BIAXIAL SHEAR TESTING OF TEXTILE PREFORMS FOR FORMABILITY ANALYSIS

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Abstract

An improved method of testing the in-plane shear behaviour of textile preforms has been presented. The biaxial shear test overcomes the limitations of picture frame and bias extension tests, in addition to being able to measure the hysteresis. This test can be conducted on a tensile test machine with the aid of a special attachment for applying the transverse loads. Three fabrics, plain woven glass, plain woven carbon and stitched carbon fabrics have been tested up to the shear limit. Bending stiffness and hysteresis values have been compared with the results obtained from Kawabata shear tester in the low-stress region (±8°).

1 Introduction

Biaxial woven and stitched non-crimp fabrics are commonly used for producing composite parts with intricate features of double-curvature. The ability of a fabric to conform to a double-curvature surface depends mainly on the in-plane shear behaviour; fabric compliance along the thread line plays an important but less significant role. Hand draping may be simulated with simple geometric algorithms [1], and these algorithms use the geometric shear limit of the material as the only material input. Mechanical forming methods require more elaborate simulation techniques [2] and a complete shear stress-strain curve as a material constitutive model.

Current methods of shear testing, picture frame [3] and bias extension [4] methods have limitations. Picture frame test suffers from alignment and clamping problems, in addition to fabric wrinkling. Elaborate sample preparation is required in order to minimise the non-uniform shear regions near the picture frame. Bias extension test is simple to perform however suffers from a number of limitations: non-uniform shear distribution, inter-tow slippage before the lock limit is reached and change in the dimensions of different regions. In this paper, a biaxial shear test method is reported that combines the advantages of the picture frame and bias extension methods.

2 Bias extension tests

Bias extension tests are relatively easy to conduct on tensile test machines and do not require elaborate sample preparation. As a result, these tests are of practical relevance to the composites industry for routine testing.

2.1 Conventional bias extension test

Bias extension test, as shown in figure 1, is relatively simple to perform. A rectangular sample is cut at bias (45°) direction and subjected to a load-elongation test. It can be seen from figure 1 that the fixed or non-shear region near the clamps does not remain constant but reduces during the test (due to tow slippage). As a result, the shear angle cannot be accurately calculated from the cross-head displacement – a camera is used to grab the images from the pure shear region ‘A’ and analyzed for shear angles at each crosshead displacement . This is a slow and time-consuming process as the images have to be analysed frame by frame. In addition, fabric sample fails before the shear lock limit is reached as a result of inter-tow slippage. However, this type of failure does not happen during actual draping, as the fabric is usually wider than the area subjected to shear. It has also been observed that the sample frays near the edges and hence the width is not repeatable for each test. In this work, fabric samples wider than the clamps have been tested. Wider samples minimise inter-tow slippage, and as a result the sample fails at a much higher load. In addition, the shear angles can be computed from crosshead displacements up to much higher shear angles.

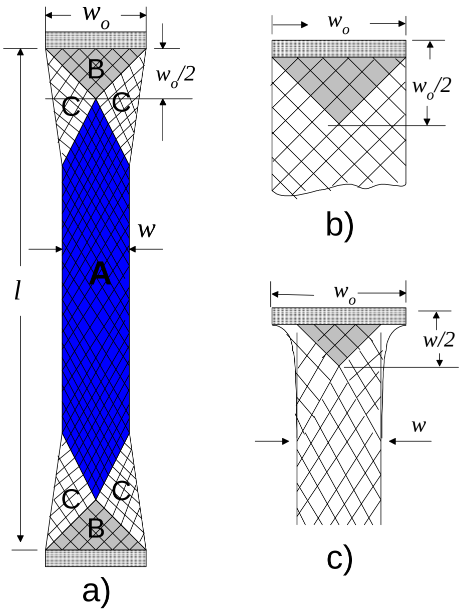


Fig.1 a) Bias extension test b) fixed region (B) before the test c) size of region B during the test

