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In situ determination of pore sizes of high density polyester woven fabrics under biaxial loading

Recep Türkay Kocaman, Samander Ali Malik, Dilbar Aibibu and Chokri Cherif

Dresden University of Technology, Faculty of Mechanical Science and Engineering, Institute of Textile Machinery and High Performance Material Technology, Hohe Straße 6, Dresden, Germany

corresponding author: recep_tuerkay.kocaman1@tu-dresden.de

Abstract. In this study an in situ pore size measurement method was developed to determine the pore size changes of high density polyester woven fabrics under biaxial loading. This unique method allows the non-destructive testing of the pore sizes under biaxial loading. Changes in the pore size distributions of samples were in situ determined with the newly developed method. The results show that the developed measurement method is very promising to define the pore size changes of barrier textiles in situ under loading.

1. Introduction

Polyester (PES) is commonly used synthetic fiber for the manufacturing of barrier fabrics. High density multifilament polyester woven fabrics can be used for the manufacturing of surgical gowns. Permeability and retention properties of barrier fabrics can be varied by choosing different process and material parameters [1]. Mechanical stresses (e.g. tension, bending) during use lead to a significant change in the pore morphology of the barrier fabric [2]. In studies [3-5] complex mechanical loads on surgical gowns during operations were analysed. It was found out that surgical gowns subjected to quasistatic and cyclic loads. These textiles were loaded by tension, pressure, shear and friction loads. The subjected loads were given approx. 0.4 N for underarm and up to approx. 20 N for elbows. These findings reveal a necessity of research for experimental determination of morphological changes (micro- and mesopores) under loads that come out during use. Therefore it is important to analyse the change of pore morphology under loading, in order to understand the barrier behavior in use. Existing measurement methods for the in situ and non-destructive analysis of pores are inadequate. Porosity measurement with liquid displacement method is suitable for the analysis of pores. However porosity changes under loads can't be measured in situ. For this reason in this study the existing "liquid displacement" method is developed further for the in situ determination of pore size changes.

2. Experimental

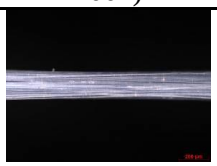
2.1. Materials

Polyester (PES) is the commonly used synthetic fiber for the manufacturing of barrier textiles. Excellent physical properties make it eligible for defining the barrier properties of fabrics. Choosing yarns with different construction parameters like fiber fineness, yarn fineness and yarn texture gives a high number of possibilities in order to define the barrier effect of the fabrics. For present research

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PES multifilament yarns were purchased from Trevira GmbH, Germany. Table 1 shows the further yarn parameters and their mentioned effect on porosity.

Table 1. Properties of PES yarns used for weaving.

Yarn type	Warp yarn	Yarn fineness [dtex]	Filament fineness [dtex]	Filament diameter [µm]	Yarn view (light microscopy, 100x)	Mentioned effect on porosity
Yarn 1	Multifilament 100 dtex f40 flat	100	2,5	15,9		As warp and weft yarn for the model weave
Yarn 2	Multifilament 100 dtex f128 flat	100	0,78	9,8		As weft yarn/ Effect of filament fineness

2.2. Weaving and process parameters

Considering the model weave construction parameters 6 woven fabrics were chosen for the experimental analysis of this study. These woven fabrics have different fabric constructions, yarn constructions and weave densities. On the basis of sample 1 as a standard model weave other samples were woven by varying the weft yarn, weave density index and fabric construction. Multifilament yarns with different construction parameters like fiber fineness were used as weft yarns. Weave density indices of the woven fabrics were calculated according to Walz-Luibrand [6].

PES barrier fabrics were woven on a rapier weaving machine PTS4/S EasyLeno (Lindauer Dornier Gmbh, Germany). Shed geometries of the weaving were asymmetric (lower shed > upper shed) and a full-width temple guide was used because of the insufficient function of the conventional temple guides. The fabrics were desized on an air flow washing unit (Then, Hong Kong) and then fixed at a coating machine (Coatema Coating Machinery GmbH, Germany) at a temperature of 200°C.

