DEVELOPMENT OF A BIAXIAL TENSILE GRIP FOR CYCLIC TENSILE TESTS OF FLEXIBLE TECHNICAL TEXTILES

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ABSTRACT

A biaxial tensile testing apparatus that can be fastened onto tensile tester was developed by the authors. This paper presents results of measurements on flexible fiber reinforced membranes of different types and various area densities performed in order to demonstrate the applicability of the equipment.

Key words: Cyclic biaxial tests, flexible technical textiles, tensile tests

1. INTRODUCTION

Flexible textiles and textile reinforced polymeric composite materials are widely used in several technical applications, such as technical clothing (protecting coveralls), sportswear (running, gym, sailing and sport clothes), medical textiles (antiseptic gauze, casting tapes) and construction textile composites (tents, shading and roofs). The tents and shading roofs are usually made of polyester (PES) fabric coated by polyvinyl chloride (PVC) or high efficiency technical textiles composed of woven glass fiber (GF) coated by polytetrafluoroethylene (PTFE).

In case of conventional application they are subjected to multiaxial stresses, therefore we must know exactly the mechanical properties of these technical textiles. Most of the traditional mechanical test, like tensile, shear, or bending tests could provide only the uniaxial properties of the materials. At some tests – like ball-bursting test – multiaxial stresses are used as well, but it gives displacement and force information just in load direction, therefore they cannot show the orientation dependent mechanical properties.

With biaxial tensile test the mechanical properties can be measured in two axes at the same time, and it can represent the orientation dependent anisotropic behavior of the flexible fabric much better than several uniaxial tests. The results of the biaxial tests could be input parameters of the finite element simulation software packages as well. The latter cannot calculate the biaxial behavior from unidirectional properties because they do not take into account the influence of the yarn crimping and the distortion of the fibers and rovings [1]. Several researchers [2-3] have studied the multiaxial properties of textiles using tensile tests.

During testing the strains or elongations of the sample part subjected to biaxial load are to be measured. If the deformation measured by the loading equipment includes the elongation of the arms of the cross-shaped sample then the measurements do not give the real elongations. Therefore the elongations should be measured locally on the biaxial loaded part. In the case of most biaxial testing devices mentioned in publications the center of the samples displaces (Fig. 1) influencing the measured values of elongations hereby the evaluation as well. To measuring the local elongation strain gauge cannot be applied since it significantly affects the results hence in general the measurement is performed with video-extensometer [4].

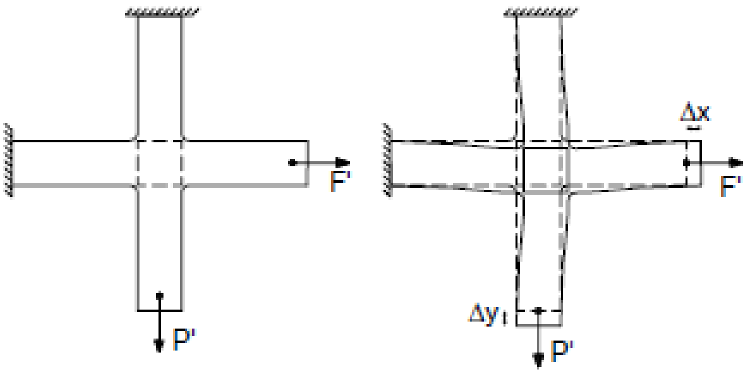


Figure 1: Displacement of the center of sample in case of equipment with two actuators [4]

In this paper a special biaxial apparatus adapted to tensile tester and developed by us as well as the results obtained by using that are presented.

2. MATERIALS AND METHODS

The materials for the biaxial tests were a GF/PTFE membrane roll composite specimen and PES textile reinforced PVC membrane rolls of the Sioen Industries (Table 1). The yarn density was not the same for every material in the main directions: in the warp direction it was about 15-20% more roving than in the weft direction.

