

Characterising the In-plane Deformation Behaviour of a Unidirectional Non-Crimp Glass Fabric

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Abstract. The in-plane deformation behaviour of a unidirectional non-crimp fabric (UD-NCF) consisting of polyamide stitches with a tricot-chain stitching pattern is investigated. The UD-NCF allows for stitch extension under specific loading conditions as the fabric only comprises polyamide stitches and no other stabilising fibre in the transverse direction to the glass tows (pure UD-NCF). The stitch extension introduces a low-energy deformation mode to the UD-NCF that is not present in biaxial fabrics or 'quasi' UD-NCF that contain a small fibre volume fraction of stabilising fibres in the transverse or 'stitch' direction. Several novel tests are introduced to characterise this complex forming behaviour. These methods generate well-defined in-plane deformation kinematics with various shear and tensile strain combinations. This research provides a method to characterise the deformation behaviour of a UD-NCF, which can subsequently be utilised to develop appropriate material constitutive models.

Introduction

When compared to biaxial textiles, the in-plane deformation behaviour of UD-NCFs is influenced by both shearing of fibres and tensile stretching along the stitch direction. 'Quasi' UD-NCFs [1] investigated in early studies [1,2,3,4,5,6,7] incorporate thin glass fibre tows orientated initially transversely to the main fibre direction. They are included to improve stability of the fabric during forming and are typically made of much higher modulus fibres than the stitches, and therefore effectively mitigate tensile strain in the stitch direction. The incorporation of stabilising tows decreases the level of intra-ply slip between the tows and prevents spreading of the tows in the transverse direction during forming, a mode of deformation that can lead to defects such as the opening of gaps between tows, which can ultimately affect the mechanical behaviour of the final composite [2]. Nevertheless, the absence of stabilising fibres in the transverse direction provides an additional low-energy deformation mode, potentially making pure UD-NCFs more formable than quasi-UD NCFs. While the forming behaviour of both biaxial engineering textiles and quasi-UD-NCFs are well studied, there is less research on the forming behaviour of pure UD-NCFs that don't include stabilising tows. This study focuses on the combined in-plane shear and tensile deformation in pure UD-NCFs.

Results and Conclusions

The in-plane shear behaviour of fabrics is usually investigated by the Picture Frame test (PF-Fig.1a) & the Uniaxial Bias Extension test (UBE-Fig.1b). In this study, a modified version of the UBE test [8] was used which includes bonding aluminium foil on the top and bottom regions with epoxy resin to keep these regions undeformed and to mitigate intra-ply slip. The pure UD-NCF considered in this study was initially subject to both shear tests. The PF test produced significantly higher shear stiffness than the UBE test. It is postulated that the different results of the two tests could be due to (a) experimental error (due to specimen misalignment in the PF rig and the rigid clamping condition) or (b) a true change in the fabric's forming behaviour between the two tests due to the stitch extension. Two different modifications to the standard PF test are proposed i.e., pre-displaced PF rig test and PF tests with less severe boundary clamping conditions, to explore option (a). The pre-displaced method is a technique for reducing the sensitivity of the PF test to sample misalignment. In this method, compressive stress is intentionally induced in the fiber directions of the sample during testing (two different pre-displacements: 4mm and 6mm were used). In a second type of modification, stiff bolting of the specimen was replaced with G-clamps with two distinct tightening pressures (low and high - the torque is 1Nm and 5Nm, respectively) to investigate the effect of the clamping condition on the shear force.

Another possible explanation for the difference in results between the standard PF and UBE tests is that stitch elongation during the UBE test reduces the shear resistance of the fabric, which is not experienced during the PF test. In [4] it was also shown that this stretching of the fabric in the stitch direction decreases the shear resistance of the fabric. The new tests with an octagon-shaped specimen (Fig.1c) and simple shear specimens (Fig.1d) are intended to produce well-defined kinematics with different combinations of shear and stitch strain. Fig.1 shows a comparison of undeformed and deformed shear specimens at 15° shear angle and tensile test specimen. In comparison to standard UBE specimen (Fig. 1b&g), the octagon-shaped specimen with 2Al sheets (Fig. 1c&h) shows a homogenous deformation with a maximum of 15° shear angle due to the low initial angle between the stitches and axial force (45°). A novel simple shear test (Fig. 1d&i) was designed to enhance the amount of stitch strain with uniform deformation of the sample by increasing the initial angle between stitches and axial force to 90°. The tensile test (Fig. 1e&j) was performed on the UD-NCF in the stitch direction

to determine the force required for stitch stretching, assuming that the tensile force is unaffected by fabric shear and boundary conditions of the specimen.

