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Image Analysis for Testing and Evaluation of the Barrier Effect of Surgical Gowns

Dilibaier Aibibu, Beata Lehmann, Peter Offermann
Dresden University of Technology, Institute of Textile and Clothing Technology
D-01062 Dresden

ABSTRACT

Clothing is used for protection against particle loaded liquids in many working environments. An important field is the operating theatre, where surgical gowns need to serve as a barrier between the infection source and clinical personnel as well as providing satisfactory wearing comfort. The micro-organisms, like bacteria and viruses, which are responsible for the transmission of disease are of various sizes and geometries. Comfort is important for the healthcare providers who often have to wear their surgical gown for several hours while doing strenuous work under hot lamps.

Principally, woven fabrics, laminates and nonwovens can be used. Membranes and coatings tend to impair the wearing comfort. Hydrophobic polyester woven fabrics are currently the only reusable material for surgical gowns which are able to fulfill these two contrary demands at the same time. They are used for short surgical operations with a small amount of liquid. Even though there are many different fabric structures on the market, until recently, their pore structure combined with their barrier performance have not been investigated at a basic level. This paper reports some of our on-going research work and results on this topic /1-5/.

Keywords: surgical fabric, nonwovens, wovens, laminates

Aims
Previous research has focused on the evaluation of the practical barrier function of the textile and the level of comfort for the wearer. But the reasons that explain the results have generally not been examined. It is necessary to know the influences of the fabric's constructional parameters, such as the fineness and cross-sectional shape of the filaments, the linear density of the filament yarns, the type of weave and the fabric density (or woven fabric count), on the pore structure within the fabric. The objective of the present study was to examine the pore structure of commercially available woven fabrics with different constructions by viewing the fabric cross-sections. These examinations were aimed at assessing the effect of the fabric parameters on fabric density. It was anticipated that this study would facilitate the selection of those filaments, yarns and fabric parameters that would produce improved barrier performance.

Choice of fabrics
After having analysed 29 commercial fabrics woven from polyester multifilament yarns, which were exclusively constructed in plain or twill weaves, three typical fabrics were selected for characterisation in this paper (Table 1). The chosen fabrics had

similar characteristics with regard to filament fineness and cross-sectional shape, yarn linear density, type of weave and fabric density.

The plain woven fabric, P 4, shows filament cross-sections that are deformed by texturing. It has similar filament fineness in the warp and weft yarns (Fig. 1 left). The cross-sections of the warp filaments of the plain woven fabric, P 5, are triangular and the weft sections are round (Fig. 1 centre). P 6 is a twill woven fabric with coarse round weft filaments and finer round warp filaments (Fig. 1 right).

Table 1: Parameters of the selected fabrics used in operating gowns

sample	type of weave	fineness of filament in dtex		cross section of filament		number of filaments in the yarn		fineness of filamet yarn in tex		yarn density /10cm		fabric density /6/
		warp	weft	warp	weft	warp	weft	warp	weft	warp	weft	
P 4	plain	0.85	0.85	deformed	deformed	112	102	9.5	8.5	456	370	0.55
P 5	plain	2.60	1.25	triangular	round	48	198	13.0	25.0	572	313	0.98
P 6	twill $\frac{2}{1}$	0.60	1.35	round	round	206	69	9.5	12.5	458	362	0.37

