# QUALITATIVE EVALUATION OF PROTECTIVE FABRICS

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## *Abstract*

*Protective garments are designed to meet the dual needs of product/process protection and workers' safety and comfort. In this paper, a qualitative evaluation of woven protective fabrics has been presented. The fabric parameters which are most important from the point of view of the user's needs have been selected and analysed. Basic mechanical parameters such as breaking load, elongation at break and tear resistance were determined in certain example fabrics before and after the washing and sterilisation processes. The worker comfort was analysed by determining air and water vapour permeability and surface resistance. The barrier properties of fabrics were analysed by determining the efficiency of filtration and fabric porosity. The durability of fabrics was evaluated in respect of their ability to stand up to the washing and sterilisation processes, and of the analysis of fabric structure deformation under external loading.*

## Introduction

Quality requirements for product/process protection (PPS) differ according to different product applications [1]. Woven protective fabrics are mainly used for apparels. When in use they are exposed to many different loads which can affect the fabric structure and change its properties. For this reason the protective fabric should present high resistance to burst, abrasion and tears.

In modern industries such as pharmaceutics and electronics, some manufacturing processes should take place in clean-rooms up to Class 100 in order to ensure high product quality, as both the protective garment and the worker himself can be a source of undesirable pollution such as dust, microbes, particles of peeled epidermis and fibres [2]. It has been shown that microflora of the human skin includes numerous bacteria such as micrococcus (0.5-2 μm), staphylococcus (0.5-1 μm), corynebacterium (0.5-8 μm), and many others. These usually create irregular agglomerations of three or more elements of size 1 to 10 μm. It must be mentioned, however, that they are carried on the particles of peeled epidermis of diameter above 10 μm [3]. From this point of view, the most important requirement is that the protective fabric used for the garment should provide good particle penetration resistance.

Durability of fabric means, among others, the fabric's ability to stand up to washing and sterilisation techniques, as well as the deformation resistance of the fabric.

The other problem is wearer comfort, which usually means breathability of the fabric, i.e. air and water vapour permeability, and low surface resistance.

## Material

**Table 1:** Fabric construction details

| fabric | weave | Raw material | | | Twist [turns/m] | | No. of threads per dm | | Surface mass g/m2 |
|---|---|---|---|---|---|---|---|---|---|
| | | warp | conductive warp | weft | warp | weft | warps | wefts | |
| 70/3 | Twill 2/1 | Torlen PM TWY 84dtex f36t300 | Silvered 93 dtex f21 (56f20 37f1) t200S | PES Trevira CS 167 dtex f32t0 | 300 | 0 | 740 | 305 | 125 |
| 70/5 | Twill 2/1 | | | PES Torlen PMFY110dtex f96t0 | 300 | 0 | 750 | 350 | 113 |
| 96/5 | plane | PES Torlen PM FY WP TWY 84dtex f48 t200s | | PES Torlen PM FY WP 110dtex f96 t0 | 200 | 0 | 540 | 300 | 85 |

The fabrics designed in the Institute of Engineering of Textile Materials, Lodz, are destined for the microelectronic and pharmaceutic industries. The fabrics were diversified by different weave, raw material, warp and weft density and by applying the calendering process.

## Methods

All fabrics were tested using conventional methods. The main parameters tested which characterise the mechanical properties of fabric are breaking load and elongation, tear resistance in weft and warp direction, and abrasive resistance.

For 70/5 and 96/5 fabrics, the tests were performed by simulating multiaxial loads. The samples of fabrics were subjected to the tensile test in the direction of weft, warp and 45 deg. The deformation behaviour of the fabrics was analysed by determining the Poisson number calculated as a ratio between transverse and longitudinal strains at different stress levels. During the fabric relaxation strain fading was observed. The strains remaining in the fabric specimens at preset stages of the relaxation process were analysed [4].

To determine worker comfort, the air and water vapour permeability and electrical resistance were evaluated.

The fabrics' barrier properties analysed were determined using the following methods:

Efficiency of filtration of the sodium chloride aerosol was determined using the TSI 3030 sizing apparatus for a 10-min measurement period at a flow rate of 3 cm/s. Efficiency of filtration of silicon dioxide aerosol was determined using a ROYCO particle counter at the same flow rate. The aerosol particles had diameters from 0 to 0.75 μm for sodium chloride, and from 1 to 10 μm for silicon dioxide.

