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Shear Characterisation of E-Glass Woven Fabrics by Picture Frame Device

ŠIMIĆ PENAVA Diana[1,a], PENAVA Željko[2,b] and KROLO Joško[1,c]

[1]University of Zagreb, Faculty of Civil Engineering, Kačićeva 26, 10000 Zagreb, Croatia

[2]University of Zagreb, Faculty of Textile Technology, Pr. b. Filipovića 28a, 10000 Zagreb, Croatia

[a]dianas@grad.hr, [b]zpenava@ttf.hr, [c]krolo@grad.hr

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Abstract. This paper describes an experimental study on the pure shear properties of E-Glass woven fabric by picture frame test. During shear deformation, the fabric yarns experience large angular change between warp and weft yarns. The picture frame test is one of the fundamental methods to characterize the in-plane shear behaviour of woven fabrics and can produce a quite uniform shear deformation state in the fabric sheet. Tests are conducted on two different size of E-Glass specimens 40x40 mm and 80x80 mm. For a double increase the specimen size, the values of shear force and axial load are also almost double increase at the maximum displacement and shear angle.

Introduction

Shear behaviour is one of the most important mechanical characteristics that contribute to the performance and appearance of woven fabrics [1]. During shear deformation, the fabric yarns experience large angular variation between warp and weft yarns. Material test methods for E-Glass woven fabric reported in the literature include biaxial tensile tests, bias extension tests and picture frame tests [2]. The picture frame test will be used as an experimental approach to characterize the shear behavior of E-Glass woven fabric. In the shear frame test, a fabric sheet is clamped within a square frame hinged at each corner. The two diagonally opposite corners are then displaced using a mechanical testing machine. The picture frame test requires very complex experimental set-up, but it can produce a quite uniform shear deformation state in the fabric sheet [3]. Because of that, the picture frame test is a good way to obtain the pure shear behavior of woven fabric, and this test will be the focus of the work presented here.

Pure Shear Behavior of Woven Fabrics

For a particular state of plane stress in E-Glass woven fabric specimen we can determine the plane in which only shear stresses act and normal stresses are zero. Parallelepiped forms of fabrics specimens on whose sides act only normal stresses $\sigma_x = \sigma$ and $\sigma_y = -\sigma$ are observed. In the plane whose normal $\vec{n}$ forms an angle $\varphi = 45°$ with the x-axis, according to Eq. 1 the normal stress is $\sigma_u = 0$, and shear stress is $\tau_{uv} = \tau = -\sigma$, Fig. 1

$$\sigma_u = \sigma \cdot \cos 2\varphi \quad ; \; \tau_{uv} = -\sigma \cdot \sin 2\varphi \; . \tag{1}$$

Such a case of stress is called a pure strain shear. Pure shear is equivalent to the simultaneous stretching and pressure with equal intensity in mutually vertical directions.

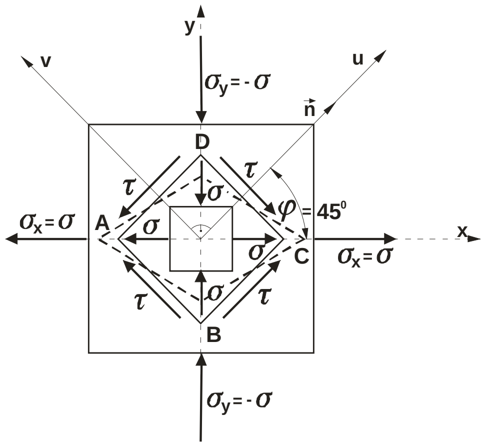
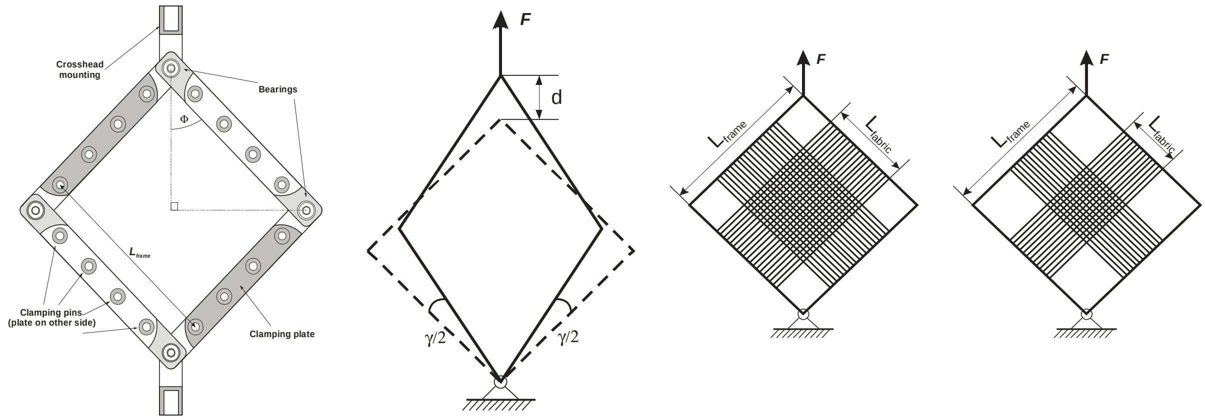


Fig. 1. Woven fabric element in pure shear behavior.

