# Changes of the Knitted Fabric Properties due to Exposure to Outdoor Natural Weathering

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**ABSTRACT**
In order to investigate the changes of knitted fabric properties due to exposure to outdoor natural weathering, a series of single jersey fabrics made from different raw materials was produced. The fabrics were exposed to summer weather conditions in duration of three months. The exposure of knitted fabrics to outdoor natural weathering in the summer period affected all investigated properties, namely, structural properties, tensile properties and heat resistance. The most significant changes were: the vertical density increased up to 31%, the mass per unit area increased up to 26%, the breaking force decreased in both directions for up to 54% and the heat resistance decreased up to 18%.

**Keywords:** knitted fabric, outdoor natural weathering, fabric parameters, heat resistance, tensile properties

**INTRODUCTION**
Outdoor-exposure tests are needed to evaluate the performance of materials when exposed to solar radiation. If a fabric is exposed to a higher dosage of radiation, it is likely to experience the higher degradation of fibers. Eichert noticed that, besides UV exposure, air pollution has big influence on degradation of coated industrial fabrics [1]. Zhang et al. in accelerated weathering tests of wool fabrics investigated photo yellowing of wool fabrics irradiated by different lamps. The results show that one should be cautious when accelerated weathering tests are performed on spectrum-sensitive textile materials [2]. Jarvinen and Puolakka investigated weathering of polyaniline-treated polyester fabrics, where fabrics were subjected to intensive water shower, humidity, cold and UV light in the laboratory. It was shown that weathered fabrics have good tolerance for all tested conditions [3]. Degradation characteristics were studied in soil, water and simulated weathering conditions by Khan et al. The loss of tensile and bending properties of the samples due to weathering is represented [4]. Polypropylene composites were also studied by Shubhra et al. Degradation studies were carried out by accelerated and natural weathering. The mechanical properties were evaluated and it was found that glass fiber/PP composites degrade more rapidly compared to silk/PP composites [5]. Yanagi et al. report an investigation of the deterioration mechanism of aged silk fabrics. The results indicate that silk decomposes first in the amorphous region with aging [6]. The investigation carried out by Dierickx and Berghe [7] was focused on the change of tensile properties due to natural weathering. The results show that the effect of weathering is material dependent, and that ultraviolet stabilized materials show only a continuously slight decrease in tensile strength with exposure to time. The effects of simulated weathering on the tensile strength and tear strength of single-fiber and blended fabrics were the focus of investigation performed by Barnett and Slater [8]. Their results show general similarity of behavior with individual variations, where molecular bonding explanations were suggested. Furthermore, four-modes of abrasion testing were used on fabrics and the results show that degradation of fabrics differ in each case [9]. Efforts were also made to compare the degradative effects produced in cotton and other textile fibers by unfiltered light and natural weather exposure tests, where the sunlight is believed to be the chief degrading factor [10].

The parameters related to comfort of fabrics have been the focus of many investigations for years, but due to a number of influencing parameters, still represents challenge for extended research.

The investigation presented in this paper focused on the exposure of knitted fabrics to outdoor natural weathering. The intention was to determine the amount by which all the parameters related to wear comfort (heat resistance, tensile properties) change due to weathering. The obtained information should be relevant and used practically in order to facilitate future design of knitted products that could accomplish the requirements set by consumers.

## EXPERIMENTAL

### Material preparation

To study the properties of knitted fabrics, 100% cotton, 50/50% cotton/modal, 100% viscose, 100% lyocell, and 100% polyester yarns in counts of 17 and 20 tex were produced. The yarn properties are shown in the *Table I*. They refer to the following properties:

- yarn count (Tt) - determined by the use of skein method, as described in ISO 2060 [11],
- number of twists (Tm) - determined on torsiometer using the untwist/retwist method, according to ISO 17202 [12],
- yarn diameter (d) - measured from the yarn images obtained using an Olympus BX51 microscope equipped with camera,
- parameters of yarn unevenness: number of thin places (Ntn), number of thick places (Ntk), number of neps (Ntn), and coefficient of mass variation (CVm) measured using the Keisokki evenness tester,
- tensile properties: breaking force (F) and breaking elongation ($\varepsilon_B$) measured on a dynamometer Statimat M produced by Textechno, according to ISO 2062 [13],
- number of fibers in lengths of 2, 4, 6 and 8 mm determined using the equipment produced by Zweigle company, and
- coefficient of yarn friction ($\mu$) determined using the F-meter G 534 produced by Zweigle, according to the ASTM D 3108-07 [14].