2.2 Wide strip bias extension test

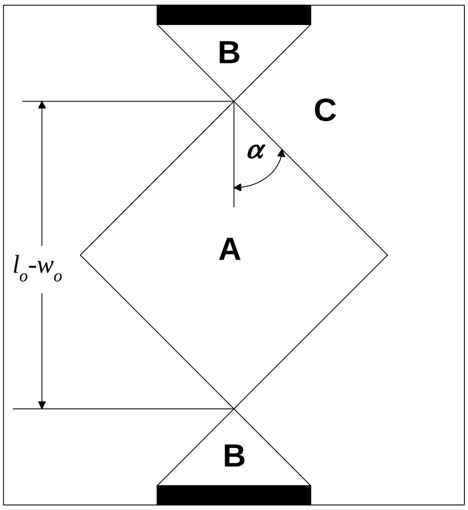


Fig.2 wide-strip test

Figure 2 shows the bias extension tests conducted on wide samples. Here, the pure shear region is a complete rhombus, and hence closer to a picture frame method. The tow slippage is significantly reduced due to the fact that each yarn has many more interlacements. In addition, the size of the region 'B' does not significantly change during the test up to very high loads. As a result, it has been possible to compute shear angles from the crosshead displacement. Computed shear angles are in good agreement with the values measured using a camera up to 50° of shear angle (figure 3). However, wide-strip bias extension test suffers from wrinkling (narrow strip would have experienced tow slippage). Additional limitation with the bias extension test is that hysteresis effects cannot be measured.

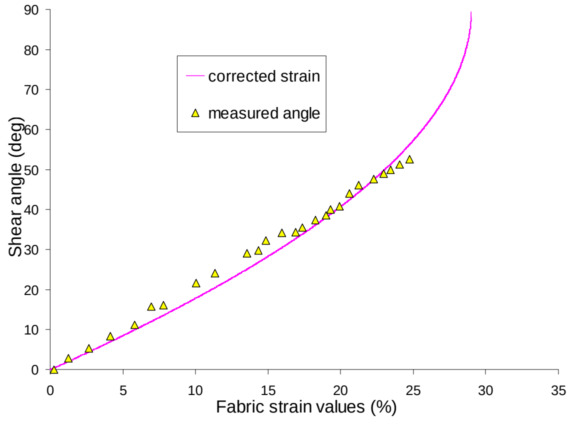


Fig.3 Computed versus measured shear angles

2.3 Biaxial shear test

Biaxial shear test is a modification to the wide strip bias extension test by incorporating a transverse load (figure 4). Ignoring the mixed shear region, the deformation of the pure shear region looks similar to that of picture frame test. Complete hysteresis tests can be conducted without the complications of having to align (the picture frame) with the yarns.

