SHEAR PROPERTIES OF WOVEN COMPOSITE REINFORCEMENT

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Abstract

A novel approach for determining the in-plane shear properties of textile reinforcements is introduced in our work. Instead of building a complete and standalone device, a simple apparatus was designed and built that can be mounted on any universal tensile testing machine converting that to a shear tester equipment. Hence the drive, force sensor and software of the tensile tester can be used to generate the deformation and to measure the force, respectively. With this apparatus various textiles in different sizes can be tested. In this study the operation of the new device is introduced. The apparatus was mounted on a Zwick Z005 device equipped with a 20 N ranged force sensor. For the experiments glass fiber woven fabric reinforcement was chosen. 2x50 mm wide symmetrical setup was applied to determine the shear properties in various directions. The appropriate repeatability of the tests was confirmed as the deviations of the recorded values were low. The apparatus offers simple and safe operation. Our next goal is to analyse and compare the results with that of other popular measuring methods.

Introduction

When designing textile reinforced composites or even textile-based engineering structures, it is crucial to know their various mechanical properties. Uni- and biaxial tensile tests are widely used, but other experiments such as bending, compression and shearing measurements also give important design information. The implementaion of these measurements can still have new approaches and possibilities. For determining the shear properties different methods can be used, such as the Kawabata Evaluation System's shear tester (KES FB-1) [1-3], the so-called window frame method, or even pulling the textile sample in bias direction that results in a shear stress state in the middle section of the woven specimen [4-9].

These measurements are basicly good for determining the initial shear properties, the shearing stimulus as cyclic load can hardly or not even be generated [7-8]. The widely used KES FB-1 system [1-2] can be applied to carry out hysteresis tests. From the test results various parameters can be determined that can characterize the textile material's handling and processing properties, such as the ease of cutting and formability or even stiffness and rigidity. From simple measurements precise and important information can be aquired on the textile's behavior. On the other hand this requires a standalone device with a lots of built-in electronics (data aquisition, torque measurment and generation of displacement).

Our aim was to combine the simplicity of the above-mentioned methods and the precision of the KES-FB system. Instead of building a complete and standalone device, a simple apparatus was designed that does not have any electronic parts. Instead, it can be mounted on any universal tensile testing machine converting that to a shear tester equipment, hence the drive, force sensor and software of the tensile tester can be used to generate the deformation and to measure the force, respectively. Our method is quite similar to Kawabata's system [1,2,10] as our device also applies a transversal pre-stress during the tests but here, by clearly mechanical ways that keeps the device simple.

Experimental

The schematic draft of the apparatus can be seen in Figure 1. The test setup is symmetrical and the specimen (recommended size: 200x150 mm) has a vertical arrangement. The textile sample is gripped along the two edges and at the center line. The two side grips can move horizontally along a linear bearing having low friction. A transverse pre-stress is applied by a long spring. The length i.e. the stress of the spring can be adjusted stepless by keys. This pretension can be considered constant as the change in length and in force is less than ±1% during the test.

The vertical deformation (stimulus) is applied by the load machine wherewith both up and down directions can be realized. From the vertical force (response) the shear stress can be calculated easily assuming that the sample is gripped symmetrically and the deformation angle (the angle between the horizontal yarns and their deformed state) is small.