TABLE I. Yarn parameters.

| Raw material | Tt, tex | Tm, $m^{-1}$ | d, mm | Ntn | Ntk | Nn | CVm, % |
|---|---|---|---|---|---|---|---|
| cotton | 19.9 | 742 | 0.18 | 0 | 13 | 15 | 11,5 |
| cotton | 16.9 | 842 | 0.16 | 0 | 10 | 18 | 11.2 |
| cotton/ modal | 19.9 | 801 | 0.18 | 0 | 8 | 15 | 11.1 |
| cotton/ modal | 16.8 | 870 | 0.17 | 0 | 10 | 38 | 12.3 |
| viscose | 19.8 | 802 | 0.18 | 0 | 13 | 30 | 12.3 |
| viscose | 16.8 | 806 | 0.17 | 0 | 3 | 38 | 11.6 |
| lyocell | 20.1 | 770 | 0.18 | 0 | 3 | 18 | 10.8 |
| lyocell | 16.8 | 851 | 0.17 | 0 | 0 | 23 | 11.2 |
| polyester | 20.0 | 684 | 0.20 | 0 | 0 | 0 | 5.9 |
| **Raw material** | **F, cN** | **$\varepsilon_B$, %** | **$n_1$** | **$n_2$** | **$n_3$** | **$n_4$** | **$\mu$** |
| cotton | 292.9 | 5.6 | 52 | 20 | 1 | 1 | 0.15 |
| cotton | 245.5 | 4.9 | 50 | 16 | 1 | 1 | 0.14 |
| cotton/ modal | 401.6 | 5.2 | 45 | 6 | 0 | 0 | 0.19 |
| cotton/ modal | 227.8 | 4.5 | 38 | 4 | 0 | 0 | 0.14 |
| viscose | 417.2 | 13.3 | 35 | 6 | 0 | 0 | 0.15 |
| viscose | 360.7 | 13.7 | 37 | 5 | 0 | 0 | 0.14 |
| lyocell | 713.4 | 9.8 | 60 | 22 | 1 | 1 | 0.13 |
| lyocell | 550.5 | 9.1 | 46 | 9 | 0 | 0 | 0.15 |
| polyester | 363.0 | 11.9 | 32 | 5 | 0 | 0 | 0.18 |

Legend: Tt - yarn count, Tm - number of twists per 1 meter, d - yarn diameter, Ntn - number of thin places on 1000 m, Ntk - number of thick places on 1000 m, Nn - number of neps on 1000 m, CVm - coefficient of mass variation, F - breaking force, $\varepsilon_B$ - breaking elongation, $n_1$ - number of fibers of length 2 mm, $n_2$ - number of fibers of length 4 mm, $n_3$ - number of fibers of length 6 mm, $n_4$ - number of fibers of length 8 mm, $\mu$- mean value of friction coefficient

Using the described yarns, a series of 9 single jersey knitted fabrics were produced. The fabrics were produced on the circular knitting machine Relanit E, gauge E28 with 48 knitting systems made by Mayer & CIE.

The grey knitted fabrics were additionally finished. The finishing of knitted fabrics was performed in industrial conditions, according to the recipe that is usually used for finishing of such materials. Due to the fact that different raw materials were used, two recipes were defined. The intention was to kept the recipe unchanged (where applicable) in order to avoid the influences of different recipe to the change of observed properties. The first recipe was used for finishing of cotton, cotton/modal, viscose and lyocell fabrics (fabrics assigned with letters C, CM, V and L; *Table II*). Those fabrics were bleached at 98ºC for 60 minutes, dyed with dyestuff produced by Ciba (rinse for 10 min at 50ºC, neutralized for 10 min at 70ºC, soaped twice for 10 min at 95ºC, rinsed for 10 min at 70ºC and rinsed for 10 min cold) and softened. The second finishing recipe was used for finishing of polyester fabric only (designed as P1 in *Table II*). This fabric was bleached at 80ºC for 30 minutes, dyed on 130ºC for 35 minutes and finally softened.

