Textile hand is related to such fabric properties as smoothness, softness, hardness, roughness, thickness, weight, warmth, sharpness, rigidity, etc. The most important of them are considered to be smoothness (28%) and softness (22%), while the importance of the rest properties (the total number of which is 21 [1]) gradually decrease, down to 0.3%. In the meantime, fabric handle and performance properties change after their finishing treatment [2,3].

The method of testing fabric by extracting it through the hole of a ring has been known from old times. Recently, new textile hand evaluation methods based on pulling a disc-shaped specimen through a rounded hole have appeared [4]. Special attention must be drawn to the works of the Denkendorf Institute of Textile Technology ITV (Germany) [5,6], which present the original ITV-Griff-Tester apparatus and describe investigations of the behaviour of socks and other garments under pulling test conditions. Analogous investigations have been performed at the Kaunas University of Technology (Lithuania) [7]. A universal test unit (KTU-Griff-Tester), operating together with either the standard tensile testing machine or an individual drive, has been created there. It allowed a specimen pulling curve P-H (force-deflection) to be registered, and images of specimen shape variations to be captured.

The KTU pulling test unit ensures even changes of distance between the limiting plates over the scale of 0-25 mm with the accuracy of 0.05 mm. It has a set of convertible pads and a digital camera, and can be used to evaluate the hand of almost all types of textiles, both traditional and technical (Figure 1).

At the first stage of the research performed at the Kaunas University of Technology, theoretical investigations of the process of specimen pulling through a rounded hole were performed:
- three cases of specimen pulling through a rounded hole were analysed [8];
- the conditions of specimen jamming in the hole of the pad or between the limiting plates were defined [9];
- the regularities of the specimens’ outer contour roughness variations were determined [10].

At the second stage of the research, experimental investigations of the behaviour of different textile materials (woven, knitted and coated fabrics) were performed, and optimal testing conditions have been chosen.
Test Method

Almost all the parameters of KTU-Griff-Tester unit match those of other devices for analogous purposes. The stand is made of plexiglass while the supporting plate is made of antireflect glass. The technical characteristics of test unit are as follows (Figure 2): radius of specimen - 56.5 mm; number of pads - 5; radiiuses of holes in pads - 7.5, 10, 12.5, 15, 20 mm; radius of the indentor ρ - 5 mm; rate of deformation - 100 mm/min.

The radius r of the pads hole and the distance h between the limiting plates were chosen in respect to the thickness δ of the tested material:

\[ \pi r > 2\pi r \delta \]  

and

\[ \pi r h > 2\pi r \delta \]  

The above conditions do not allow the specimen to jam in either the hole of the stand (equation 1) or between the limiting plates (equation 2). The wavy shape of the specimens’ outer contour was defined and predicted, making the assumption that it can be described as a sine curve, the length of which is in close relation with the arc length of a certain ellipse [10].

Results and Discussion

On the basis of equations 1 and 2 optimal testing conditions were chosen. According to these equations, the relationship between the two parameters \( R_i \) and \( R_{i'} \) on one hand and specimens thickness δ and ratio \( \delta/h \) on the other were determined by showing the limits where the specimen \( (R=56.5 \text{ mm}) \) does not jam in either the hole of the pad (Figure 3) or between the limiting plates (Figure 4). The optimal radiiuses (in millimetres) of the pads hole for the material not to be jammed are as follows:
When the specimen \( R \) is pulled through the hole \( r \), the value of deflection \( H \) increases but the radius \( R \leq r \). For idealised materials, which do not experience any type of deformation, this will happen when \( H \) is 52 mm \((r=10\, \text{mm})\); 53 mm \((r=15\, \text{mm})\) and 54 mm \((r=20\, \text{mm})\), respectively. However, for real materials \( H>H^* \).

The typical curves (Figure 6) of five underwear knitted fabrics pulled through a rounded hole (Table 1) prove that reliable characteristics of the material’s resistance to such types of deformation can be obtained by strictly maintaining the values of the \( h/\delta \) ratio constant. It is evident that the shape of the curves and their main parameters (the slope angle \( \tan \alpha \) of the curves’ initial part, the maximum pulling force \( P_{\text{max}} \) and the maximum deflection height \( H_{\text{max}} \)) significantly differs, i.e. the different materials withstand the pulling process in a different way. It may seem from the first view that the softest material is \( V \) and the hardest is \( G-1 \), but this is not enough data to fully characterise textile hand.