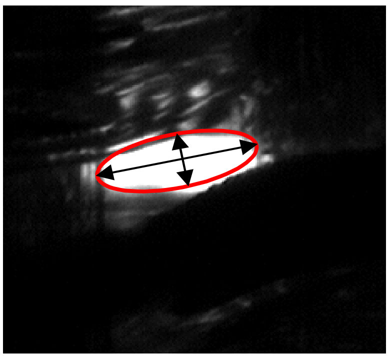


**Figure 1:** Measurement of the pore size

Fabric porosity was determined using image analysis methods. Images of fabrics were registered in transmitted light using a 140 magnification and an image resolution of 1024x1024, giving the length measurement unit of 0.5 μm. Initial analysis showed that pores were present only along some warp threads called 'critical', i.e., along threads containing silvered or carbon fibres used to assure good surface resistance. For plain weave fabrics, pores cumulated also along side warps in the reed splits. Images were registered along randomly chosen 'critical'" warp threads. Pores were identified and diameters and area of pores were determined using image analysis methods. For each sample of fabrics analysed, the number of pores per 10 mm of warp length was calculated.

The fabric durability was evaluated as follows:

The fabrics were washed and sterilised between 1 and 50 times. At each stage of the washing and sterilisation process –(W&S), parameters determining mechanical properties, comfort and barrier properties were calculated and compared using methods of statistical data analysis.

The fabrics were subjected to pulsatory loading in warp, weft and oblique directions for different load levels. The porosity of fabrics was determined at the preset test stages.