Table 2. Properties of PES yarns used for weaving.

Weave number	Warp yarn	Weft yarn	Warp density [cm^{-1}]	Weft density [cm^{-1}]	Binding	Weave density index	Machine speed [rpm]
1	Yarn 1	Yarn 1	68	36	Plain 1/1	0,9	300
2	Yarn 1	Yarn 1	68	27	Plain 1/1	0,68	300
3	Yarn 1	Yarn 1	68	22	Plain 1/1	0,55	300
4	Yarn 1	Yarn 2	68	36	Plain 1/1	0,9	300
5	Yarn 1	Yarn 1	68	39	Twill 2/2Z	0,55	300
6	Yarn 1	Yarn 1	68	48	Twill 2/2Z	0,68	300

2.3. In situ pore size measurements

Mean flow pore sizes and pore size distributions within the fabrics were determined using liquid displacement method by using pore size meter PSM 165 (Topas GmbH, Germany) according to the testing method based on ASTM E 1294-89 and ASTM F316-03. A perfluorocarbon (surface tension σ = 16 mN/m) was used as testing fluid. Here the challenge was the accomplishment of a measurement with the existing sample holder with connecting it to the pore size meter in order to measure the in situ pore sizes. The sample holder should have the capability to fit to the biaxial sample under loading to take the measurement. For these reasons the test instrument was modified by adding a special sample

holder which is connected to the standard measuring cell in Topas GmbH (Figure 1). This special sample holder is designed to measure the pore sizes and pore size distributions when the fabrics are under monoaxial or biaxial tension. Air supply is connected with a hose from the test instrument to the special sample holder. The woven fabric under tension can be clamped with this special sample holder and air can be carried to the clamped sample with this hose. The height of the sample holder is also adjustable to achieve to clench the tensioned woven fabric.

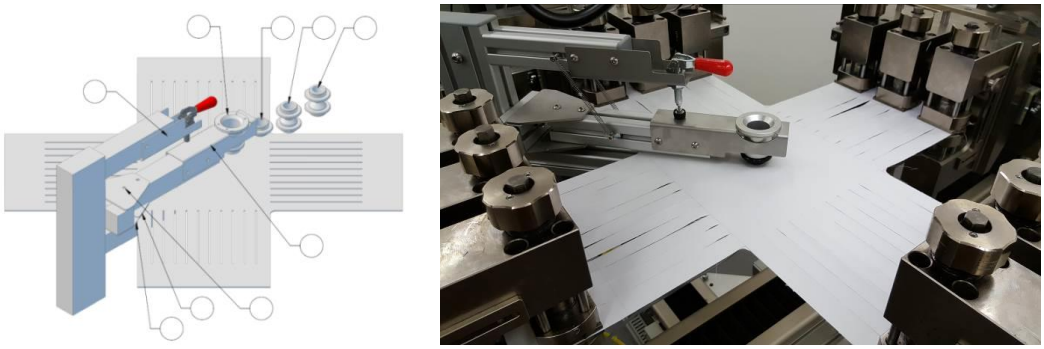


Figure 1. Construction of the special sample holder (left, Topas GmbH) and in situ measurement of pore sizes under biaxial loading (right).

2.4. Biaxial loading

PES barrier fabrics were biaxially loaded in different loading situations from 30% to 50% of the breaking load of the fabric. The samples were acclimatized for all the tests mentioned below at standard atmosphere for conditioning according to DIN EN ISO 139:2005 + A1:2001. A biaxial tensile test machine (Zwick GmbH, Germany) was used for the measurements. As biaxial tensile tests were performed at different loads with respect to breaking force of fabrics, therefore breaking forces of PES high density woven fabrics in warp and weft directions were measured according to the textile testing methods based on DIN EN ISO 13934-1. A uniaxial tensile test machine UPM 1445 (Zwick GmbH, Germany) was used for the determination of breaking forces. Table 3 shows the breaking forces of barrier fabrics which are used for the analyses.

Table 3. Breaking force values of PES woven fabrics.