P 4 **P 5** **P 6**

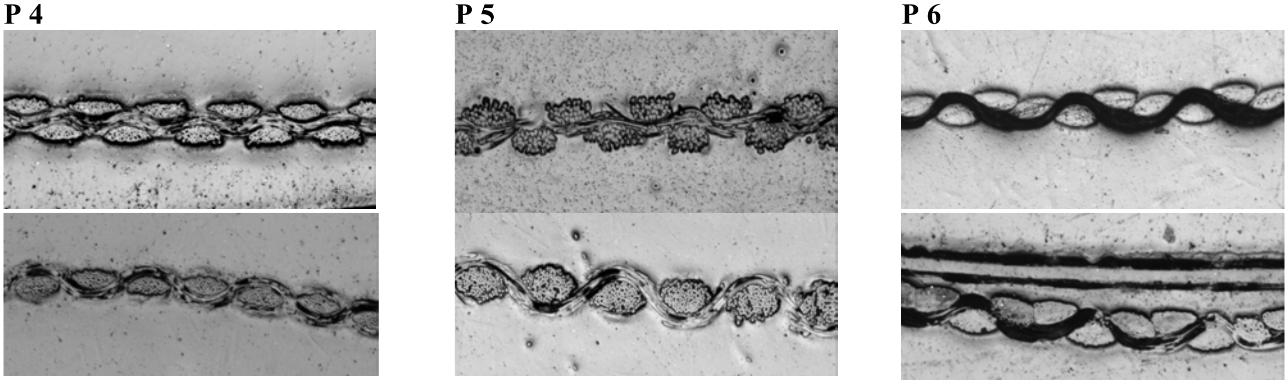


Fig. 1: Light optical microscope images of the wovens – above: warp section, below: weft section

Preparation of samples

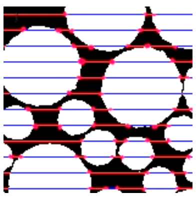
First it was necessary to prepare the cross-sections of the operating room gown fabrics for microscopic imaging. Textile samples were vertically embedded in epoxy resin in a cylindrical sample support to cut either warp yarns (= warp section) or weft yarns (= weft section). After the sample had hardened, it was removed and polished.

The inner pore structure was determined with images obtained transversely to the fabric plane by light-optical microscopes, laser scanning microscopes and scanning electron microscopes. In the presentation, we refer to light-optical microscope images. Because of the resolution range, the light-optical microscope could only visualise filament distances as small as 0.22 µm, which covers the range of the size of major bacteria (up to 0.5 µm), but not all viruses (0.01 to 0.3 µm).

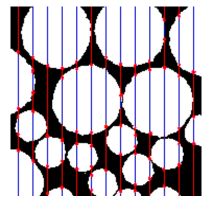
Determination of the pore structure of the woven fabrics

The microscopic images were converted into binary form. The fabric was represented as a two-phase texture (filaments and pores). However, it was essential that the two components could be clearly identified by contrasting them sufficiently. In order to determine the geometrical parameters of the pore structure (pore width and pore length, pore area and pore form factor), we use the linear analysis and the Quant methods of ImageC ® by Aquinto. Measurements were made in rectangular measurement fields on the measuring line. Each sample was analysed in several orthogonal measurement fields to obtain a pattern repeat by sampling at random.

Pore width and pore length were measured using the linear analysis methods. The distances between cutting lines and the cutting direction (horizontal and vertical) were chosen at random. The distance between individual filaments corresponded to the pore width (horizontal) and the pore length (vertical), which were obtained automatically (Fig. 2). A bar diagram was constructed to give the pore size distribution.



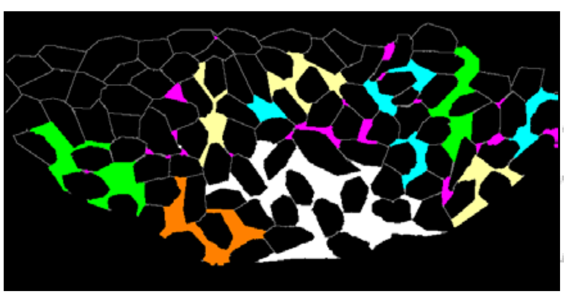
horizontal



vertical

Fig. 2: Determination of filament distances (chosen distance of cutting lines: 2 µm)

Quant is an extended object-related image analysis technique for particles. Its basis is a very efficient object search algorithm, the so-called contour tracing method. This method can be applied to determine the pore areas and form factors of closed pores (Fig. 3) in accordance with the classification previously set.



pore area [µm²]		P4 and P 5:	P 6
1	pink	0<…<=40	0<…<= 2
2	blue	40<…<= 80	2<…<=10
3	yellow	80<…<= 120	10<…<=20
4	Green	120<…<= 200	
5	orange	200<…<= 500	20<…<= 40
6	white	>500	>40

form factor: (1 = circle, 0.87 = square, 0 ≈ long stretch pore)

A. $f=4\pi F/U^2$

F: area [µm^2] U: perimeter [µm]

Fig. 3: Determination of pore areas and form factors

Results and discussion

Pores in the filament yarn:

Figure 4 and Figure 5 demonstrate that the pore spaces were smallest in the filament yarns of P 6 where the filaments had a round section.