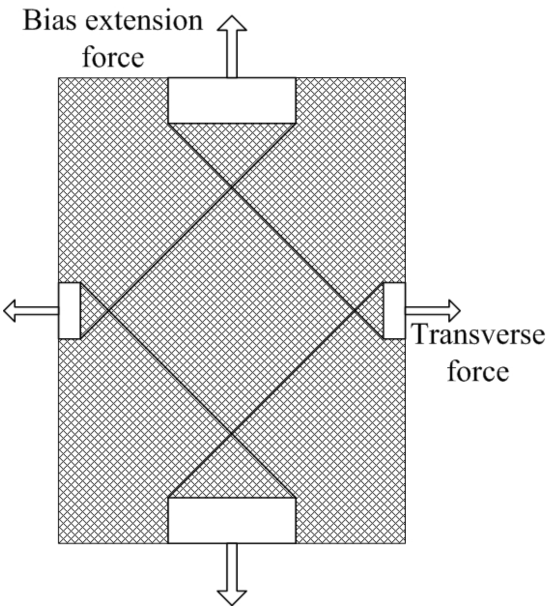


Fig. 4 Biaxial shear test scheme

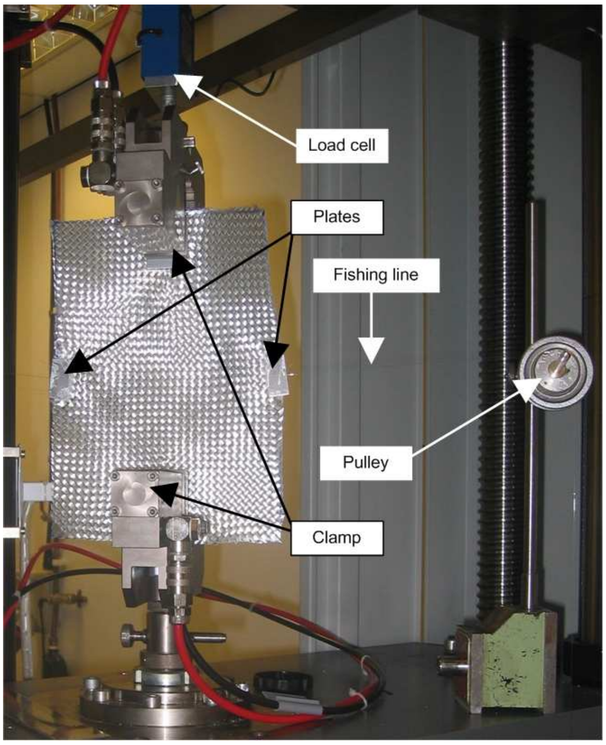


Fig. 5 Transverse loading arrangement

Fabric sample is clamped between 6 cm wide jaws in the loading direction. Two small clamps are mounted in the transverse direction. Transverse loads are applied with the aid of dead weights attached to the fabric with monofilament nylon strings over pulleys (figure.5); the transverse load is constant during the test. However, in a biaxial test machine, transverse loads can be gradually increased.

3 Experimental work

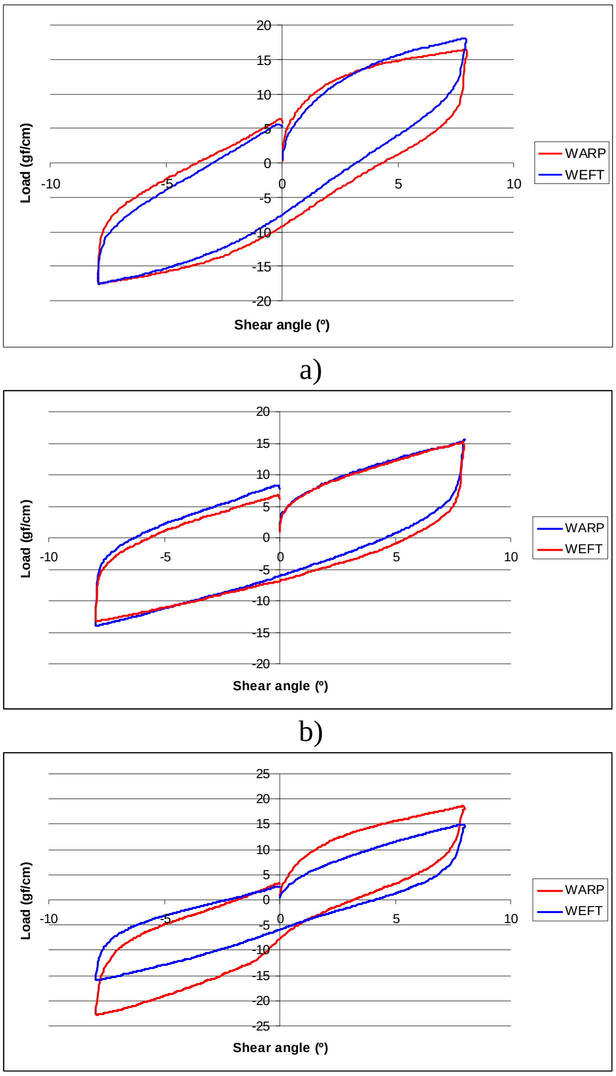
Table 1. Specification of the fabrics

	WVG	WVC	BASC
Fabric style	Plain	Plain	Biaxial stitch
Area density [g/m^2]	740	518	536
Yarn spec	1200 Tex	12k	12k
End/cm	2.8	3.2	3.3
Pick/cm	2.8	3.2	3.3

Three fabrics have been used for experimental work, plain woven glass, plain woven carbon and stitched carbon fabrics (table 1). The two carbon fabrics have similar area densities. A heavier glass fabric has been selected to account for the higher density of glass in comparison to carbon.