Table 1. Used materials and their main physical properties

Fabric	Description	Matrix	Reinforce-. ment	Area density [g/m^2]	Yarn density (warp/weft) [pcs/100 mm]
1.	Sioen B6000 (white)	PVC	PES	900	62/62
2.	Sioen B7119 (grey)	PVC	PES	630	72/62
3.	Sioen C2357 (yellow)	PVC	PES	350	152/126
4.	Anon (beige)	PTFE	GF	385	144/128

Besides the yarn densities the deformation properties of the membranes in different directions are significantly influenced by the crimp of the yarns as well. This can be established from SEM images of the cross section. Contacting of the warp and weft yarns that is the binding point determines a loop or wave element the arc length of which in direction x (l_x) is longer by value b_x of the crimp than the projected double size c_x of the binding cell.

$$b_x = \frac{l_x - c_x}{c_x} \tag{1}$$

$$l_x = c_x(1 + b_x) \tag{2}$$

A wave element can be described by the aid of half a period of sinus function of amplitude A and its derivative (4) ($0 \le x \le c_x$):

$$y = A \cdot \sin \frac{\pi \cdot x}{c_x} \tag{3}$$

$$y' = \frac{A \cdot \pi}{c_x} \cos \frac{\pi \cdot x}{c_x} \tag{4}$$

The correct arc length (5) can be approximated with the first two terms of the binomial series of the integral according to Equation (6) ($|y'| < 1$).

$$l_x = \int_0^{c_x} \sqrt{1 + (y')^2}\, dx = \int_0^{c_x} \sqrt{1 + \frac{A^2 \cdot \pi^2}{c_x^2} \cos^2 \frac{\pi \cdot x}{c_x}}\, dx \tag{5}$$

$$l_x \approx \int_0^{c_x} \left[1 + \frac{A^2 \cdot \pi^2}{2 \cdot c_x^2} \cos^2 \frac{\pi \cdot x}{c_x} \right] dx = c_x + \frac{A^2 \cdot \pi^2}{4 \cdot c_x} \tag{6}$$

The cruciform specimens (Fig. 2) were cut of the rolls according to the specifications of ASTM D4851-07 and by using a steel ruler and a razor type knife.

