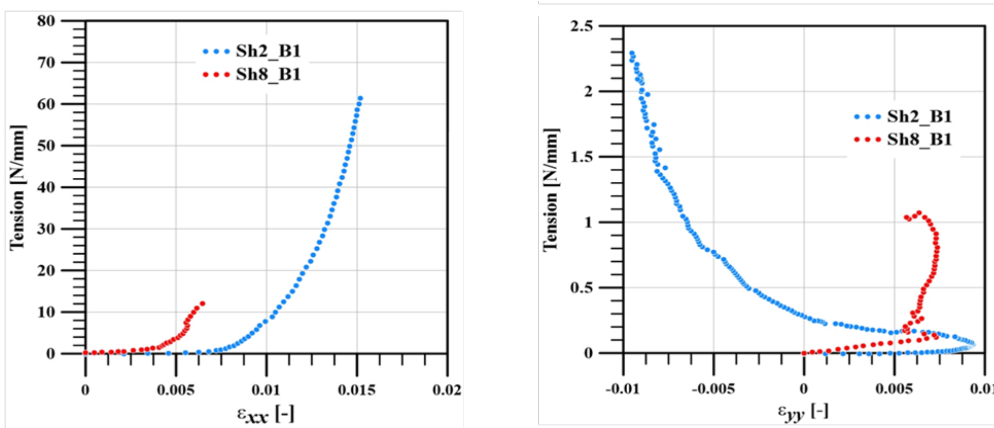


(b)

Figure 2. (a) Schematic of multiaxial test specimens: displacement along the longitudinal (CF), transverse (GF) and diagonal directions; (b) loading device

EXPERIMENTAL RESULTS AND DISCUSSION

The tests were performed with various ratios of deformation along the three loading directions. One set of tests consisted of subjecting the test specimens to an equi-biaxial displacement rate of 1 mm/min along the CF tow and GF yarn directions and a constant displacement rate of 2 mm/min along the diagonal direction (Sh2_B1). The second set of combined shear-biaxial tension tests were similar to the first, except that the displacement rate along the diagonal was 8 mm/min (Sh8_B1). The load-strain response along the CF tow direction for representative Sh2_B1 and Sh8_B1 specimens revealed that the compliance of the specimen significantly decreased with increase of the diagonal deformation (Figure 3a), which reveals a strong inter-dependency between shear and tensile deformation modes. It is consequence ofthe notable contraction (Poisson's effect) in lower diagonal displacement rate (Sh2_B1), which was not observed for higher diagonal rate having tensile transverse to carbon direction strain (ε_{yy} in Figure 3b). Therefore, the shear behavior of the fabric is highly dependent on the biaxial traction, which reduces the shear deformation, namely the initiation of the defects as wrinkles. This implies that deeply understand the multiaxial loading interaction at meso- and macro-scale can mitigate shear-induced defects such as wrinkling during the forming process of liquid composite molded components.



(a) (b)

Figure 3. Shear-biaxial tension test tension vs. strain response for specimens Sh2_B1 and Sh8_B1 along the: (a) CF tow (ε_{xx}), and (b) GF yarn (ε_{yy}).

CONCLUSIONS

The proposed mixed-mode loading conditions on a new multi-branched fabric test specimen enabled the characterization of the mechanical response of a heavy tow unidirectional non-crimp fabric (UD-NCF) under combined shear and tension deformation modes that are typical of preforming process. Two different loading conditions were considered for the study, including biaxial tension with distinct shear rate deformations. The tensile load-strain responses along the fabric carbon fiber tow and transverse directions revealed that the specimen compliance notably decreased with an increase in the shear deformation, which reveals a strong inter-dependency between shear and tensile deformation modes for the UD-NCF. This implies that deeply understand the yarns interaction at meso- and macro-scale for multiaxial deformations can mitigate shear-induced defects such as wrinkling during the forming process of liquid composite molded components. The subsequent stage of the study focuses on additional experiments to further observe the associated local deformation mechanisms for mixed-mode loading conditions and to extend the knowledge to other textile reinforcements.

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