## Mechanical properties of fabrics

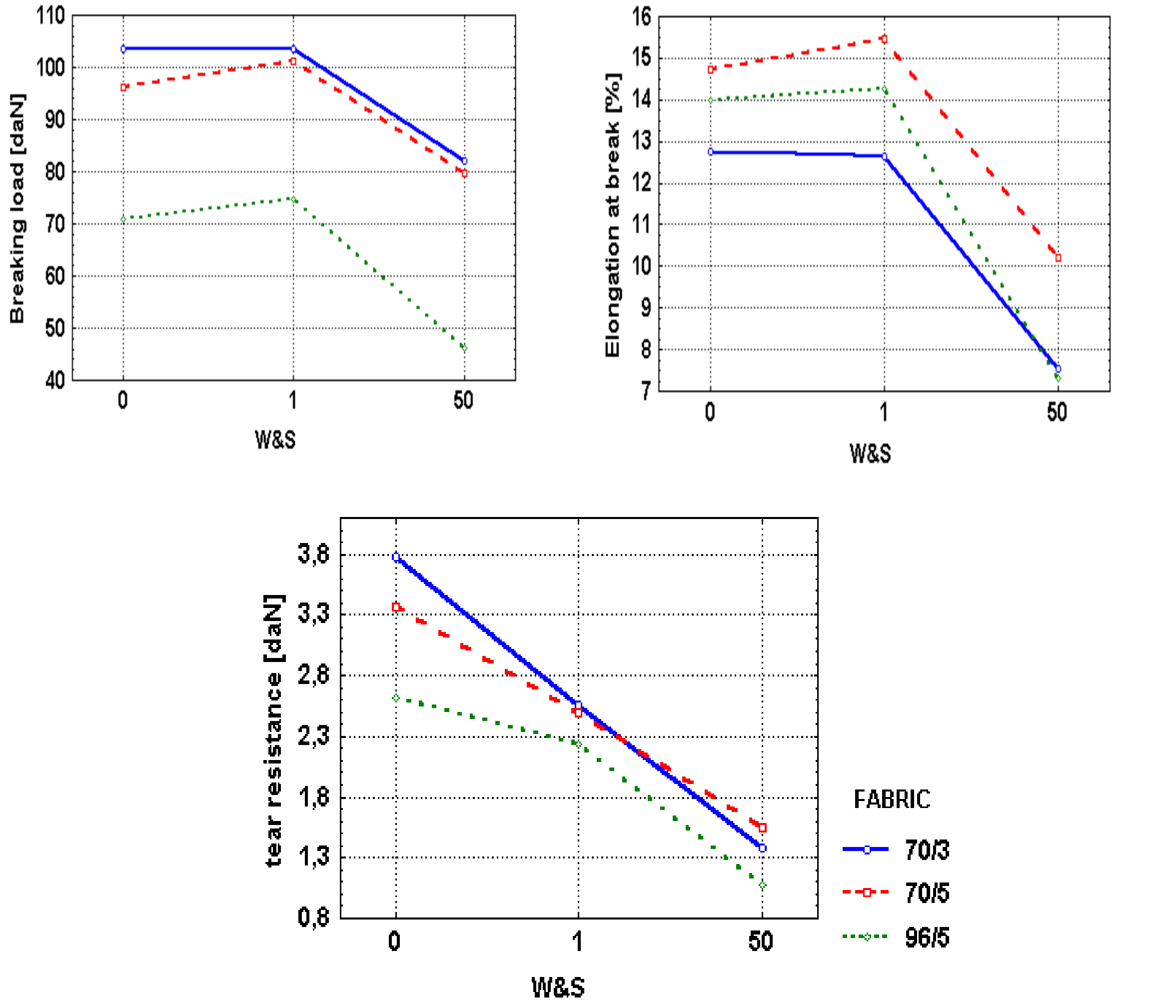



**Figure 2**: Mechanical parameters of fabrics before and after process of washing and sterilisation

Figure 2 presents the basic mechanical parameters of the fabrics. The diagrams represent mean values of parameters for samples of fabric in weft and warp directions. We note that the mean values of all parameters decrease significantly after 50 times of washing and sterilisation process in relation to their initial values. For all fabrics the breaking load and tear resistance are higher for calendered fabrics and in the warp direction. The difference in elongation at break for fabrics analysed is not statistically significant. All fabrics showed very high abrasion resistance.

## Comfort

When analysing the diagrams presented in Figure 3, one can see that initial values of air and water vapour permeability grow after washing and sterilisation, and are lower for calendered fabrics. Higher air permeability for 70/3 fabric in relation to 70/5 fabric results from the different properties of the yarn used for weft (lower number of filaments, textured). All fabrics show good surface resistance, varying from <$10^4$ ohm for 96/5 to <$10^7$ ohm for 70/3, which grows for 70/5 and 70/3 fabrics after washing and sterilisation. the lower resistance of 96/5 fabric results from the higher number of conductive warp threads.

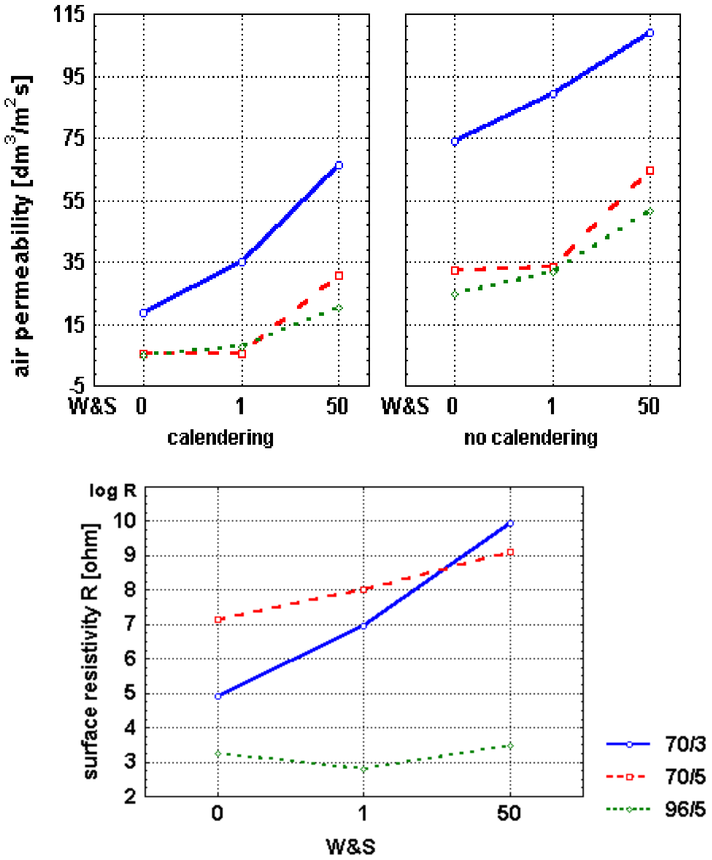
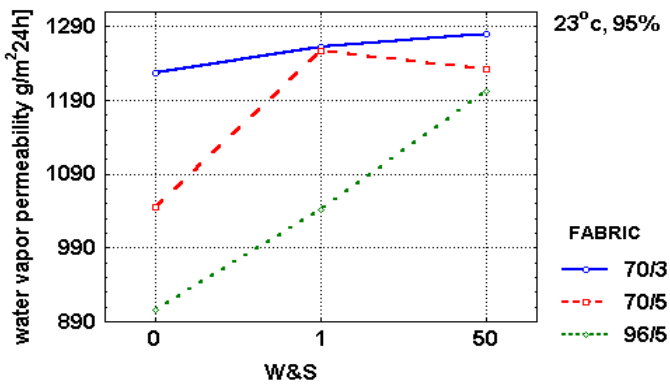