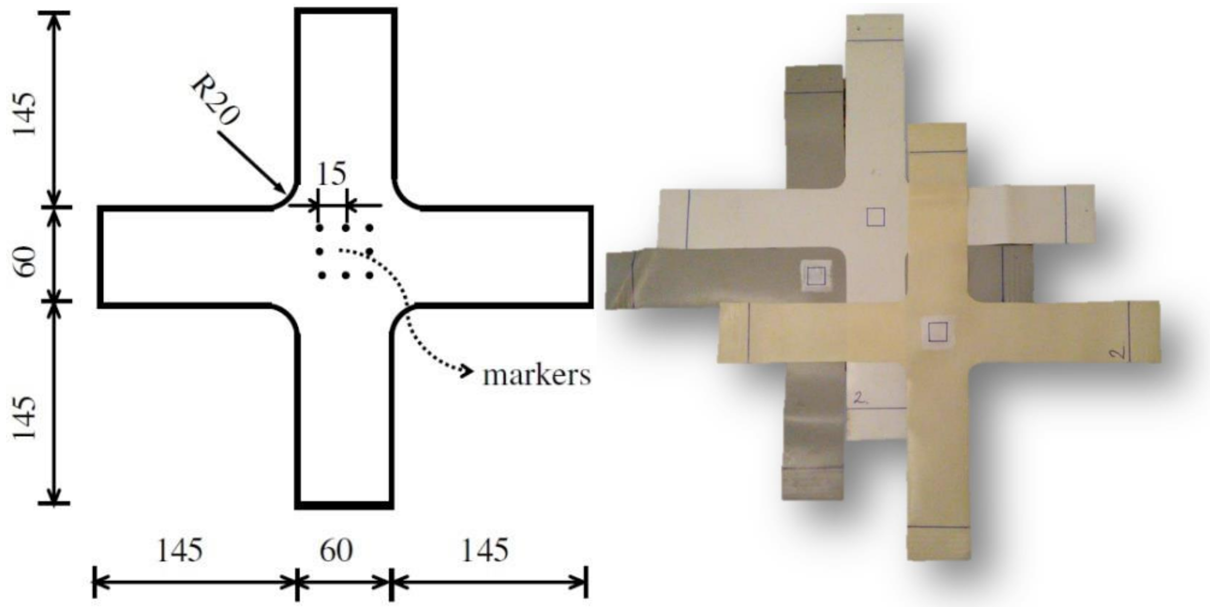


Figure 2: Standard cross-shaped textile samples for biaxial test

The advantage of the measuring frame elaborated is that the center of samples does not displace – in case of proper setting – and the elongations are measured on the medium biaxial loaded allowing to create more real material model from the measurements. The frame makes possible to grip the cruciform sample according to Fig. 3. The arms towards warp are gripped upwards and the other are gripped downwards. As a consequence the biaxial loaded range of the sample contains the square drown in the middle. A drawback of the measuring frame is that the arms of the sample may be loaded to equal degree in both measuring directions. This problem can be eliminated by applying arms of different widths however this solution has got its limits as well. In this paper samples of equal widths were used.

It was found that the measurement is influenced by the light conditions, this could be avoided if more than one light source would illumine the specimen. However, this may result glare, which may influence the measurement. An appropriate matte coverage white paint could avoid this effect.

The test was performed on a Zwick Z050 universal tensile tester on a cross-shaped specimen. The test setup can be seen in Table 2 and Figure 3. The elongation was measured with a Messphysik ME-46 full image video-extensometer in both warp and weft direction by measuring the deformation of the square in the middle with an identical gauge length of 30 mm. The load in the warp direction was higher than in the weft direction by the weight of the support frame and the video-extensometer (4.066 kg). One specimen was tested. Wavy grip jaws were used. No specimen slippage was observed during testing.