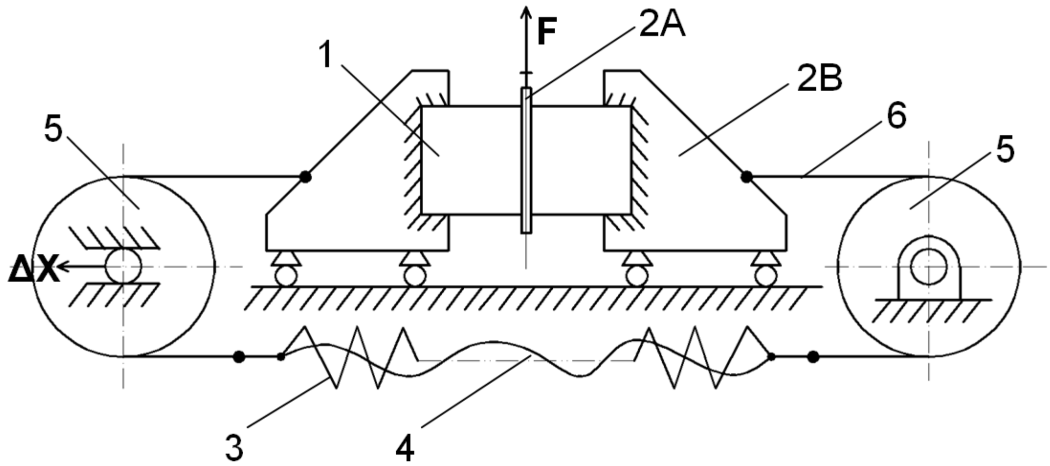

Figure 1. The schematic draft of the apparatus. 1: textile specimen, 2A & 2B: grippers, 3: steel spring, 4: HPPE yarn, 5: rollers with bearing, 6: thin rope

The theoretical deformation of the textile test sample can be seen in Figure 2. Due to the construction concept, during the shear tests the transversal yarns of the specimen have approximately constant length and almost pure shearing takes place. The half-gripping distance (Y_0) that is the distance between the central and the outer clamps is identical to the length of the horizontal yarns between the clamps (assuming that the sample is gripped either in weft or in warp direction). When vertical – shearing – displacement is induced

(Figure 2B) the clamps come closer to each other (Y_1). This horizontal displacement is regulated by the transversal force induced by the spring ensuring that the length of the horizontal yarns remain the same during the whole test.

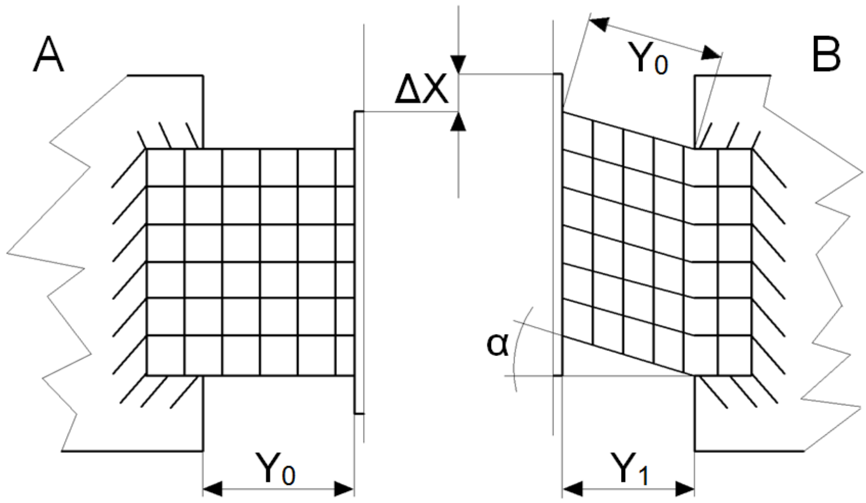

Figure 2. The specimen at shear test. A: gripped specimen, B: deformed state during test

The steel pretension spring was designed to have a maximum loaded length of 291 mm, while the unloaded one is only 119 mm including the hooks at both ends. The pretension is chosen to be 20 N, i.e. 0.1 N/mm, as 200 mm wide samples are designated to be measured. To ensure this force the manufactured spring was calibrated and a simple method was applied. The spring was gripped to the Zwick Z005 universal tensile tester and the crosshead was moved until reaching 20 N force. At this displacement a strong (0.24 mm diameter) high performance polyethylene (HPPE) fishing line was applied to tightly link the two ends of the spring. This yarn ensured that the spring can only be stretched by the adjustment gears until reaching the strain related to 20 N.

The mounted apparatus can be seen in Figure 3. The whole apparatus can be tilted to a horizontal position around the motherboard (Figure 3:5) after removing two fixing bolts. Then the clamps (Figure 3: 3). can be fixed at any position by a locking lever (in the back side) in order to ensure their appropriate distance (2x50 mm). At this point the textile specimen can be fixed to the grippers in a horizontal position by clenching the two sides of each gripper by screws. Both grippers provide a rough surface (sanding paper) at one side and soft rubber on the other side to avoid slipping of the specimen. After the specimen is well-fixed, the apparatus can be tilted back to operating position then fixed by the bolts. Then the locking levers can be loosened, therefore the side clamps can move free. The pretension can be applied (Figure 3: 4) by shortening the rope until reaching the sufficient strain of the spring. The central clamping unit is then fixed and its two sides are clenched with screws.