**Figure 3:** Parameters determining worker comfort

## Barrier properties

At the initial stage of research, two aerosols were proposed for analysing the barrier properties of fabric: a water solution of sodium chloride and a water suspensoid of silicon dioxide dust [5]. These two methods led to completely different conclusions. Further analysis of results of the efficiency of filtration of sodium chloride showed that during filtration some particles of aerosol were broken up, creating even smaller particles of diameter then 0.05 µm, so they could easily penetrate through the fabric. (It has been noted that in certain cases the number of particles in front of the fabric was lower than behind it). We can see that the results of efficiency of particle filtration are correlated with the results of air permeability (Figure 3). Thus the results obtained do not seem to be fully reliable from the point of view of particle penetration, and another method should be applied to determine the penetration of particles through the fabric, such as the method proposed by DuPont [6] using aloxite dust and Chrysolite asbestos fibres.



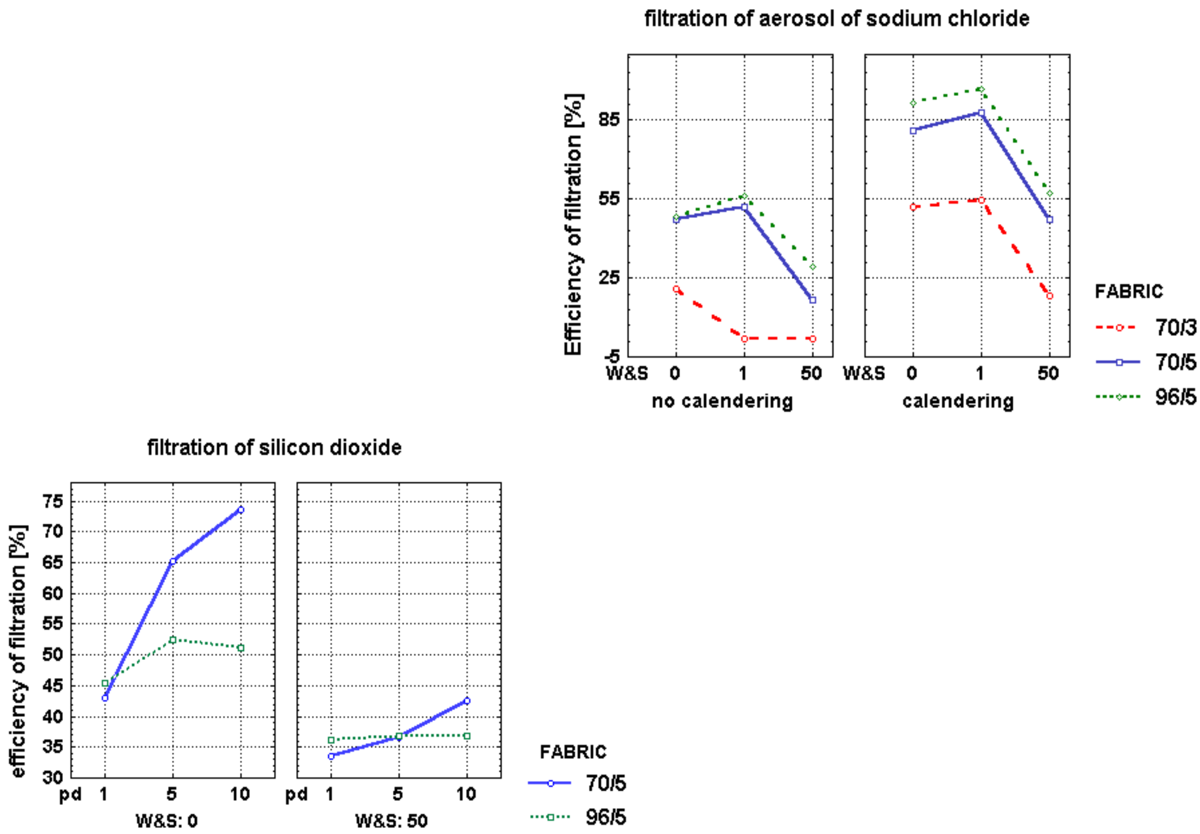




**Figure 4**: Efficiency of filtration of sodium chloride and silicon dioxide aerosols

At the next stage of research, the porosity of fabrics was analysed as a factor determining the fabric's particle penetration resistance . It has been assumed that the lower the number of pores and the smaller the pore size, the better the barrier properties of the fabric. The method of microscopic image analysis was applied as previously described. Pores were identified along randomly chosen 10-mm long sections of 'critical' warps and the number of pores per 10 mm was determined. To avoid possible mistakes connected with some difficulties in precise measurement of pores of smaller than 2 μm diameter, only pores of the diameter higher than 2 μm were taken into account in the comparative analysis of fabrics. The results of the analysis are shown in Figure 5.