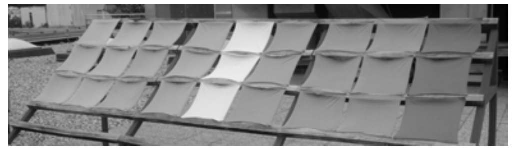
TABLE II. Knitted fabric designation.

| Nr. | Sample | Yarn count, tex | Raw material |
|---|---|---|---|
| 1 | C1 | 20 | cotton |
| 2 | C2 | 17 | cotton |
| 3 | CM1 | 20 | cotton/modal |
| 4 | CM2 | 17 | cotton/modal |
| 5 | V1 | 20 | viscose |
| 6 | V2 | 17 | viscose |
| 7 | L1 | 20 | lyocell |
| 8 | L2 | 17 | lyocell |
| 9 | P1 | 20 | polyester |

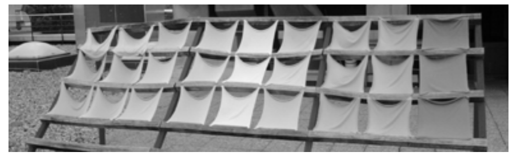
**Exposure of Fabrics to Outdoor Natural Weathering**

Exposure of knitted fabric to outdoor natural weathering by direct weathering was carried out using the test rack made of untreated wood that was mounted on a support (*Figure 1*). The exposure angle was fixed at 45°, facing the equator. The climate in which the samples were exposed was, according to Trewartha's modification of Köppen's climate classification [15], classified as Dfa – humid continental with severe winters, no dry season and hot summers (more than 9ºC for 4-7 months of year). The exact geographic location was latitude: 45° N and longitude: 16° E).

Specimens were exposed in an unstrained state (direction of fabric courses was parallel to the ground line) in such a manner that there is a free flow of air against the front and back of the specimens – so called open exposure. The samples were exposed to summer weather conditions in duration of three months (from July to October). During the exposure, the specimens were periodically inspected to ensure that they were properly attached to the exposure rack [16]. The number and dimensions of the test specimens were those specified in the appropriate test method for the heat resistance measurement [17].



a.



b.

FIGURE 1. The exposure of knitted fabrics: a. the start of exposure, b. the end of exposure.

The observed climatic factors during the exposure period were total solar radiant exposure, air temperature, relative humidity and rainfall. The parameters referring to the climatic conditions during the period of exposure are given in *Table III*. The temperature and relative humidity are given as a monthly mean of daily mean, while the precipitation is given as monthly total of rainfall.

TABLE III. Climatic conditions during the test

| Duration of exposure | Total solar radiant exposure, J cm$^{-2}$ | Temperature, °C | Relative humidity, % | Precipitation, mm |
|---|---|---|---|---|
| 15.07.-31.07. | 12211 | 20,4 | 67 | 63,3 |
| 01.08.-30.08. | 16622 | 23,2 | 61 | 15,6 |
| 01.09.-31-09. | 13740 | 20,3 | 63 | 42,0 |
| 01.10.-15.10. | 5305 | 12,5 | 71 | 26,5 |
| **Total in season** | **47878** | **19,1** | **66** | **147,4** |

**Measurement of Fabric Properties**

For both, unexposed and exposed knitted fabrics were determined essential structural parameters: horizontal density, vertical density, density per cm$^2$, thickness and mass per unit area. The horizontal and vertical density (Dh and Dv) were determined by counting the number of stitches on a length of 10 mm. The stitch density (D) was determined by multiplying the number of courses and wales per unit area. Knitted fabric thickness (t) was experimentally determined using a thickness meter with a pressure of 10cNcm$^{-2}$. The mass per unit area (m) was determined by weighing a knitted fabric sample with an area of 1 dm$^2$.