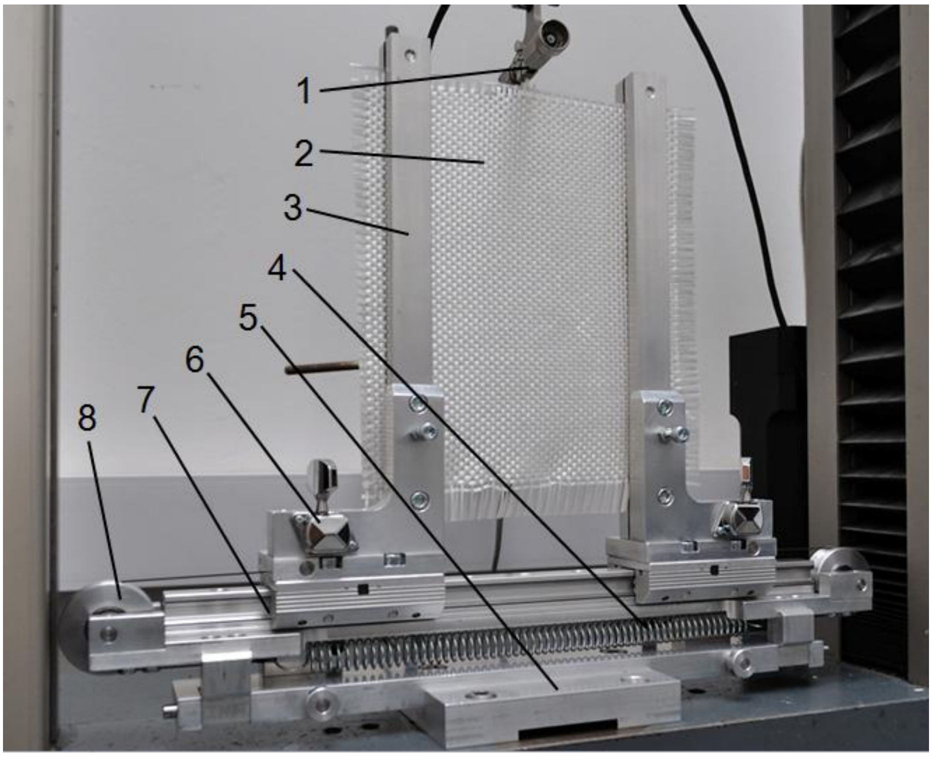

Figure 3. The shear apparatus. 1: changeable clamping unit connected to the crosshead, 2: test specimen, 3: clamps, 4: pretension spring, 5: motherboard, 6: gears for adjusting pretension, 7: linear bearing, 8: rollers with bearings

For the measurements a glass fibre plain weave (1/1) fabric was chosen. The applied Krossglass (Poland) STR 022-250-110 type fabric had an areal density of 250 ± 15 g/m^2 and a yarn density of 5/cm in both warp and weft directions. For the tests the half gripping distance (Y_0) was chosen to be 50 mm. The width of the central gripping clamp was additional 8 mm, therefore 150 mm wide samples were cut. The height of the samples was 200 mm in all cases and the cutting direction was 0°, 15°... 90°, respectively. Hysteresis tests were carried out in 3 samples of each cutting direction, between ±8° shear angles.

Results and discussion

The deformation of the glass fabric during test can be seen in Figure 4. For the demonstration image a high vertical displacement of the central gripper was set hence it can be clearly seen that the side grippers slightly moved closer to each other while the pretension spring ensured an almost constant transversal stress. The stress in the weft yarns are constant during the test (neglecting the slight bending close to the grippers). At the hysteresis measurements as the maximal shear angle was ±8° the related displacement was approximately ±7 mm.

The apparatus makes available to carry out the hysteresis tests on the samples in different directions which could be used to characterize the shear behavior of the different weaving patterns as well in the future.