Sample number	Breaking force in warp direction [N]	Standard deviation	Breaking force in weft direction [N]	Standard deviation
1	1080	88.1	659	20.9
2	1220	18.9	502	6.65
3	1190	53	433	11.5
4	1150	67.3	660	14.3
5	1320	69.4	758	10.5
6	1350	52.4	911	8.53

There is not a defined sample dimension for the tensile testing of textiles under biaxial loading. The sample dimensions were adapted from the norm MSAJ/M-02-1995 which is a testing method for elastic constants of membrane materials. Figure 2 shows the adapted cross sample with dimensions. Sample preparation, type of loading and machine speed were reconsidered from the past experiences [7]. Barrier fabrics were loaded at biaxial tensile testing machine from 30% up to 50% of breaking load. A preloading force of 5 N was used for testing and the machine was set at 5 mm/min extension rate.

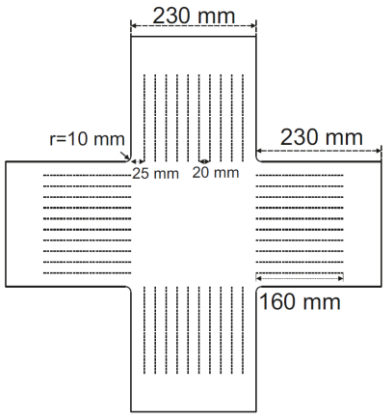


Figure 2. Sample dimensions for biaxial testing adapted from testing method according to the norm MSAJ/M-02-1995.

3. Results and discussion

3.1. Pore size distribution under loading

Figure 3 shows the cumulative pore portions of chosen samples. Fabric and construction parameters of chosen samples are already given in Table 2. Pore portions without loading and under loading 30, 40 and 50% of breaking force are shown in following graphs. It is clear that in all samples the pore size distribution changes due to application of load. Furthermore it is also observed that pore size increased with increase in biaxial tensile loads. The largest enlargement is reported in sample 3, while the least change is observed in sample 1. In sample 3 the maximum pore size is around 16 µm without loading and after a loading of 50% it becomes around 221 µm. Under this loading, 16.4% of the pores are bigger than 16 µm, which shows that these pores come out after biaxial loading. The results show that larger mesopores in the plain woven fabrics lead to larger enlargement of pores after loading when a comparison was made between sample 1, 2 and 3. Sample 1 shows a maximum pore size of around 9 µm without loading and it becomes around 47 µm under a loading of 50% of breaking force. 19.1% of pore sizes are larger than 9 µm after loading of 50%, which is a higher value than the one in sample 3.