When analysing the diagrams in Figure 6, one can see that the porosity of fabrics 70/3 and 70/5 shows similar features. No pores were identified before and after 1 washing and sterilisation in the fabric 70/5 calendered fabric, and only 1 pore in fabric 70/3. The number of pores rises after 50 W&S processes to 3 for calendered and 6-8 for uncalendered fabrics. At the same time the pore diameter grows, reaching 5 to 6 μm for uncalendered and 4-5 μm for calendered fabric after 50 W&S. Both the number of pores and the pore diameter are significantly higher for 96/5 fabric. The difference is even stronger if we consider the higher number of 'critical' warps in 96/5 fabric. For uncalendered 96/5 after the first W&S, both the number and diameter of pores decrease, and then significantly grow after 50 W&S.

There is a relation between the fabric porosity and the efficiency of filtration of silicon dioxide: fabrics with relatively high number of pores and high pore diameter provide a worse barrier against the penetration of particles through the fabric.

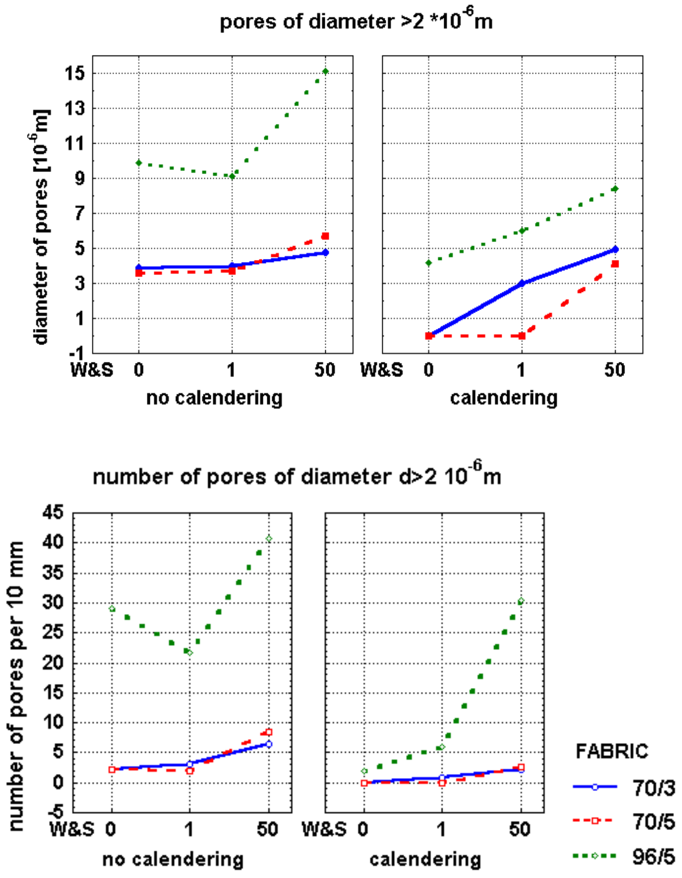



**Figure 5:** Fabric porosity by image analysis

## Fabric durability - washing and sterilisation

The diagrams in Figures 2-6 show most of the parameters before, after one and after 50 repeats of the washing and sterilisation process. Most of them either do not change their values or display insignificant changes from the point of view of fabric quality. After 1 cycle of W&S the value of breaking load remained the same, and decreased by about 25-30% after 50 cycles of W&S reaching 80 daN for 70/ fabrics and 50 daN for 96/5.