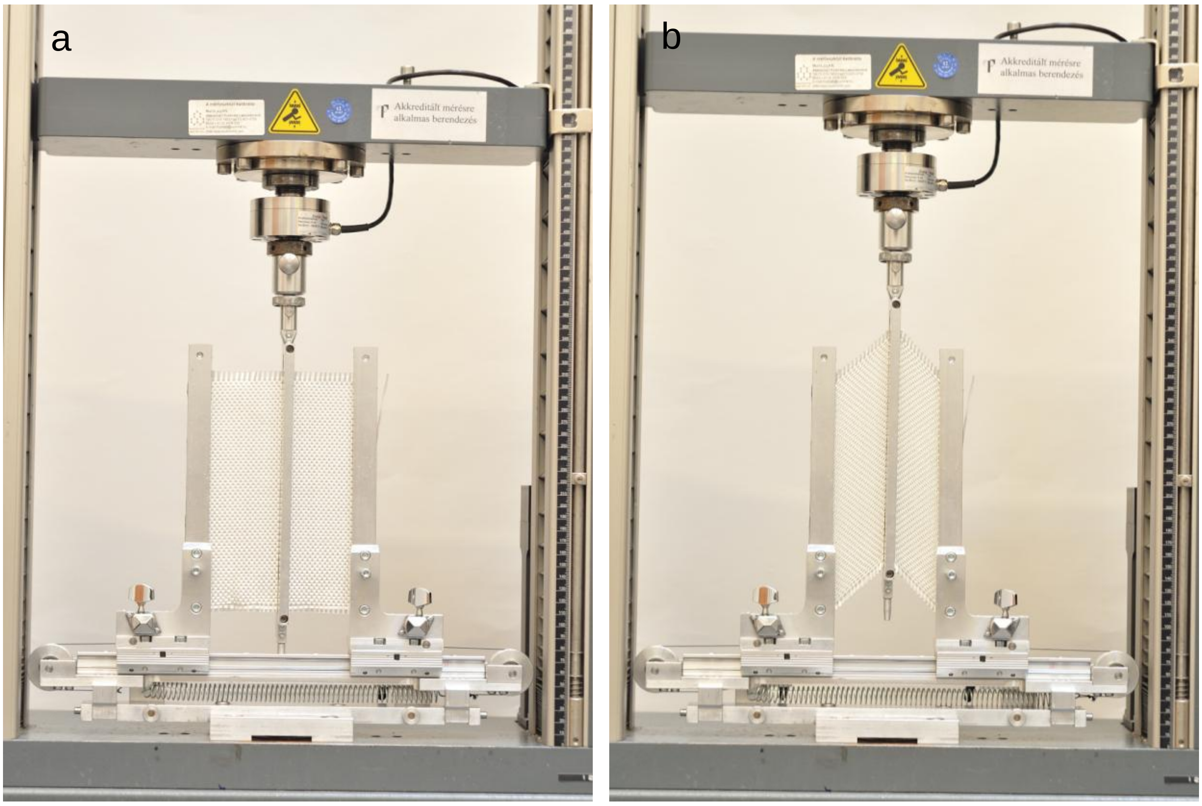

Figure 4. The specimen at shear test. a:constant transversal stress and no shearing, b: highly deformed state (transversal stress is still applied)

Figure 5. shows the results of the test in 0°and 45° directions. As our method provides a symmetrical setup, two parts of the sample is sheared in parallel. Therefore the resulted forces are divided by two to get the average of the left and right sides. It can be seen that in 45° direction the measured shear stress (expressed in N/m format) is an order of magnitude higher. There is a difference between the first shear deformation (virgin curve) and the next cycle. There is a hysteresis between the pulling (upper part of the curve) and pushing characteristics that is caused by the friction between the yarns at cross over points. Small values of 2HG5 (hysteresis width value) indicates good comfort (of garments) and good formability while larger values indicate inelasticity and stiffness [10]. In the case of the 45° sample the characteristics is uneven that can be originated from the appearance of wrinkles and from the phenomenon that the neighboring yarns are abuting each other that results in higher resistivity and in increased forces as well as the frictional conditions are altered.