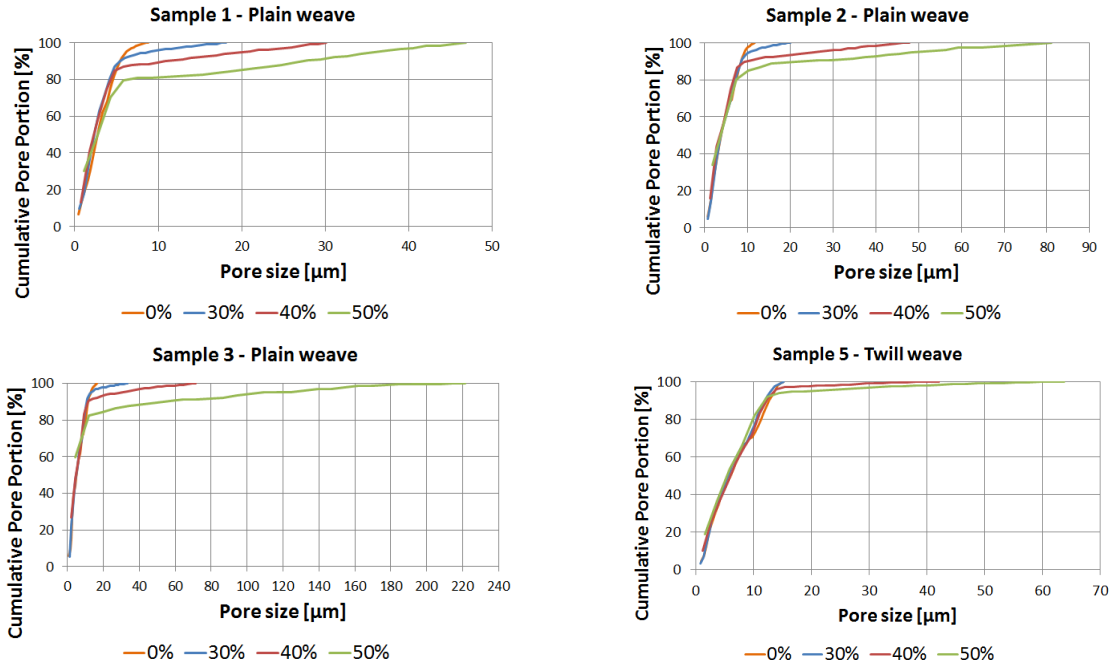


Figure 3. Cumulative pore portions of chosen samples.

Twill weave shows a different tendency when compared with plain weave having same weave density index. Under a loading of 50% of breaking force in sample 5 only 5.8% of pores are larger than the maximum pore size without tension, which is around 15 µm. This value is 16.4% in plain woven sample with same weave density index. The effect of loading to the pore sizes seems less in twill weave than in plain weave. The main reasons could be the bindings of fabrics which affect also to the permeability properties of these kinds of woven fabrics [1] and weft density of the fabrics; twill weave with same density index as plain weave has higher weft density (sample 3 and sample 5) . In twill woven fabrics the enlargement of the mesopores is not alike plain woven fabrics. In 1/1 plain woven fabrics a better orientation of yarns in 0° and 90° directions can be achieved when compared with 2/2 twill woven fabrics. This orientation difference could change the enlargement of mesopores under loading. Moreover, there is not a mentionable change at pore size range of sample 5 under loading 30% of breaking force. The mentionable change starts after 40% loading and the maximum pore size increases from around 15 µm to around 42 µm under 40% loading.

3.2. Mean flow pore sizes

Samples were evaluated in respect to their mean flow pore sizes in order to see the effect of fabric and yarn construction parameters. Figure 4 shows the comparison of mean flow pore sizes of 1/1 plain woven samples with different weave density indices according to Walz-Luibrand. It can be observed that under loading of 40% of breaking force there is an increase at mean flow pore sizes in all the samples. The change in the pore size distributions also influences the mean flow pore size values. Moreover a decrease of weave density index by decreasing the weft density leads to higher mean flow pore size values. This is also valid for under tensile loading measurements.

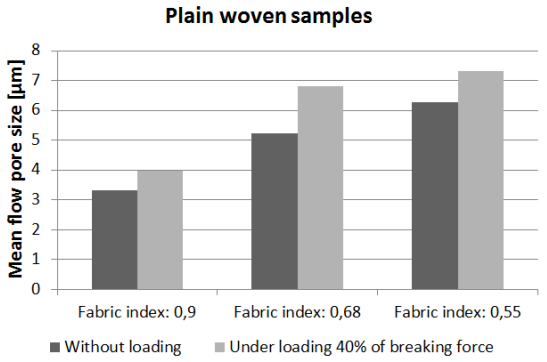


Figure 4. Mean flow pore sizes of plain woven samples with respect to fabric index.

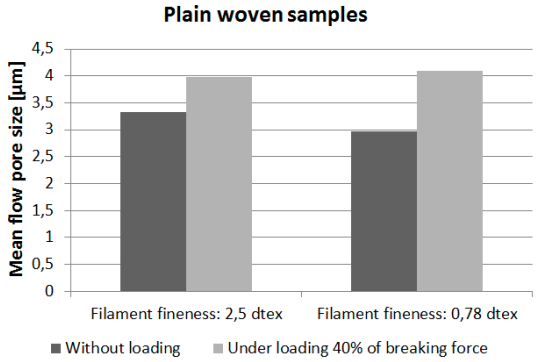


Figure 5. Mean flow pore sizes of plain woven samples with respect to filament fineness.