Tear resistance decreased from 30% for 70/3 to 11% for 96/5 after 1 cycle of W&S, and by 30% after 50 cycles of W&S, reaching 14N for 70/ and 10N for 96/5.

Elongation did not change after 1 cycle of W&S, and dropped by about 30-40% after 50 cycles.

The value of air permeability significantly increased after 1 cycle of W&S. The increase rate was still high during the next cycles of W&S, and reached its limit value after about 20 cycles. Water vapour increase was highest after 1 cycle of W&S, and did not change significantly after successive cycles.

Surface resistance did not change after 50 cycles of W&S for 96/5, and increased from $10^7$ohm to $10^9$ohm and from $10^5$ohm to $10^{10}$ohm for 70/5 and 70/7 fabrics respectively.

As described in the previous section, the barrier properties of fabrics depend on the number of cycles of W&S. The influence of washing and sterilisation is stronger for 96/5 fabric.

Tests have showed that the analysed fabrics can stand up to 20 cycles of W&S without significant change in their quality.

## Fabric durability – pulsatory loading

At the initial stage of the test, it was found that an applied load lower than 20 daN does not affect the fabric structure. Thus fabrics 70/5 and 96/5 calendered were subjected to pulsatory loading in warp weft and 45 deg directions at the following stages:

1. 50 cycles of 30 daN load with structure control after the $5^{th}$ and $25^{th}$ cycle.
2. 10 cycles of 50 daN load
3. Break

Before testing, and after each stage, the images of the same fabric sections were registered and analysed to determine their fabric porosity.

After 5 cycles of 30 daN load, the change in fabric porosity was noticed for 96/5 fabric for a load direction of 45 deg only.

After the first stage of loading, the 96/5 fabric showed significant increase in both the number of pores and pore diameter in all load directions, while 70/5 fabric showed no visible changes.

After the second stage, a further increase in number of pores and pore diameter was noticed in the 96/5 fabric, while in the fabric 70/5 very few pores of a diameter lower than 2 μm appeared. The increase in pore number and diameter was lowest in the 45 load direction, mainly due to high transverse deformation.

After applying the breaking load, the structure of 96/5 fabric was completely destroyed with pores of average diameter higher than 15 μm on each thread interlacement for weft and warp load directions, and of about 5 μm in 45 deg load direction. At the same time, the porosity of the 70/5 fabric increased to a much lower degree, with a maximum pore diameter lower then 10 μm