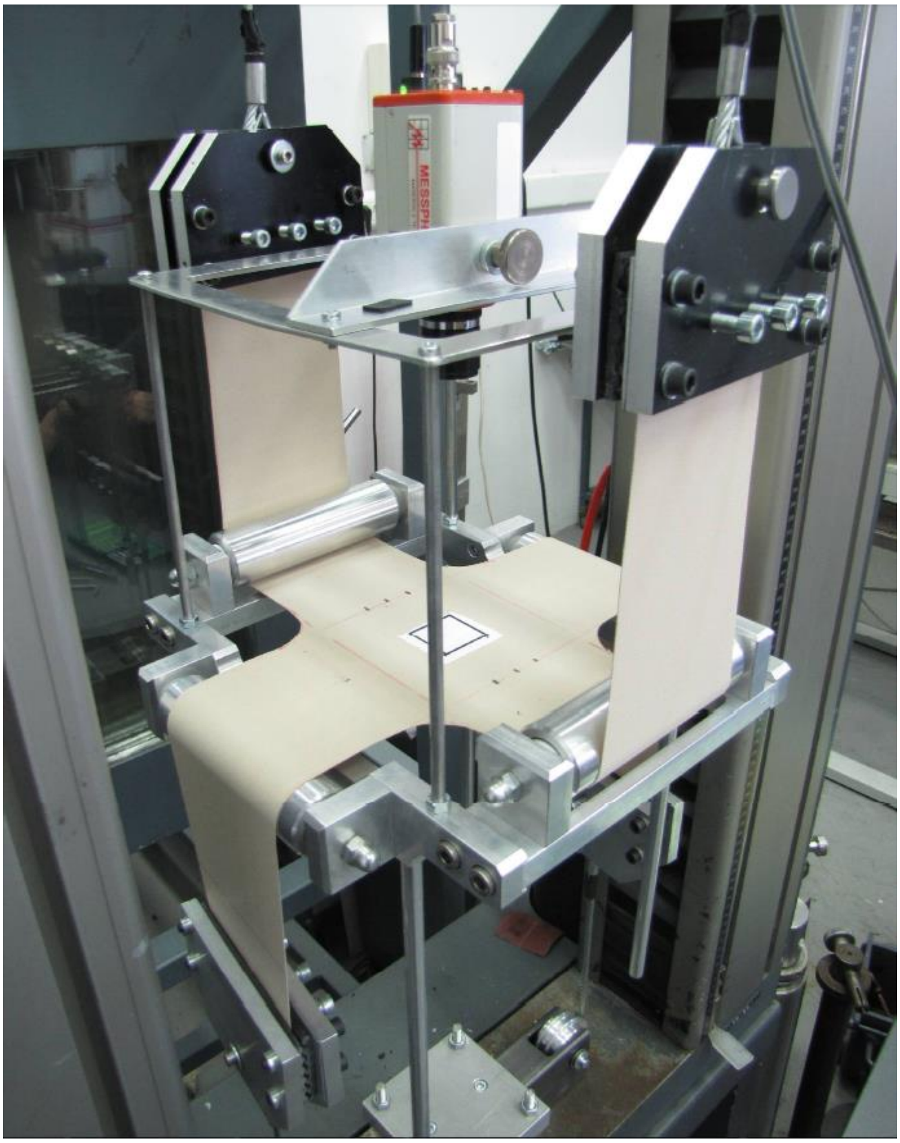


Figure 3: The elaborated biaxial testing apparatus for cyclic biaxial tests

Table 2. Testing machine and test setup of the cyclic biaxial measurements

Machine type	Zwick Z050
Loading rate	0.2 (kN/m)/s
Minimum load (weft direction)	0.25 kN/m
Maximum load (weft direction)	30 kN/m
Specimen dimensions (warp x weft)	100 mm x 100 mm
Temperature	23°C
Relative humidity	44%

The crimp of yarns was studied with the aid of micrographs taken by electron-microscope (JEOL JSM 6380A) in both warp and weft directions.

3. RESULTS AND DISCUSSION

Records of stimulus (load-time) and response (elongation-time) functions used for biaxial tests are depicted in Figs. 4-6 where the green, blue, and red curves respectively show the changing of the force with time (left sides), the elongation in warp and weft directions (right sides) during cyclic biaxial tensile tests. The relationship between the stimulus and response measured during 5 cycles can be seen in Figs. 4, 5, and 6 for the white (B6000), grey (B7119), and yellow (C2357) membranes, respectively.

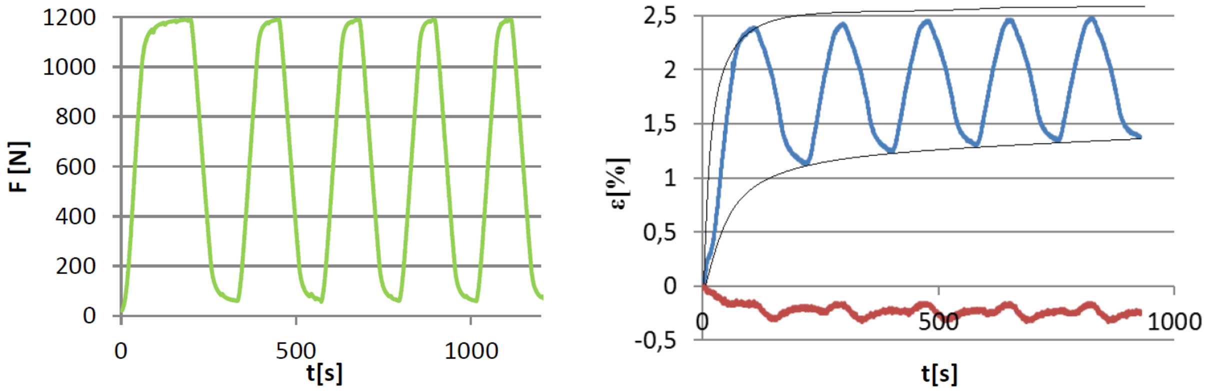


Figure 4: Stimulus and response functions recorded during cyclic biaxial test performed on white PVC membrane of 900 g/m^2 area density