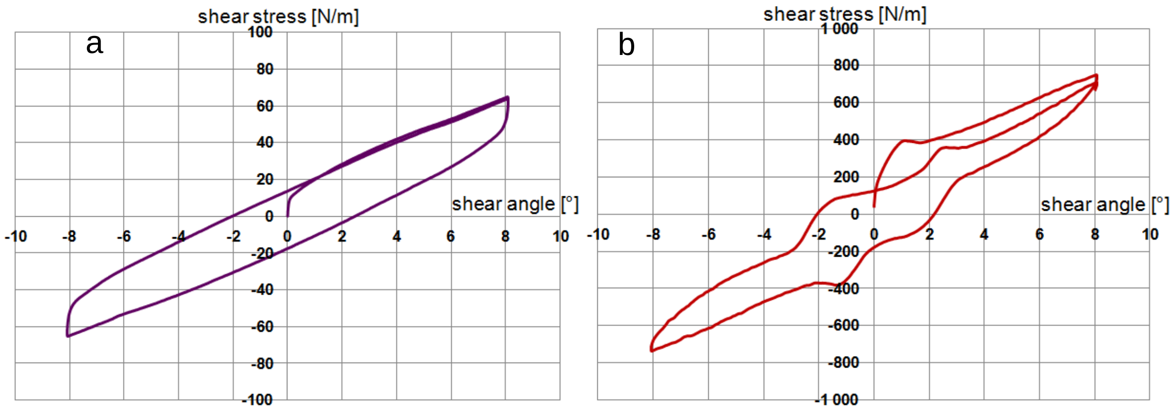

Figure 5. Hyteresis test of specimens in 0°(a) and 45°(b) cutting directions

Shear properties are principally measured in the manufacturing direction, but in our study we tried to measure the textile's resistance in 15° increments. The quasy-orthotopic material loaded in a direction different from the main directions results in an uneven deformation state. Thus the left and right sides behave differently. With our method the averaged stress value and deformation angle of the two sides can be determined. Table 1. introduces the measured (apparent) shear properties where besides the average values indicated is the deviation. The shear rigidity is calculated as the slope of the force-shear angle curve's linear part (here between 0.5° and 2.5°). The hysteresis of the forces are also calculated at 0.5° and 5°, respectively which characterize the handling properties of the textile.

Direction	**Shear rigidity**	**Hysteresis of shear force at 0.5º**	**Hysteresis of shear force at 5º**
[°]	*G [N/m°]*	*2HG [N/m]*	*2HG5 [N/m]*
0	4.22 ± 0.1	14.5 ± 0.43	14.8 ± 0.55
15	12.5 ± 2.67	34.1 ± 3.23	42.2 ± 9.72
30	42.9 ± 22.7	344 ± 73.5	325 ± 61.8
45	29.8 ± 8.96	201 ± 16.7	107 ± 8.73
60	44.2 ± 14.2	193 ± 24.1	192 ± 84.9
75	13.2 ± 4.32	46.0 ± 2.74	49.8 ± 7.85
90	3.93 ± 0.11	15.4 ± 1.42	14.8 ± 1.06

Table 1. Brief summary of the resulted parameters as a function of cutting direction

From these results a polar diagram can be depicted. Figure 6. reveals the (apparent) shear rigidity as a function of the cutting angle. It can be seen that the textile sample have moderate resistance in weft and warp directions which was our expectation at our traditional, biaxial woven material. The highest values occurred at 30° and 60° which were approximately 40% higher than in the 45° (symmetry line) direction.

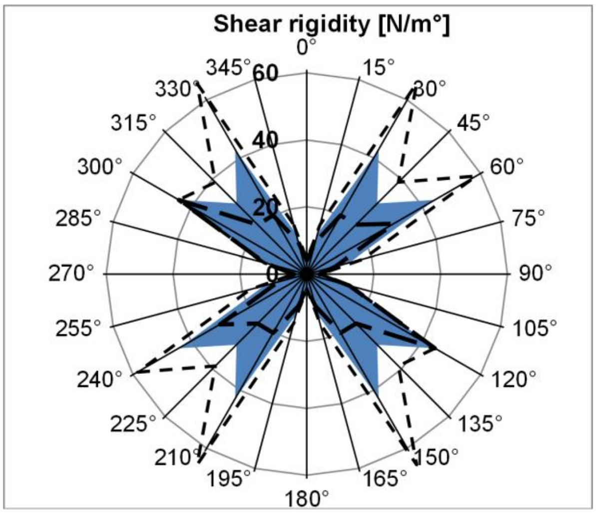

Figure 6. Shear rigidity (G) of the glass fibre samples as polar diagram (the dashed lines indicate the deviation)