The “picture frame” test is one of the fundamental methods to characterize the in-plane shear behaviour of woven fabrics. A schematic of the picture frame test is presented in Fig. 2a. Tensile force *F* is applied across diagonally opposing corners of the picture frame rig causing the picture frame to move from an initially square configuration into a rhomboid, Fig. 2b.



a) b) c) d)

Fig. 2. A picture frame test: a) schematic view, b) deformed frame, c) specimen size 8x8 cm with corner cut-offs, d) specimen size 4x4 cm with corner cut-offs.

During the shear occurs rotation of the yarn (shearing between weft and warp yarns), denoted as the shear angle γ [rad]. γ is commonly assigned as zero (0) at the initial stage when weft and warp yarns are perpendicular to each other. Test data are often analysed to produce graphs of shear force against shear angle, where the shear angle, γ, is calculated from the geometry of the picture frame as

$$\gamma = \frac{\pi}{2} - 2 \cdot \Phi \ , \tag{2}$$

$$\cos\Phi = \frac{1}{\sqrt{2}} + \frac{d}{2 \cdot L_{frame}} \ , \tag{3}$$

where are: Φ - the frame angle calculated by Eq. 3, L_{frame}=150 mm is the side length of the picture frame, and *d* is the vertical displacement of crosshead, Fig. 2b. T_s [N] is the shear force of the fabric specimen. The shear force, T_s, can be calculated from the Eq. 4:

$$T_s = \frac{F}{2 \cdot \cos \Phi}. \tag{4}$$

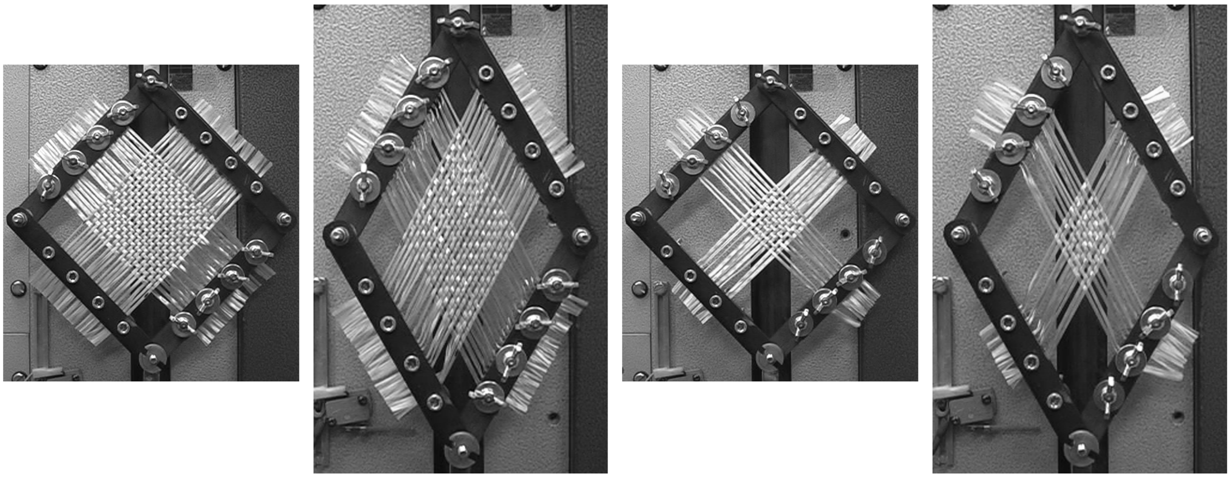
F is the measured axial picture frame force using Eq. 6 Shear stress τ [MPa] can be directly calculated from shear force, Eq. 5 Shear strain remains the same as shear angle γ.

$$\tau = \frac{T_s}{L_{fabric} \cdot t}. \tag{5}$$

L_{fabric} is the side length of the inner deformed specimen, t [mm] is fabric thickness.

Experiment

This section presented the picture frame test, and discussed the shear behavior using two different size specimens. All the tests were conducted in a tensile tester. Plain-weave type glass fabric, commercial code: RT 300 the manufacturer Kelteks d.o.o., Croatia has been used for the purpose of this investigation. The basic of RT 300 is the glass fabric of E-glass. The E-glass plain weave woven roving has weight 300 g/m^2, density in both directions is 25 ends/10cm, fabric thickness is 0.42 mm, yarn linear density for warp and weft is 600 tex.