3.1 Kawabata shear tests

Kawabata shear tester applies a small tension to the fabric while conducting a trellis like shear deformation. Because of this tension, it is possible to measure the shear hysteresis as shown in figure 6. However, the main limitation is that Kawabata shear tester is designed to conduct up to 8^o of shear angle, where as the textile preforms can deform up to 50-60^o.



a)

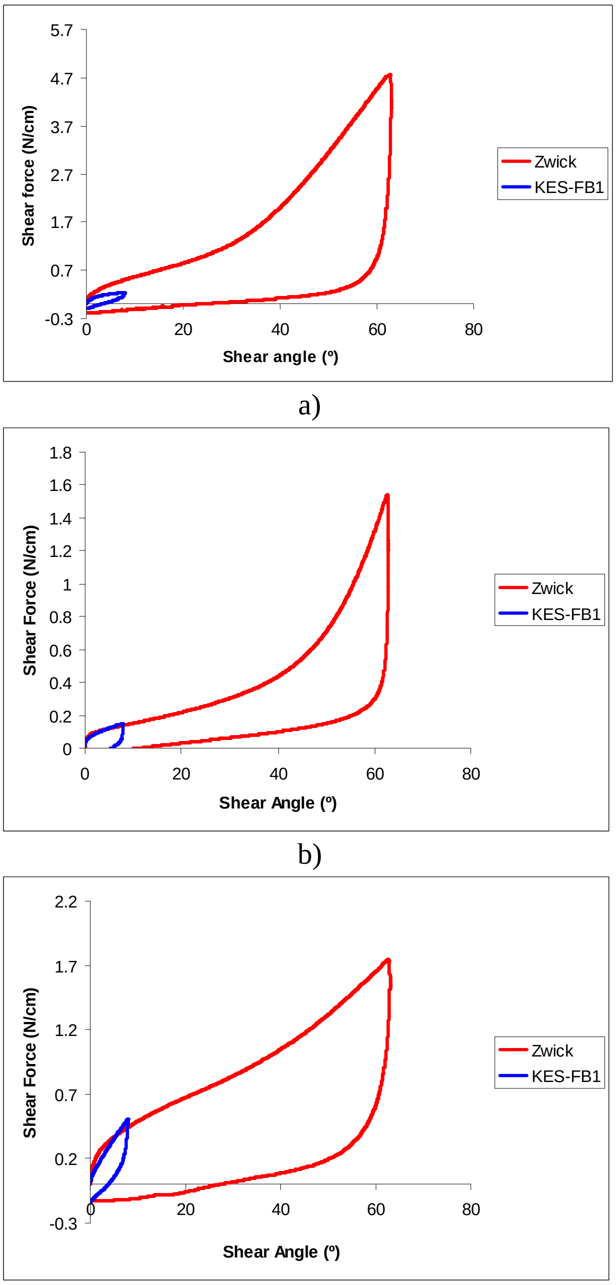
b)

c)

Fig.6. Kawabata shear test curves for a) woven glass b) woven carbon and c)stitched carbon fabrics

3.2 Biaxial shear tests

Biaxial shear tests have been conducted on all three fabrics using the experimental setup shown in figure 5. A 200cN side load has been applied on each side. The load-elongation data has been recorded for the forward and the reverse strokes. Shear force (per unit width) and shear angles are computed for each cross-head position [5]. Shear force vs shear angles are plotted for all there fabrics as show in figure 7.



a)

b)

c)

Fig.7. Biaxial shear test curves for a) woven glass b) woven carbon c) stitched carbon fabrics

The shear stress-strains curves obtained from the biaxial tests are compared with the Kawabata shear curves as shown in figure 7. Shear stiffness (G), Shear hysteresis (2HG, 2HG5) values at 0.5^{o} and 5^{o} of shear angle are compared (table 2).

Table 2: Comparison with Kawabata shear tests

Fabric	**G (cN/cm*deg)**		**2HG (cN/cm)**		**2HG5 (cN/cm)**	
	KES	**biaxial**	**KES**	**biaxial**	**KES**	**biaxial**
WVG	2.38	3.68	16.01	43.77	14.41	53.95
WVC	1.44	0.82	13.11	19.55	12.91	20.84
BASC	5.24	3.07	20.15	41.81	27.99	52.21

3 Discussion

Plain woven carbon fabric has the lowest G, 2HG and 2HG5 values. Biaxial shear test shows that woven glass fabric is slightly stiffer than stitched carbon fabric. Kawabata system predicts that the stitched carbon fabric is stiffer –this may be due to the short gauge length used and the sensitivity of Kawabata shear tests to misalignment errors (it is relatively difficult to align a stitched fabric in comparison to a woven fabric). However, biaxial shear test is less sensitive to alignment errors due to far field clamping. Any case, a complete shear force-strain curve may be used in forming simulations..

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