UNION OF ENGINEERS AND TEXTILE
TECHNICIANS OF SERBIA

VI INTERNATIONAL SCIENTIFIC CONFERENCE

CONTEMPORARY TRENDS AND INNOVATIONS IN THE TEXTILE INDUSTRY

VI MEĐUNARODNA NAUČNA KONFERENCIJA

SAVREMENI TRENDOVI I INOVACIJE U TEKSTILNOJ INDUSTRIJI

PROCEEDINGS

EDITOR:
Prof. dr SNEŽANA UROŠEVIĆ

Belgrade, 14-15th September, 2023
Union of Engineers and Technicians of Serbia
Dom inženjera „Nikola Tesla“

UNION OF ENGINEERS AND TEXTILE TECHNICIANS OF SERBIA

AND

UNION OF ENGINEERS AND TECHNICIANS OF SERBIA
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INFLUENCE OF PILLING ON THE STRUCTURAL CHARACTERISTICS OF FLAX PLAIN WEFT-KNITTED FABRICS

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ABSTRACT: *In this study, the structural characteristics of plain weft-knitted fabrics both before and after pilling were analyzed, and evaluated their tendency to develop surface fuzz and pilling. Five knitted fabrics made from flax yarn, each with different structural features as the number of wales, courses, mass per unit area, and thickness, were examined. To induce pilling, a Martindale device with two different abrasives: the investigated knitted fabric and a wool woven fabric, was used. The obtained results revealed that the grade of pilling decreased as the number of rubs increased, and that using the investigated knitted fabric as an abrasive resulted in lower grades of pilling. Regardless the pilling was caused by the investigated knitted fabric or the wool woven fabric, a reduction in all examined structural characteristics of the knitted fabrics after pilling, was observed.*

Keywords: *flax, plain weft-knitted fabrics, structural characteristics, pilling.*

ISPITIVANJE UTICAJA PILINGA NA STRUKTURNE KARAKTERISTIKE LANENIH DESNO-LEVIH KULIRANIH PLETENINA

APSTRAKT: *U radu su ispitivane strukturne karakteristike desno-levih kuliranih pletenina, pre i posle pilinga. Takođe, procenjena je i sklonost pletenina ka promeni maljavosti i sklonost ka pilingu. Ispitivanja su obuhvatila pet pletenina proizvedenih od istog lanenog prediva, ali različitih strukturnih karakteristika (broj nizova, broj redova, površinska masa i debljina). Pilling je generisan na Martindale-ovom uređaju upotrebom dva različita abraziva (ispitivana pletenina i vunena tkanina). Dobijeni rezultati su pokazali smanjenje ocene pilinga sa povećanjem broja pokreta abraziva; te ocene su niže u slučaju kada je ispitivana pletenina korišćena u svojstvu abraziva. Piling je doveo do smanjenja svih ispitivanih strukturnih karakteristika pletenina, kako nakon pilinga izazvanog ispitivanom pleteninom tako i nakon pilinga izazvanog vunenom tkaninom.*

Ključne reči: *lan, desno-leve kulirane pletenine, strukturne karakteristike, piling.*

1. INTRODUCTION

Pilling is a surface defect of fabric manifested with small fiber balls, known as pills, attached to the fabric surface by one or more fibers. Pills are formed by rubbing the loose fibers on the fabric surface during wearing, dry cleaning, and washing of fabrics. Due to the presence of pills, the fabric surface appearance becomes unattractive and the fabric handle uncomfortable [1-7]. Furthermore, pilling reduces the service life of textile products [2].

It is evident from the literature survey [1-9] that pilling is affected by fiber, yarn, and fabric parameters, washing, dyeing, softening, and ambient atmosphere. For example, considering the effect of fiber, pilling is influenced by the type of fiber, fineness of individual fibers, fiber length, fiber tenacity, inter-fiber friction, and fiber crimp. Considering the effect of yarn, pilling is affected by the spinning technique, yarn fineness, yarn twist, and yarn hairiness. Additionally, considering the fabric parameters, pilling is influenced by the fabric mass per unit area and fabric compactness. Moreover, Coldea and Vlad showed in their investigation [9] that woven fabrics have a higher resistance to pilling than knitted fabrics.