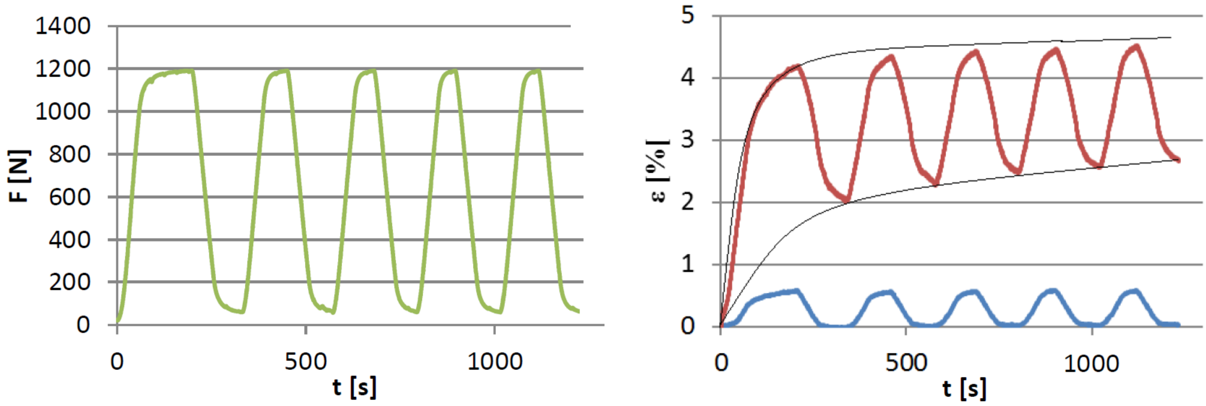


Figure 5: Stimulus and response functions recorded during cyclic biaxial test performed on grey PVC membrane of 630 g/m^2 area density

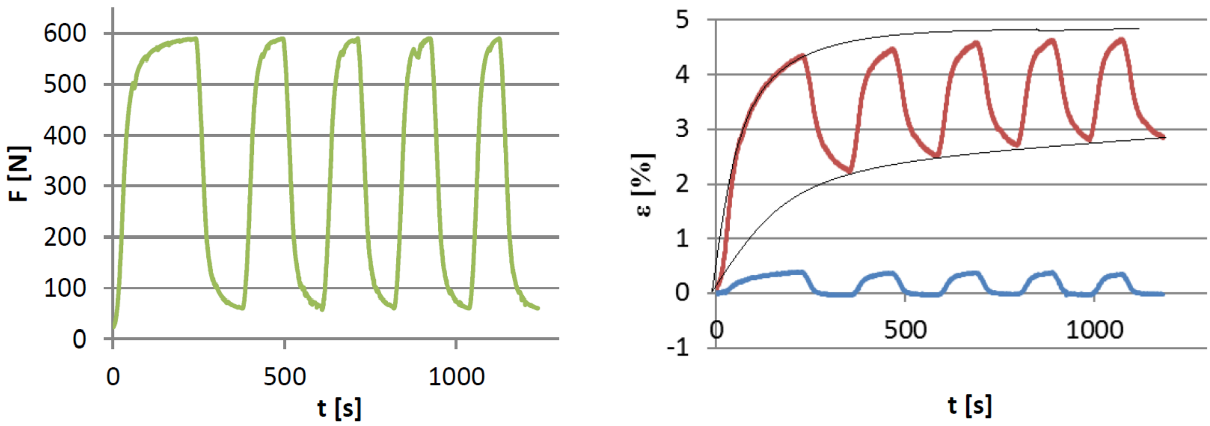


Figure 6: Stimulus and response functions recorded during cyclic biaxial test performed on yellow PVC membrane of 350 g/m^2 area density

The measurements were carried out on another membrane of glass fiber reinforced PTFE matrix as well whose results are shown by Figs. 7 and 8. The registered force-time curves, representing the actual loading of the sample are presented in Figure 7, the related elongation-time curves are presented in Figure 8 where the measurements were extended to 16 cycles.