To test the heat resistance of textiles, the sweating guarded hotplate (SGHP) was used. During the testing of heat resistance, the power supplied to keep the plate temperature at 35ºC (the temperature of human skin) was measured. Heating was provided by distributed resistance wire on the inner surface of each part. The temperature measurement within the part was carried out using thermistors. Before the start of the measurement, specimens were conditioned for 24 hours at 20°C and 65% relative humidity. During the tests, the sweating guarded hotplate was placed into an air conditioned chamber where the following conditions were established and maintained: 20°C and 65% relative humidity of the air. The velocity of airflow was 1 m $s^{-1}$. The specific thermal resistance of textile materials ($R_{ct}$) was determined as the quotient of the temperature difference between the measuring plate and the air and the specific heat flux through the fabric sample [17]. As proposed in the standard, for each specimen were performed three measurements plus a single measurement of a bare plate before each measurement. The fabric tensile properties were measured in the directions of courses and wales using the dynamometer Textechno [18].

## EXPERIMENTAL RESULTS

The results of measured fabric parameters before and after the exposure are given in the *Table IV*.

TABLE IV. The results of measured knitted fabric parameters.

| Sample | Values of parameters before exposure | | | | |
|---|---|---|---|---|---|
| | Dh, loops/ cm | Dv, loops/cm | D, loops/cm² | t, mm | m, g m⁻² |
| C1 | 15,5 | 16,0 | 248 | 0,43 | 148,10 |
| C2 | 16,0 | 17,0 | 272 | 0,38 | 127,54 |
| CM1 | 16,0 | 18,0 | 288 | 0,42 | 150,44 |
| CM2 | 16,0 | 18,0 | 288 | 0,38 | 127,71 |
| V1 | 15,5 | 18,5 | 286 | 0,40 | 150,20 |
| V2 | 16,0 | 19,0 | 304 | 0,36 | 131,10 |
| L1 | 16,0 | 17,0 | 272 | 0,40 | 150,18 |
| L2 | 16,5 | 17,0 | 280 | 0,35 | 128,08 |
| P1 | 15,5 | 17,0 | 263 | 0,38 | 149,38 |
| Sample | Values of parameters after exposure | | | | |
| | Dh, loops/ cm | Dv, loops/cm | D, loops/cm² | t, mm | m, g m⁻² |
| C1 | 15,0 | 21,0 | 315 | 0,40 | 171,57 |
| C2 | 16,0 | 20,0 | 320 | 0,37 | 135,72 |
| CM1 | 16,0 | 22,0 | 352 | 0,41 | 174,19 |
| CM2 | 15,0 | 20,0 | 300 | 0,37 | 134,27 |
| V1 | 14,0 | 23,0 | 322 | 0,38 | 189,53 |
| V2 | 14,0 | 22,0 | 308 | 0,35 | 158,50 |
| L1 | 15,0 | 21,0 | 315 | 0,36 | 171,37 |
| L2 | 16,0 | 21,0 | 336 | 0,33 | 139,03 |
| P1 | 15,5 | 18,0 | 279 | 0,35 | 153,32 |

Legend: Dh - horizontal density, Dv - vertical density, D - density per $cm^2$, t - fabric thickness, m - mass per unit area.

The results of measured heat resistance are given in the *Table V*.

TABLE V. The heat resistance of knitted fabrics before and after exposure.

| Sample | Values of parameters before exposure | | Values of parameters after exposure | |
|---|---|---|---|---|
| | $R_{ct}$, $m^2KW^{-1}$ | CV, % | $R_{ct}$, $m^2KW^{-1}$ | CV, % |
| C1 | 0,0223 | 0,11 | 0,0251 | 0,15 |
| C2 | 0,0173 | 0,05 | 0,0196 | 0,10 |
| CM1 | 0,0237 | 0,21 | 0,0248 | 0,25 |
| CM2 | 0,0216 | 0,13 | 0,0252 | 0,10 |
| V1 | 0,0186 | 0,15 | 0,0200 | 0,25 |
| V2 | 0,0177 | 0,22 | 0,0180 | 0,18 |
| L1 | 0,0182 | 0,10 | 0,0201 | 0,30 |
| L2 | 0,0161 | 0,14 | 0,0191 | 0,25 |
| P1 | 0,0261 | 0,23 | 0,0260 | 0,25 |