The coarse filaments with a triangular section in P 5 produced a pore share of 30.53 % for pores larger than 10 µm, which is unlikely to provide a barrier for bacteria. For the warp yarn of P 6, which consisted of round microfilaments, it was found that 93.5 % of all pores were smaller than 4 µm and there were no channels between pores. This suggests that such a textile structure is likely to provide an effective barrier and prevent the transmission of bacteria. Analysis of the pore area (Fig. 6, 7) confirmed the results obtained by the linear analysis.

In P 5, 92.5 % of the pores were larger than 40 µm^2. In P 6, this applied only to 1.9 % of all pores. The larger the pore area, the less circular it was.

P4 **P5** **I. P6**

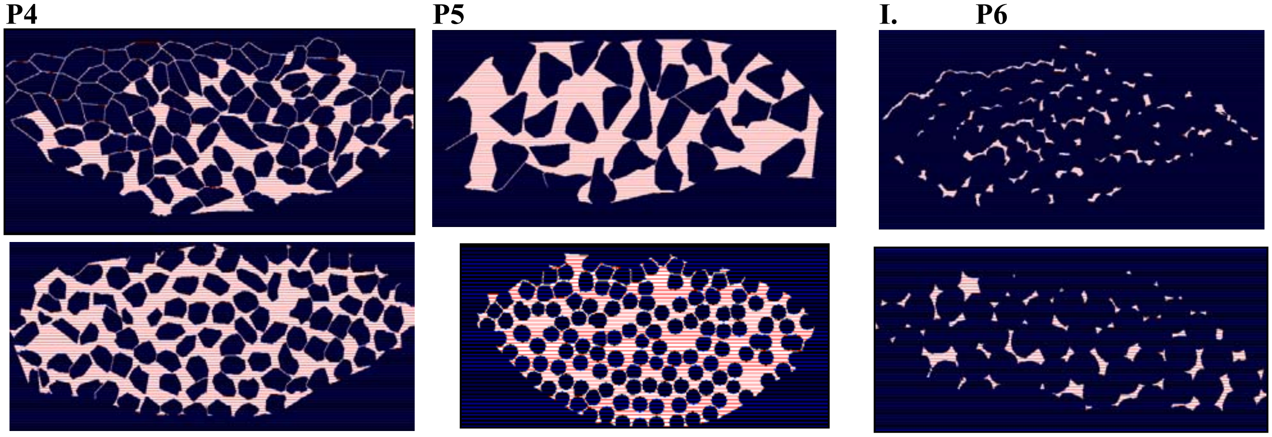


Fig. 4: Cross-section of filament yarns (above: warp yarn, below: weft yarn) and horizontal linear analysis

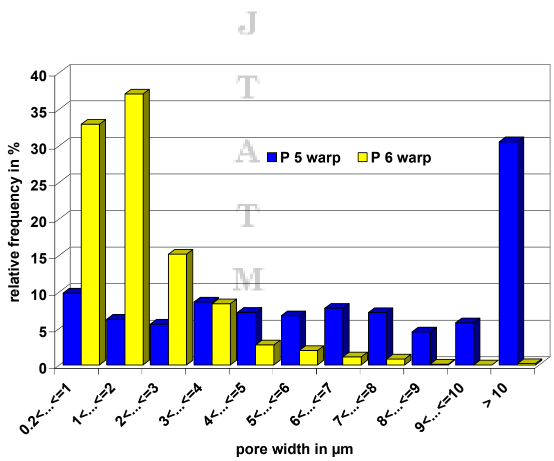


Fig. 5 Relative frequency distributions of the pore classes for fabrics P 5 and P 6