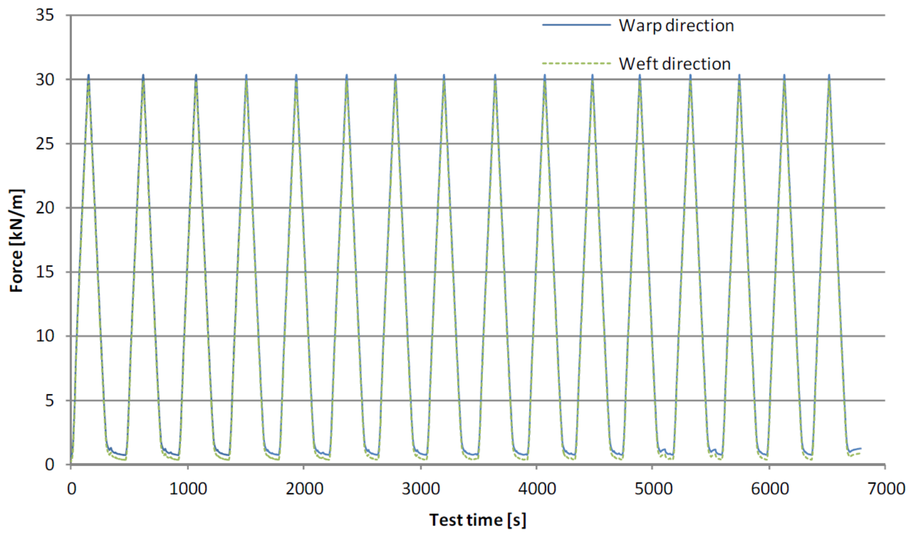


Figure 7: Registered force-time diagrams of the cyclic biaxial test at the PTFE/GF technical textile samples

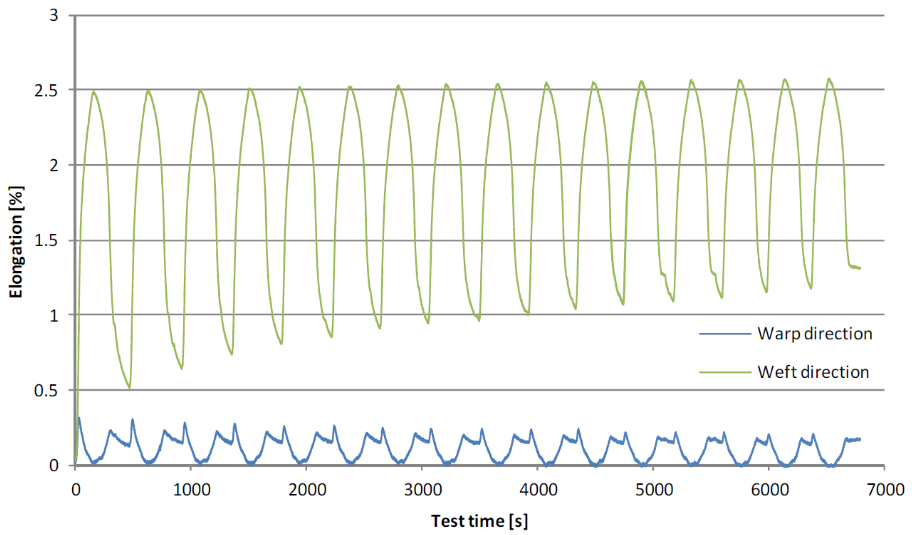


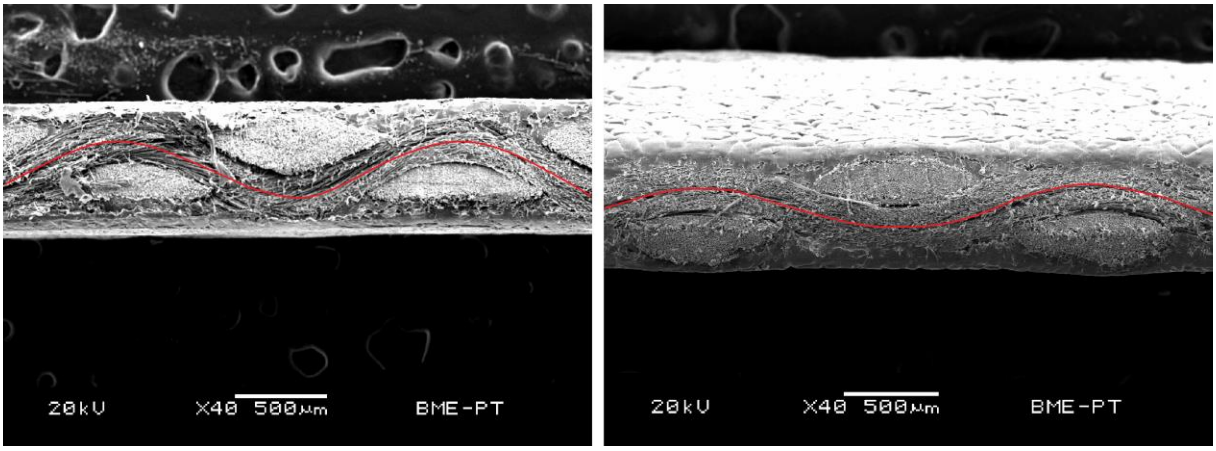
Figure 8: Registered elongation-time diagrams of the cyclic biaxial test at the PTFE/GF technical textile samples

