MATERIALS TECHNOLOGY

CALCULATION OF THE POROSITY OF SINGLE- AND MULTI-PLY CLOTH MADE OF CHEMICAL FIBRES

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A system for automated calculation of the structure of multi-ply fabrics, SETKA, by qualitatively and quantitatively estimating the pore position parameters and shape of the channels in single- and multi-ply fabrics is examined. The SETKA system allows considering the characteristics of flow of gas or liquid through a fabric, increasing the reliability of calculations of its permeability.

The porosity is an important property of industrial fibres used for reinforcement and sewing work clothes, and as elements in filters or contact devices. Standard evaluation of the porosity with the fibre positioning density and average diameter is totally insufficient for obtaining such characteristics of cloth as the air and water permeability, flow of filler in filling of the structure of the composite, surface area of the fibre substrate, etc.:

$$A = 1 - \left( \frac{d_{wa}}{P_{we}} + \frac{d_{we}}{P_{wa}} - d_{wa} d_{we} \right) P_{wa} P_{we},$$

where $A$ is the porosity coefficient of the cloth, $A = S_{\text{pore}} / S$ ($S_{\text{pore}}$ is the total pore area in the repeat of the cloth, $S$ is the area of the repeat); $d$ is the average diameter of the fibre in the plane of the cloth; $P$ is the fibre density, the number of fibres per unit of length, and subscripts "wa" and "we" refer to the warp and weft, respectively.

Even for single-ply cloth, the orthogonal position of the flat fibres assumed by Eq. (1) is far from the truth; the geometry of multi-ply cloth widely used in the areas listed above is much more complex. We will examine the following questions of the position of pores in cloth:

- the error of Eq. (1) caused by inhomogeneous compression of the fibres and their deviation from straight lines in the plane of the cloth;
- the change in the pore size over the thickness of the cloth;
- the through porosity of the cloth in directions different from the normal to its surface;
- the position of the pores in sections of the cloth parallel to its surface.

The studies were conducted by the computer experiment method using the SETKA 3.1 system for automated calculation of the structure of cloth and the methods in [1-5]. The SETKA software uses the following input data on the cloth: weave structure, coded with a special algorithm [4, 5]; density of the cloth over warp and weft; warp and weft parameters (linear density, fibre section size in the free state, diagrams of compressive and bending strength). The program solves equations expressing the conditions of the bending energy minimum of warp and weft fibres and their equilibrium under the effect of the forces of interaction of intersecting fibres. The shape of bending of the fibres and their position in space are determined as a result. This makes it possible to find any geometric parameters of the structure of the cloth and construct images of the sections of the cloth.

Our goal was to demonstrate the qualitative characteristics of the position of the pores in cloth and the possibilities of the SETKA 3.1 system for studying the porosity of cloth. This was done with the fabrics whose parameters are reported in Table 1 and Fig. 1. Porosity coefficient $A$ (or simply "porosity") and the average pore size (diameter) in the fabric $d_{\text{pore}}$, calculated with the equation $d_{\text{pore}} = 4S_{\text{pore}} / L$, where $L$ is the total perimeter of all pores in the repeat of the fabric (so-called hydraulic diameter), were used as the porosity characteristics.
### TABLE 1. Cloth Parameters

<table>
<thead>
<tr>
<th>Description</th>
<th>Weave</th>
<th>Linear density of fibres, tex</th>
<th>Density of cloth, fibres/dm</th>
<th>Compression coefficient**</th>
<th>Thickness of cloth, mm (calculated)</th>
<th>Volume filling coefficient, % (calculated)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Single-ply serge</td>
<td>Serge 2/1 (Fig. 1a)</td>
<td>111</td>
<td>200</td>
<td>0.8</td>
<td>0.64</td>
<td>84</td>
</tr>
<tr>
<td>B Paper machine drying net</td>
<td>¾-ply satin (Fig. 1b)</td>
<td>Complex Lavan fibres</td>
<td>Complex polyester fibre in polyamide shell</td>
<td>310</td>
<td>186</td>
<td>0.7</td>
</tr>
<tr>
<td>C Three-dimensional cloth</td>
<td>Fig. 1c</td>
<td>Complex filament</td>
<td>Lavan fibres</td>
<td>111</td>
<td>160</td>
<td>0.8</td>
</tr>
</tbody>
</table>

*In the numerator: data on warp; in the denominator: data on weft.

** Compression coefficient: ratio of the fibre diameter in the cloth in the direction normal to its surface to the diameter of the fibre in the free state.

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Inhomogeneous compression of the fibres and their deviation from straight lines. The fibres in a fabric are compressed due to the interaction of warp and weft; the compression coefficient in the transverse direction is 0.4-0.6 for complex fibres (weak twisting) or 0.6-0.8 (strong twisting) and 0.7-0.9 for yarn [1, 2]. The mechanisms of compression of textile fibres were investigated in detail in [6], and a correlation was established between the fibre compression coefficient $\eta$ and its flattening in the transverse direction $\eta^*$, which can be approximated by the ratio $\eta^* = 1/\eta^{0.25}$ in the indicated range.

Figure 2a, b graphically illustrates the change in the position of the fibres in cloth in the presence and absence of compression of the fibres. The forces of interaction of warp and weft in serge-weave fabrics divert them from straight lines; this causes a significant change in the pore shape (Fig. 2c, d).

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![Fig. 1. Weave of cloth (section along warp).](image-url)