P 4 **P 5** **P 6**

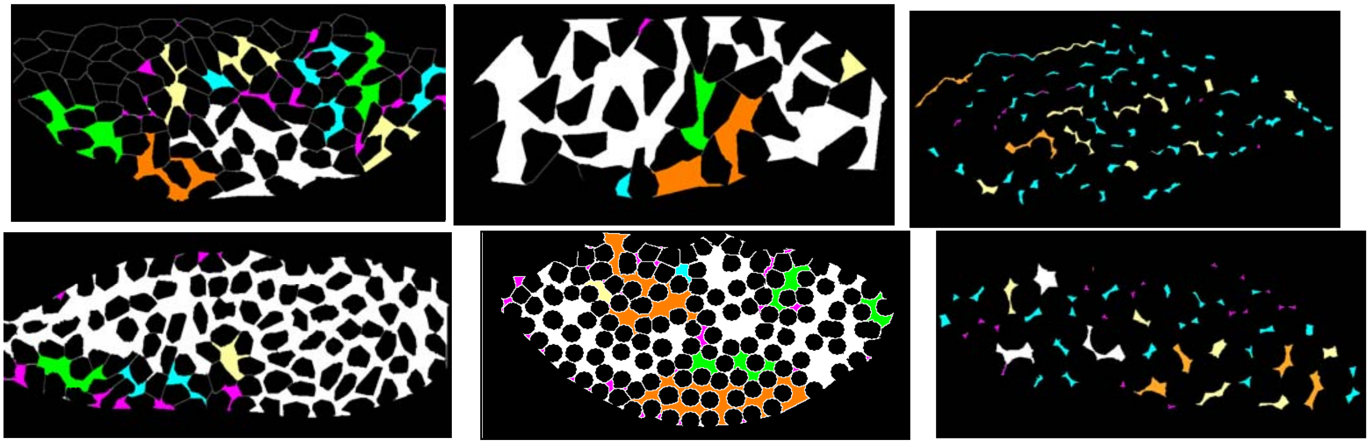


Fig. 6: Cross-sections of multifilament yarns and the determination of pore areas and form factors (above: warp yarn, below: weft yarn)

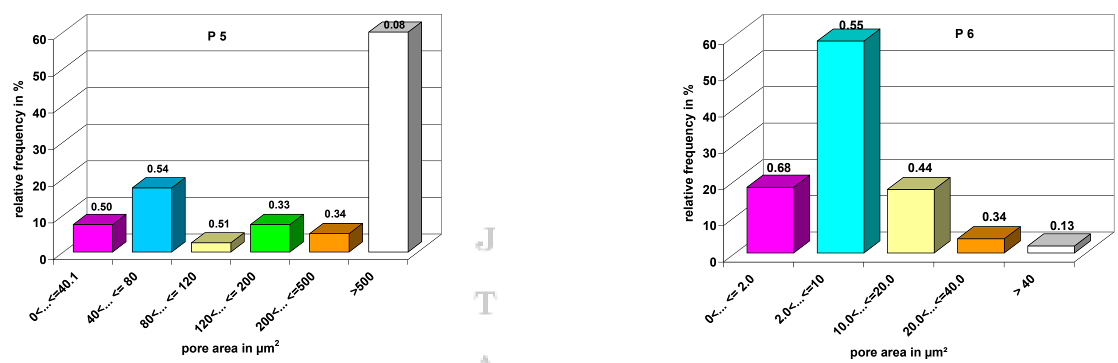
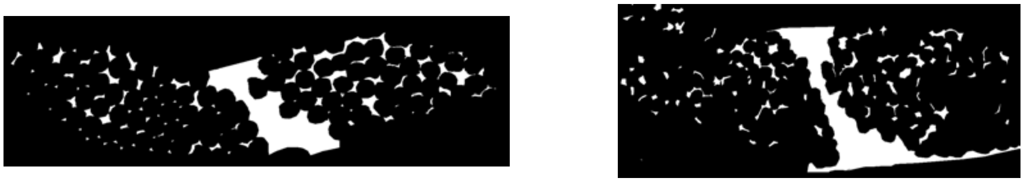


Figure 7: Relative frequencies distributions of the pore areas and associated form factors of the closed form areas in P 5 and P 6 warp sections

<u>Pores resulting from the fabric structure:</u>
Plain weave (Fig. 1): The weft yarns had more crimp within the fabric, while the warp yarns, as might be expected, had less crimp. In P 4 (warp section), the warp yarns were overlapping each other so that three filament yarns were found to be partially on top of each other. This has the potential to improve the particle barrier performance.

Twill weave (Fig. 7): On the left side it was shown that in the twill weave (P 6) the pores between two weft yarns (12.6 tex) were large because the yarns were comparatively thick. Although thinner filament yarns were used as warp yarns, the spaces between the filament yarns were also wide (Fig. 7 right). This applied to almost all pores between two warp yarns or two weft yarns and it was confirmed in Fig. 8. The maximum distance between filament yarns was 81.33 µm.