Legend: $R_{ct}$ - heat resistance, CV – coefficient of variation

The results of the knitted fabric tensile properties (breaking elongation, maximum breaking force and work to break) measured in the direction of courses and wales are given in the *Tables VI and VII.*

TABLE VI. Tensile properties of knitted fabrics in the direction of courses.

| Sample | Values of parameters before exposure | | |
|---|---|---|---|
| | E, % | F, N | W, cN x cm |
| C1 | 208,26 | 166,12 | 66734,56 |
| C2 | 188,26 | 140,93 | 47524,11 |
| CM1 | 182,51 | 146,24 | 58077,37 |
| CM2 | 175,83 | 111,32 | 39248,70 |
| V1 | 171,73 | 118,92 | 50674,82 |
| V2 | 176,51 | 93,62 | 34141,20 |
| L1 | 173,28 | 146,28 | 51507,53 |
| L2 | 191,46 | 118,76 | 38987,21 |
| P1 | 176,23 | 271,87 | 138402,40 |
| Sample | Values of parameters after exposure | | |
| | E, % | F, N | W, cN x cm |
| C1 | 182,54 | 154,01 | 62432,89 |
| C2 | 158,58 | 105,64 | 39159,10 |
| CM1 | 121,09 | 126,12 | 39320,79 |
| CM2 | 135,03 | 89,98 | 31733,02 |
| V1 | 69,34 | 95,16 | 19478,30 |
| V2 | 94,89 | 65,50 | 15452,60 |
| L1 | 105,65 | 93,64 | 23728,42 |
| L2 | 99,97 | 53,88 | 13287,52 |
| P1 | 123,05 | 153,85 | 60962,63 |

Legend: E - elongation, F - maximum force, W - work to break

The graphical presentations of the change of fabric parameters after exposure (regarding the fabric parameters, tensile properties and heat resistance) are given on *Figures 2-5*.

TABLE VII. Tensile properties of knitted fabrics in the direction of wales.

| Sample | Values of parameters before exposure | | |
|---|---|---|---|
| | E, % | F, N | W, cN x cm |
| C1 | 70,28 | 329,95 | 57987,26 |
| C2 | 62,51 | 250,54 | 38194,23 |
| CM1 | 64,70 | 289,83 | 52353,00 |
| CM2 | 59,33 | 234,09 | 36704,30 |
| V1 | 51,42 | 189,16 | 31451,73 |
| V2 | 51,45 | 182,67 | 30659,10 |
| L1 | 49,27 | 261,58 | 35142,14 |
| L2 | 47,43 | 202,82 | 23680,03 |
| P1 | 74,00 | 479,80 | 137700,90 |
| Sample | Values of parameters after exposure | | |
| | E, % | F, N | W, cN x cm |
| C1 | 69,19 | 271,88 | 50540,86 |
| C2 | 66,03 | 169,50 | 29243,46 |
| CM1 | 63,86 | 185,78 | 33092,04 |
| CM2 | 61,99 | 167,13 | 28496,85 |
| V1 | 64,87 | 134,64 | 23049,21 |
| V2 | 66,04 | 114,90 | 19200,41 |
| L1 | 47,59 | 151,69 | 18361,95 |
| L2 | 46,28 | 113,15 | 12946,67 |
| P1 | 46,71 | 302,46 | 58370,13 |

Legend: E - elongation, F - maximum force, W - work to break

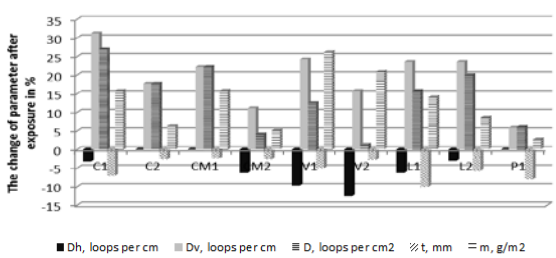



FIGURE 2. The change of knitted fabric parameters after exposure.