The Kawabata parameters (hysteresis width at 0.5°and 5°, respectively) 2HG and 2HG5 can be seen in Figure 7. as polar diagrams. The deviation is also indicated, by dashed line. The difference caused by the cutting angle is even higher than in the case of the apparent shear rigidity. The results show that the formability of the textile is approximately 30 times worse in 30° direction which should be taken into account e.g. when trying to lay and then adjust the textile into/onto a composite mould. For instance in hand layup method this can result in processing difficulties and in unexpected textile deformations when the textile layer is gently adjusted to its final position within the mould. When handling the material the shearing deformations can be various depending on the direction of the applied push/pull force.

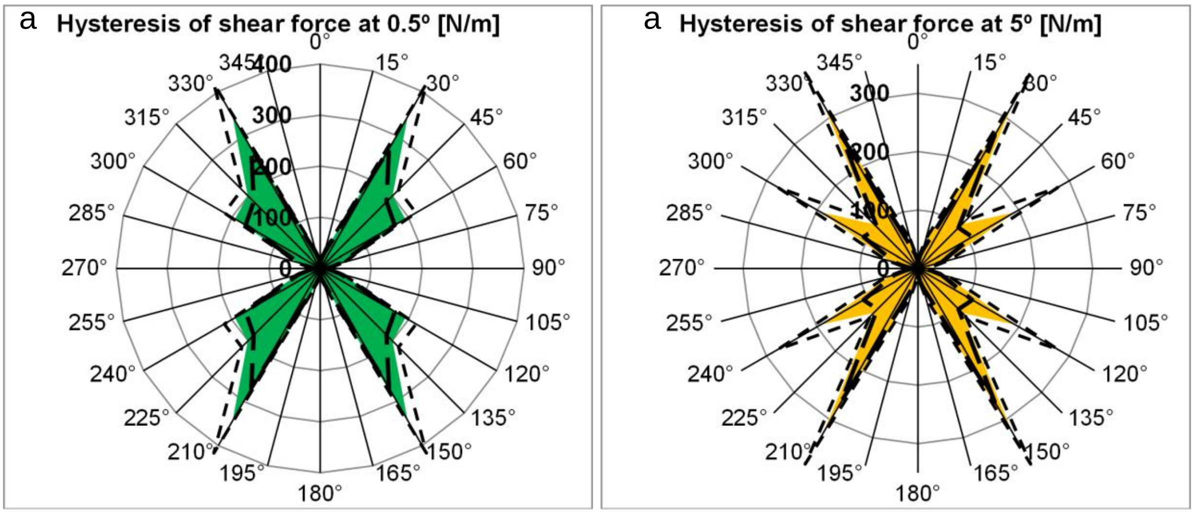

Figure 7. 2HG (a) and 2HG5 (b) parameters of the glass fibre samples as polar diagram (the dashed lines indicate the deviation)

Summary

A simple apparatus for determining the shear properties of various textiles has been developed. The apparatus can be mounted on almost any kind of universal load machine depending on the motherboard converting the load machine into a shear tester. The apparatus has symmetrical arrangement and apart from that the shearing conditions are like at the Kawabata KES-FB1 system. The pretension and the distance of the clamps can be adjusted. The main advantage of the device is that besides the good repeatability, cost-effectiveness, and appropriate stress state the tests can be carried out rapidly. The software of the load machine can also be used for the evaluation.

Shear properties of a woven glass fiber plain weave reinforcement was determined. Hysteresis tests were carried out in the ±8° shearing interval and the Kawabata parameters were determined. The measurements were also implemented in different cutting directions in 15° increments. Due to the dissimmetry uneven deformation states are occurred. The resistance in 30° and 60° was found to be the highest where significant wrinkling of the specimen also took place.

Our next goal is to compare the results with that of other, widely used methods and to measure and analyze the behaviour of different garments and textile composites.

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