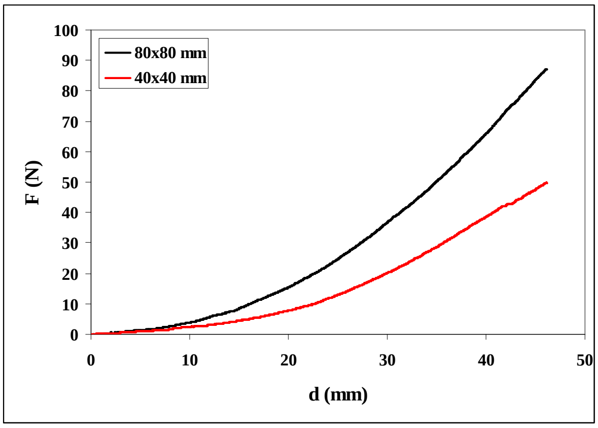
a) b) c) d)

Fig. 3. Picture frame test with specimen: a) 80x80 mm specimen before shear, b) 80x80 mm specimen after shear, c) 40x40 mm specimen before shear, d) 40x40 mm specimen after shear.

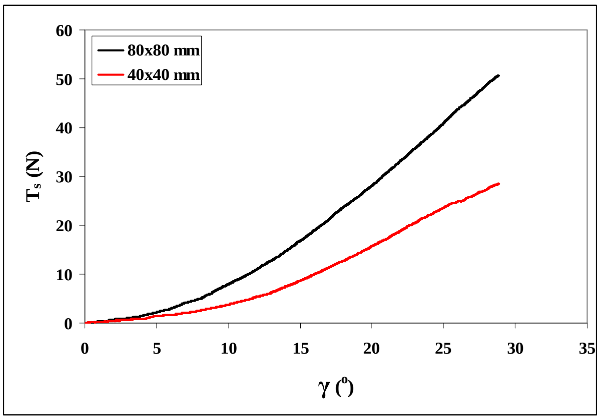
The experiment was carried out by measuring a displacement d of crosshead fixture under the action of tensile force F, Fig. 2b. Two different size specimens (80x80 mm and 40x40 mm) with corner cut-offs were tested, Figs. 2c, 2d. First, the whole empty fixture (frame) is placed onto the tensile machine, and connected with the crossheads. The distance between the upper and lower crossheads has to be adjusted and angles between the arms of fixture are 90^o. After three trials of this test, the average value of load F_1 is calculated at each displacement point. Afterward, the specimen is clamped carefully and tightly into the plates of fixture. Since the arms can rotate freely at the hinges, the angle between two groups of yarns varies, thus resulting in a pure shear deformation of the fabric under an external diagonal tensile load. We load the fixture at the designated speed, recording the displacement and force F_2, simultaneously by computer. The test under the same condition is conducted for 3 repeats for each specimen. The effective force F required to pull the crosshead of the testing machine is recorded and the shear force is subsequently calculated using

$$F = F_2 - F_1 \ . \tag{6}$$

The value F_1 is determined on the frame without including a fabric specimen. F_2 is the force required to deform the frame with the specimen. The shear frame tests were run at room temperature and at a crosshead rate of 100 mm/min. Frame with a specimen size of 80x80 mm before shear is shown in Fig. 3a, and after shear in Fig. 3b. Frame with a specimen size of 40x40 mm before shear is shown in Fig. 3c, and after shear in Fig. 3d. Diagram of mean values of test results of action of axial load F and the corresponding displacements d for both size specimens is shown in Fig. 4a. According to experimental values from Fig. 4a and using Eq. 2, 3, 4, calculated mean values of shear force T_s and the corresponding shear angle γ are shown in diagram in Fig. 4b.



a)



b)

Fig. 4. Shear behavior of specimens: a) load vs. displacement, b) shear force vs. shear angle.

At maximum displacement d = 46 mm, axial load F is 44.4% higher for a larger specimen. For maximum shear angle γ = 28.8°, shear force T_s is 44.4% higher for a larger specimen.

Conclusion

The size of the tested specimen affects the values of shear stress, shear force and shear angle. A larger specimen size would indicate the deformation of a greater number of crossovers. There is no standard ratio for the length of a test specimen L_{fabric} to the length of the frame. The fabric area is directly related to the number of crossovers in the material. A larger specimen would have more yarns and more crossovers between the yarns. With an increased number of yarns and crossovers, a larger force is required to shear the specimen. For a double increase the specimen size, the values of shear force and axial load are also almost double increase at the maximum displacement and shear angle.

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