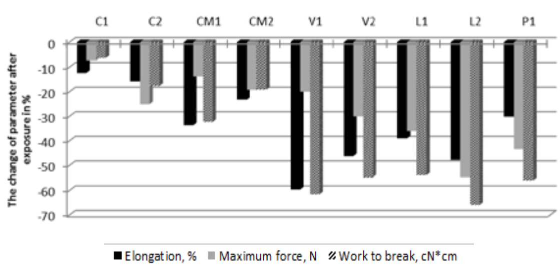



FIGURE 3. The change of parameters describing the tensile properties measured in the direction of courses after exposure.

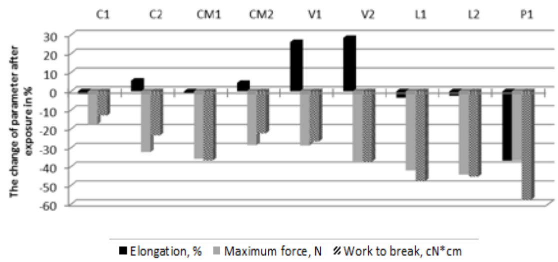



FIGURE 4. The change of parameters describing the tensile properties measured in the direction of wales after exposure.

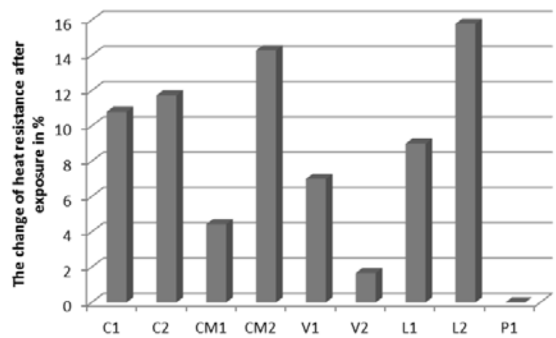



FIGURE 5. The change of heat resistance after exposure.

## DISCUSSION

### Fabric parameters

The exposure of fabrics to direct weathering caused changes of dimensional characteristics, as can be seen in the *Table IV* and *Figure 2*. The horizontal density of produced fabrics is in the range 15, 5-16, 5 loops per cm. After the fabric exposure, the horizontal density had relatively low decrease up to 12, 5% (*Table V*). The vertical density of produced fabrics was in the range 16, 0-19, 0 loops per cm and it increased for all the fabrics up to 31, 3 (fabric made from cotton assigned C1). The previous leads to the conclusion that exposure of the fabrics to climatic condition, but also the placement of fabrics on rack, caused the extension of fabrics in the direction of rows and shrinkage in the direction of wales. As previously mentioned, the thickness of all fabrics decreased (up to 10 % for fabric made from lyocell, specimen assigned L1), while the mass per unit area increased (up to 26, 7 % for fabric made from viscose assigned V1).

Considering the effect of yarn count or raw material, there were no perceived regularities in the change of fabric structural parameters after exposure except for mass per square meter. Namely, the higher decreases of mass per square meter were for fabrics knitted using courser yarns.

An average change of parameters higher than that are obtained to vertical density – increasing by 19,5 %, overall fabric density – increasing by 13,9%, thickness – decreasing by 5,1 % as well as mass per square meter – decreasing by 12,9%.

**Tensile Properties**

As seen from the *Table VI* and *Figure 3*, there was a significant decrease of all parameters describing the tensile properties in the direction of courses after the exposure. This explicitly refers to the fabrics produced from regenerated cellulose fibers (viscose and lyocell), as well as polyester. For example, the breaking elongation of fabric V1 before exposure was 171,7%, and after exposure only 69,3% (decrease of 59,9%). The fabrics made from viscose and lyocell showed a decrease of breaking elongation in direction of courses from 38,7 up to 59,9%. The relatively smallest differences within the values were obtained for fabrics made from 100% cotton from 12,0 and 15,4% respectively. (specimens assigned as C1 and C2).