P 6 (weft section) **P 6 (warp section)**

Fig. 7: Pores between multi filament yarns in twill weave (P 6)

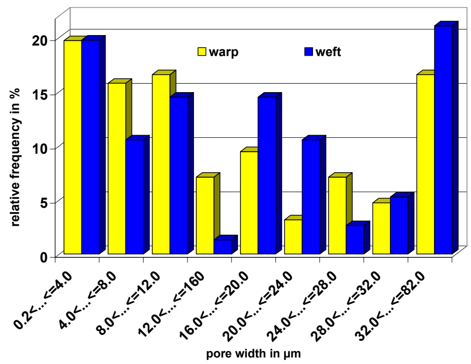
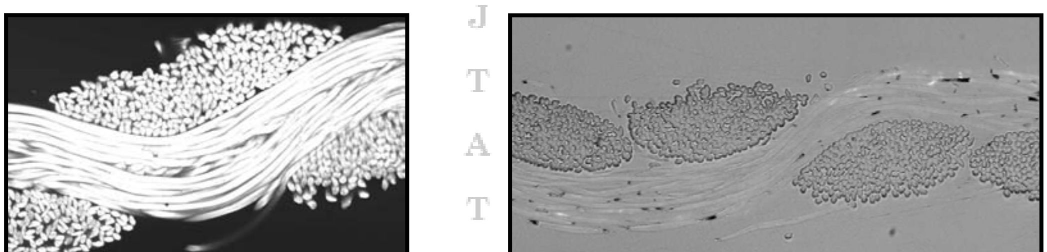


Figure 8: Relative frequency distributions of the pore classes in the warp and weft sections resulting from the fabric structure (P 6)

This confirms our previous finding in which another twill weave fabric K 2/2 (warp: 10 tex, 730 ends/10 cm, weft: 20 tex, 590 picks/10 cm) was examined /5/. The low pick count and coarse weft yarns in this fabric also resulted in large pore spaces in the weft cross-section. In the warp cross-section, the two adjacent finer warp yarns (10 tex) were pressed more tightly against each other (Fig. 9).



warp section **weft section**

Figure 9: Pores resulting from the fabric structure - P 3 /5/

Moreover, the results of penetration tests with micro-spheres and observation of the contamination on the back of the fabric confirmed that most of the fabrics in fact have minimal barrier effect (Fig. 10).

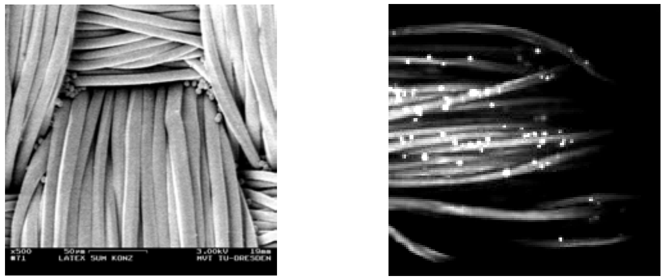


Figure 10: Latex micro spheres (5 µm) (left) and gold micro-spheres (1 µm) on the back of the fabric after the penetration test

Summary and outlook

1. The image analysis methods linear analysis and Quant of ImageC® by Aquinto are well suited to characterise the pore structure of woven fabrics. They allow good measurement of the horizontal and vertical pore spaces, pore areas and form factors of closed pores with sufficient accuracy and reliability.
2. It is necessary to optimise commercially available surgical woven fabrics which are made of polyester (PET) filament yarns so as to ensure that they can provide a barrier function. The penetration of particle-loaded liquids can be explained by the pore geometry.
3. Pores are found both within the multifilament yarn and within the woven fabric structure. Their size, geometry and number depend on the yarn and fabric parameters.
4. Round cross sections of the filaments are favourable for a maximum packing density. Triangular cross-sections and coarser filaments result in wider pore spaces.
5. The selection of the appropriate type of weave as well as woven fabric count (yarn density) are important factors for improving the barrier performance. Twill weaves are particularly critical since they may have large pores between two weft yarns at the crossing points.
6. The objective for future study is to model the theoretical density of woven fabrics for operating room protective gowns. By assuming that the model fabrics are woven from multifilament yarns with known circular filament cross-sections and with predetermined warp and weft yarn counts, it will be possible to simulate the 3D fabric structure /6/. Subsequently, the filament cross-sections, filament counts and yarn spacing can be varied to improve fabric density.

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