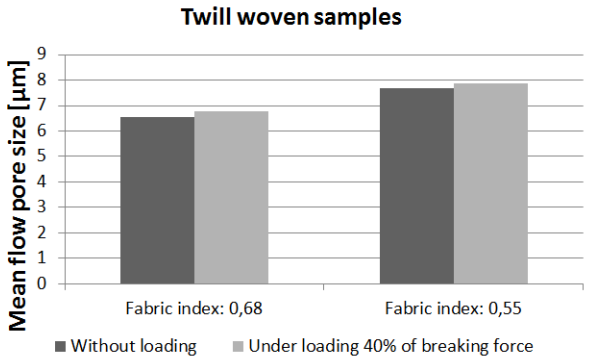


Figure 6. Mean flow pore sizes of twill woven samples with respect to fabric index.

Figure 5 shows the mean flow pore sizes of plain woven samples with respect to filament fineness. It is observed that both of the samples show an increase in mean flow pore size values under tension, but this increase is substantial in sample 4. Sample 4 shows a lower value of mean flow pore size than sample 1 in unloaded condition. This could be due to the effect of filament number, which changes the permeability properties of woven fabrics [1]. But it is hard to make the statement that sample 4 preserves its barrier properties under loading.

Figure 6 shows the comparison of mean flow pore sizes of 2/2 twill woven samples with different weave density indices. It is seen that the twill woven samples show a different trend than plain woven samples under loading. Increase in mean flow pore size values under tension is very small in comparison with plain woven samples. This could be because of the small change in pore size range in twill woven samples which was discussed above. Both findings show that loading has not a mentionable effect on pore size change up to 40% of breaking load. Increase of mean flow pore size values by decreasing the weave density is also valid with twill woven samples.

4. Conclusion

The pore size distributions and mean flow pore size values appear to change under tensile loadings and these changes can be recorded by the newly developed method. In general, pore size distribution of plain woven samples have higher tendency to change under biaxial tensile loads than pore size distribution of twill woven samples. Furthermore, there is not a significant change in pore sizes under 30% of breaking force in twill woven sample whereas significant changes are observed at 40% of breaking force. Furthermore, the change in pore size under loading is different depending upon weave density index, fabric construction and yarn construction. Sample with lower weave density index showed higher pore size changes under tensile loading. Changes in mean flow pore size values were also observed under tensile loading. Samples showed increased mean flow pore size values under tension. This increase was more prominent in plain woven samples than twill woven ones. Twill woven samples showed minor increase of mean flow pore sizes under tension. This is also valid for different weave density indices. From these findings, it can be inferred that in situ determination of pore sizes under loading with the new developed method showed promising results.

5. References

[1] Laourine E and Cherif C 2011 Characterisation of barrier properties of woven fabrics for surgical protective textiles *AUTEX Res. J.* **11** pp 31-36
[2] Havlova M 2013 Air permeability and constructional parameters of woven fabrics *Fibres & Textiles in Eastern Europe* **21** pp 84-89
[3] Altman K W, Mcelhaney J H, Moylan J A and Fitzpatrick K T 1991 Transmural surgical gown pressure measurements in the operating theater *American J. of Inf. Cont.* **19** pp 147-155
[4] Smith J W and Nichols R L 1991 Barrier efficiency of surgical gowns – Are we really protected from our patients pathogens *Archives of Surgery* **126** pp 756-763
[5] Smith J W, Tate W A, Yazdani S, Garcia R Y, Muzik A C and Nichols R L 1995 Determination of surgeon generated gown pressures during various surgical procedures in the operating room *American J. of Inf. Cont.* **23** pp 237-246
[6] Walz F and Luibrand J 1947 Die Gewebedichte *Textil Praxis Bd.* **2** pp 330-335
[7] Wendt E and Krzywinski S 2011 Uniaxiale und biaxiale Prüfverfahren zur Bestimmung des Deformationsverhaltens technischer Textilien *Tech. Text.* **54** pp 258-261

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