In direction of wales the fabrics had different behavior, *Table VII* and *Figure 4*. The average changes of breaking elongation in direction of wales was relatively lower in comparison to changes in direction of courses (decreasing by 20, 8% and increasing by 2, 1% respectively). The most significant decrease of breaking elongation in the direction of wales (almost 40%) was measured for polyester fabric (P1). Fewer changes of breaking elongation after exposure were obtained with fabrics made from cotton, cotton/modal blend 50/50, as well as lyocell. So, with cotton fabric knitted from yarn count of 20 tex (specimen assigned C1), breaking elongation decreased by 1, 6 % whereas with cotton fabrics knitted by relatively finer yarn of 17 tex, breaking elongation after exposure increased by 5, 6%. Regarding the breaking force, there was a significantly decrease in both directions after exposure. In direction of courses, decrease was from 7, 3% for cotton fabric (specimen assigned C1) up to 54,6 for % with fabric made from lyocell (specimen assigned L2), whereas in direction of wales from 20% for fabric made from cotton (specimen assigned C1) to 44,2 % for fabric made from lyocell (specimen assigned L2). However, the results indicate that the investigated fabrics have more emphasized decrease of breaking force in direction of wales than that in direction of courses.

Work to break, as a value derived from breaking force and breaking elongation, decreased to a large extent to both direction, averagely by 41, 2 and 34, 4% respectively. The highest values were obtained for L2 (in the direction of courses) and P1 (in the direction of wales).

**Heat resistance**

The heat resistance of fabrics before exposure is in the range 0,0161-0,0261 $m^2KW^{-1}$. After the exposure, the values are between 0,0180 and 0,0260 $m^2KW^{-1}$ (*Table V, Figure 5*). The results indicate interesting facts regarding the change of heat resistance due to exposure. As seen from the *Figure 5*, the exposure did not have negative influence to the heat resistance of knitted fabrics. More accurately, the heat resistance increased after exposure for fabrics made from cellulose fibers either natural (cotton) or regenerated cellulose fibers (modal, viscose, lyocell). The reason for such behavior of cellulose fabrics should the changes of structural properties that to some extend affected the size and shape of holes within the knitted structure and furthermore the ability of fabric to transfer the heat. The heat resistance of polyester fabric remained at almost the same level. The reason for this could be found in the nature of man-made fibers (low hygroscopic properties of polyester fibers) and because of that, relatively lower changes of structural parameters after exposure (Dh remained the same, Dv increased by 5,9 %, and mass square increases by only 2,7%).

**CONCLUSION**

The exposure of knitted fabrics to outdoor natural weathering in the summer period affected all investigated properties, namely, structural properties, tensile properties and heat resistance. The most significant changes were as follows:

- horizontal density for all knitted fabrics made from different fibers mostly decreased with maximum decrease of 12,5% whereas the vertical density increased up to 31,3%,
- thickness decreased up to 10% whereas the mass per unit area increased up to 26,7%,
- breaking elongation in the direction of courses decreased to a large extent for all fabrics, and it ranged from 12,0 up to 59,9%; the relatively large decrease in direction of courses obtained for fabrics made from regenerated cellulose fibers (viscose, lyocell); in the direction of wales the breaking elongation had different behavior – for some fabrics it decreased, whereas with the others it increased.
- Breaking force for all fabrics significantly decreased up to 54,6% in both directions; the relatively higher decrease of breaking force was obtained in direction of wales.
- heat resistance decreased differently and it ranged from 0,4% to 18,6%

- emphatically decrease of work done to break after exposure was found for all fabrics; it was especially visible with fabrics made from regenerated cellulose fibers.

It has to be taken into account that the presented results may show variability when comparing with results from repeat exposures at the same location at a different time, but is important to determine the range of performance of the fabric made from different kind of fibers.

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