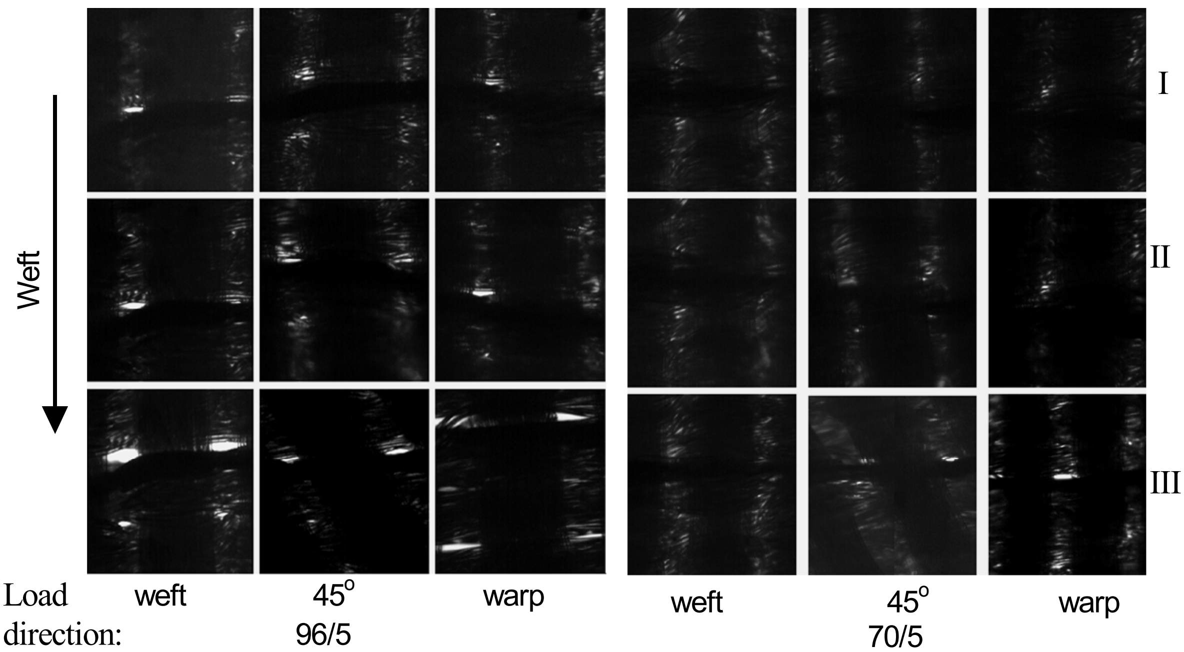



**Figure 6**: The effect of pulsatory loading on the fabric porosity. Images of the same 0.5 mm-long sections of 96/5 and 70/5 fabrics: I – before loading, II – after 50 cycles of 30 daN load, III – after the breakage.

## Deformation behaviour of fabrics - multiaxial loading

To simulate multiaxial loading, 96/5 and 70/5 calendered fabrics were subjected to the tensile test in warp, weft and 45 deg directions. At the preset stress levels transverse and longitudinal strains were determined and the Poisson number was calculated. The results are presented in Figure 7. It has been found that for 96/5 fabric the Poisson number is lower for warp and weft direction and is higher for 45 deg direction of load than the corresponding values for 70/5 fabric, which results from the different fabric structure.

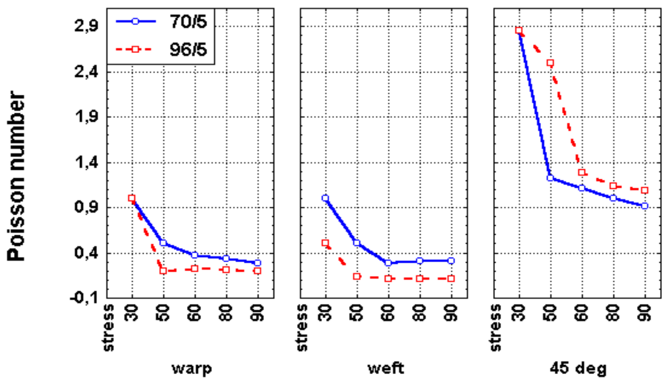



**Figure 7:** Poisson number at different stress levels

During the fabric relaxation, strain fading was observed. The strains remaining in the fabric specimens on preset stages of relaxation process were analysed. It has been found that the decrease in strains was more rapid for 70/5 fabric. After applying a 90 daN load, the strains remaining in the fabric specimen after a practically infinite relaxation time, measured as a percentage of initial strains, were about two times lower in warp and 45 deg load direction and 30% lower in the weft load direction than the corresponding strains in 96/5 fabric specimens.

## Conclusions

On the basis of the test results, the quality evaluation of protective fabrics can be made. According to the user's needs, different parameters can have different importance in the fabric evaluation. For instance, it has been shown that plain weave fabric can provide a better barrier against the penetration of extremely small particles. Due to higher floating lengths, particles can penetrate through the twill weave fabric between fibres, especially with high velocity. The same remark applies to textured multifilaments as a warp and weft. On the other hand, in the case of plain weave, it is more difficult to apply a number of warp and weft threads high enough to obtain low fabric porosity, which can result in worse barrier properties for particles of higher diameter. It has also been shown that 70/5 fabric represents better durability, especially in respect to deformation behaviour and its ability to stand up to cyclic loading when compared with 96/5 fabric. The conclusion can be drawn that for optimal fabric design and evaluation, the user needs and potential hazards which the fabric can be exposed to should first be determined.

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