In Fig. 9 it can be observed that the cause of the difference in mechanical behavior in warp and weft directions – besides the different yarn densities – is to be sought in the different crimps of yarns. Looking from warp direction (Fig. 9.a) the weft yarn exhibits higher crimp that the warp yarn looking from weft direction (Fig. 9.b). The crimp values of the technical textiles were determined on the basis of SEM micrographs using the method described in Chapter 2 and they are shown by Table 3.

Table 3. The crimp of yarns of the technical textiles

Fabric	Description	Crimp			
		warp (b_y)		weft (b_x)	
		[-]	[%]	[-]	[%]
1.	Sioen B6000 (white)	0,0010	0,10	0,0421	4,21
2.	Sioen B7119 (grey)	0,0008	0,08	0,0224	2,24
3.	Sioen C2357 (yellow)	0,0019	0,19	0,0356	3,56
4.	PTFE/GF (beige)	0,0123	1,23	0,0412	4,12

From the crimp results it can be concluded that the weft yarns were stronger pre-tensioned during producing membrane type B6000 although in general the tension in warp direction is larger. This is confirmed by both the biaxial examinations and the results of SEM micrographs. In case of materials B7119, C2357, and PTFE/GF the pre-tension was as usual at the same time that of membrane PTFE/GF was probably the least because the crimp was large in both structural directions consequently also the yarn reserve.
In the direction with large crimp the yarn reserve is larger therefore the structural elongation of the membrane rising from the yarn straightening. This may cause the grey marked increase caused by creep effect in biaxial elongation shown in Figs. 4-6. The crimp values obtained in warp and weft directions correspond to the measured elongations.



(a) (b)

Figure 9: Cross section of the PTFE/GF technical textile specimen from the warp direction (a) and from the weft direction (b)

4. CONCLUSIONS

In this paper four different membranes were examined using a biaxial tensile tester device developed at our Department in cyclic mode. The biaxial tensile tests were performed until the load up to 25% of the warp direction tensile strength. To study the membranes structure there were carried out images taken by scanning electron microscope in warp and weft directional cross sections.
It is important to study further the influence of the light conditions for the measurement to reduce the sparkling of the specimens. It is needed more explanation the effect during the biaxial cyclic tests creep, where the minimum and maximum strain values increasing of the time.
The overall conclusion is that the in our laboratory developed testing device functioned well and is suitable for biaxial tensile testing of high-strength, flexible, sheet-like materials such as

engineering membranes and technical fabrics.

5. REFERENCES

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ACKNOWLEDGEMENTS

This work was supported by the Hungarian National Research, Development and Innovation Office (NKFI Hivatal) and by the Hungarian Science and Technology Foundation (TÉT 12 DE-1-2013-0006; TÉT_12_MA-1-2013-0008), by the Hungarian Research Fund (OTKA K100949) and by the New Széchenyi Plan (Project ID: TÁMOP-4.2.1/B-09/KMR-2010-0002. This project was connected to the scientific program of the “Development of quality-oriented and harmonized R+D+I strategy and functional model at BME” project. Gábor Szebényi acknowledges the financial support received through János Bolyai Scholarship of the Hungarian Academy of Sciences.