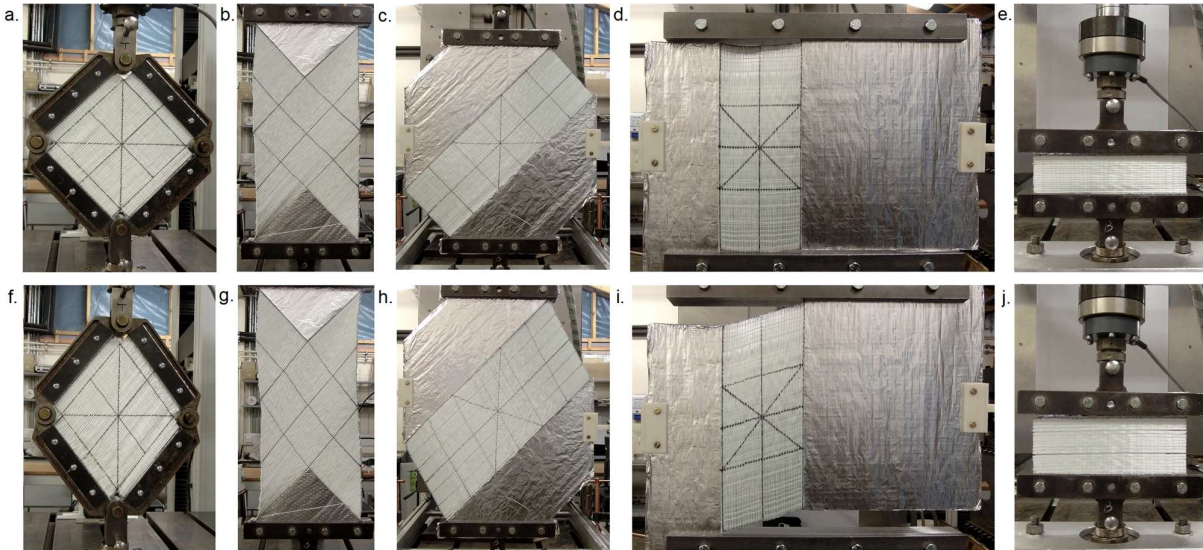


Fig. 1 Undeformed and deformed specimens (a)&(f) Standard PF test (b)&(g) Standard UBE test (c)&(h) Octagonal-shaped UBE specimen glued with 2AI sheets (d)&(i) Simple shear test (d)&(j) Tensile test

All modified PF tests show lower normalized shear force data when compared to the standard PF test result. Both the G-clamp combined curve (high and low tightening pressures) and the 6mm pre-displaced curve exhibit approximately the same normalized force, which is significantly less than the standard PF test. However, the normalized force obtained in the standard UBE test is still lower for the UD-NCF at low shear angles, possibly because the standard UBE specimens are subjected to stitch tensile strain due to the less limiting boundary conditions. When compared to the standard UBE test, 2AI octagonal-shaped UBE and the simple shear tests show an increase in normalized axial force at high shear angles due to the constrained ends of the stitches (Fig. 2a). Unlike PF tests, all the other test specimens experience stitch stretching because only two of the four sides of the specimen are clamped. Therefore, the total axial force of each test is a combination of the force required to shear the fabric and to stretch the stitching. The combined data are plotted in a three-dimensional space of axial force, shear angle and tensile strain in the stitch direction (red surface in Fig. 2b). The multicolored surface shown in Fig. 2b represents a polynomial surface fitted to the experimental shear data. We propose decoupling the combined axial force signal into shear and stitch tensile contributions (see Fig. 2c). The results provide data for creating material constitutive models for forming simulations.

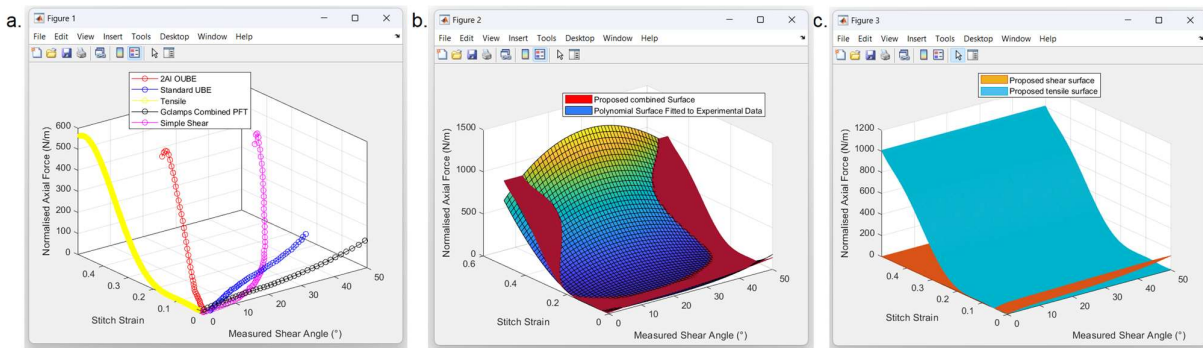


Fig. 2 – (a) 3D plot of shear and tensile results (b) Comparison of experimental and proposed combined surfaces (c) Proposed two distinct surfaces for shear and tensile

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