In this research seven criteria were chosen to describe fabric hand. They were as follows:

- \( \tan \alpha \) – the slope angle of the \( H-P \) curves’ initial zone;
- \( P_{\text{max}} \) – the maximum value of force (N);
- \( H \) – the deflection value, which corresponds to \( P_{\text{max}} \) (mm);
- \( \Delta \delta \) – the variation of material thickness (%) due to the changes of measurement loading, e.g., from 1 up to 5 N;
- \( \Delta H = H_{\text{max}} - H^* \) the difference between the maximum deflection value and its idealised (theoretical) value \( H^* \) \((H^*=52\, \text{mm}, \text{when } r=10\, \text{mm})\);
- \( h \) – the distance between limiting plates (mm);
- \( m \) – the surface weight of the specimen (g/m²).

Of all these criteria, the \( \Delta H \) criterion is of exclusive importance, because it depends greatly upon the anisotropy level of the tested material (Figure 7).

Knitted fabrics \( V \) and \( R \) (Table 1) are highly anisotropic. In the pulling process their rounded shape turns into an oval (Figure 8) and the values of their pulling height are significantly higher than that of fabric \( G-2 \). The latter material, being stiff and almost isotropic, is pulled through the hole of the pad without even reaching the level of \( H^* \). On the other hand, the oval-shaped specimen is pulled more easily than the disc-shaped one, but it does not mean that the low value of \( P_{\text{max}} \) indicates that the tested material is soft. That may be the result of fabric anisotropy, which is significantly well assessed by the parameter \( \Delta H \).

**Figure 6. Typical pulling curves of knitted materials: a) \( h=5.5 \delta \); b) \( h=\text{const}=2\, \text{mm} \).**

**Figure 7. Dependence between ratio \( h/\delta \) and the maximum value \( H_{\text{max}} \) of the specimen’s pulling height.**

<table>
<thead>
<tr>
<th>Sign</th>
<th>Stitch or weave</th>
<th>Content</th>
<th>Thickness ( \delta ) (mm)</th>
<th>Surface weight, ( \text{g/m}^2 )</th>
<th>( \varepsilon_s/\varepsilon_l )</th>
</tr>
</thead>
<tbody>
<tr>
<td>G-1</td>
<td>plain knit</td>
<td>100% cotton</td>
<td>0.53</td>
<td>153.6</td>
<td>1.93</td>
</tr>
<tr>
<td>G-2</td>
<td>warp-knit tricot</td>
<td>50% cotton, 50% PA</td>
<td>0.39</td>
<td>96.8</td>
<td>0.65</td>
</tr>
<tr>
<td>M</td>
<td>weft-knit 1x1 rib</td>
<td>100% cotton</td>
<td>0.75</td>
<td>175.6</td>
<td>7.58</td>
</tr>
<tr>
<td>V</td>
<td>weft-knit 2x2 rib</td>
<td>100% cotton</td>
<td>0.79</td>
<td>142.7</td>
<td>12.5</td>
</tr>
<tr>
<td>R</td>
<td>interlock 1x1 rib</td>
<td>100% cotton</td>
<td>0.87</td>
<td>213.5</td>
<td>-</td>
</tr>
<tr>
<td>A</td>
<td>hopsack weave</td>
<td>50% wool, 50% PA</td>
<td>0.70</td>
<td>254.4</td>
<td>-</td>
</tr>
</tbody>
</table>
The sum of the above-mentioned criteria (Figure 9) sufficiently well characterises those material properties (smoothness, softness, hardness, roughness, thickness, weight, etc.), which are considered to be related to fabric hand. For the determination of these criteria, a thickness gauge, scales and a KTU-Griff-Tester test unit are needed. The analysis of criteria and the optimisation of their quantity and structure is still ongoing. In the future the quantity of criteria may be different.

The test data has proved that all the mentioned criteria are reliable. This data states that all six materials have a range of hand degradation as follows: V (1.0) - M(1.8) - R(2.4) - G-2(2.5) - G-1(3.4).

A comparative analysis of diagram areas has shown that fabric V is better than the rest by 1.8-3.4 times.

Conclusions

The absolute values of the measured P and H parameters are significantly affected by the quality of the holes' edges (chamfer angle and cleanness).

The anisotropy level of the material tested greatly influences not only the shape of the $H$–$P$ curve but also the geometry of the deformed (i.e. pulled) specimen.

The selection of optimal testing conditions must be carried out in respect to the thickness $\delta$ of specimen, i.e. the $r$ and $h$ values must be chosen according to the $\delta$ value, e.g., $r > \sqrt{2\delta}$ and $h/\delta = \text{const}$.

A more qualitative evaluation of textile hand can be made on the basis of the complex of criteria, the majority of which are obtained in the pulling process.

References