In our previous paper [4], we established that pilling changes compression, strength, and comfort properties of flax plain weft-knitted fabrics. As a continuation of the mentioned research, in this paper, we investigated the influence of pilling caused by two different abrasives (investigated knitted fabric and wool woven fabric) on some structural characteristics (number of wales, number of courses, mass per unit area, and thickness) of flax plain weft-knitted fabrics.

2. MATERIALS AND METHODS

2.1. Materials

In this study, five plain weft-knitted fabrics were used as experimental materials. Investigated knitted fabrics were produced from the same folded flax spun yarn, with a linear density of 27x2 tex, and different structural characteristics such as number of wales, number of courses, mass per unit area, and thickness. All studied fabrics were produced on the same flat bed-knitting machine under the same technological conditions, except for cam settings, which were changed during knitting. Obtained knitted fabrics were laid on a flat surface and dry-relaxed under standard atmospheric conditions for several days. The structural characteristics of all investigated knitted fabrics, determined after dry relaxation and before pilling, are given in Table 1.

Table 1: Values of structural characteristics of the investigated knitted fabrics

Structural characteristics	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
Number of wales, cm^{-1}	6.6	7.0	7.9	8.0	8.3
Number of courses, cm^{-1}	6.7	7.2	8.4	10.1	12.0
Mass per unit area, $g \cdot m^{-2}$	183	189	211	226	256
Thickness, mm	0.713	0.726	0.769	0.779	0.806

2.2. Methods

The number of fabric wales and courses was determined according to standard EN 14971:2006 (Method A) [10]. The mass per unit area of knitted fabrics was determined by measuring the mass (in g) of a sample with an area of 10 cm^2 and expressing the mass per unit area ($g \cdot m^{-2}$). The thickness of knitted fabrics was measured on a thickness tester type 414-10 (*AMES*, USA) at a pressure of 9.96 kPa. The measurements of the structural characteristics were performed at room temperature of 31±1°C and 40% relative air humidity. The average of ten measurements for the number of knitted fabric wales, courses, and thickness, as well as five measurements for mass per unit area of each sample, before and after pilling, was considered.

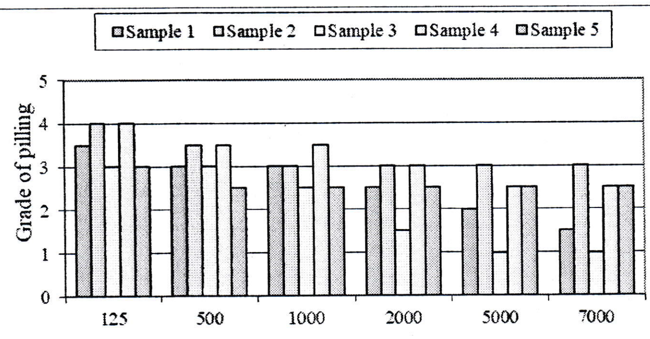
The knitted fabric propensity to pilling was determined based on the standard ISO 12945-2 (Modified Martindale method) [11] using a Martindale device (SDL ATLAS M235 Martindale Abrasion and Pilling Tester). Two abrasives were used for the pilling test, the investigated knitted fabric and the wool woven fabric. The knitted fabric pilling was visually evaluated after 125, 500, 1000, 2000, 5000, and 7000 rubs giving a grade from 5 (no pilling) to 1 (dense surface fuzzing and/or severe pilling) [11]. The investigated structural characteristics of knitted fabrics were determined after 7000 rubs on the Martindale device.

Statistical analysis of the results was conducted using the *t*–test [4, 12].

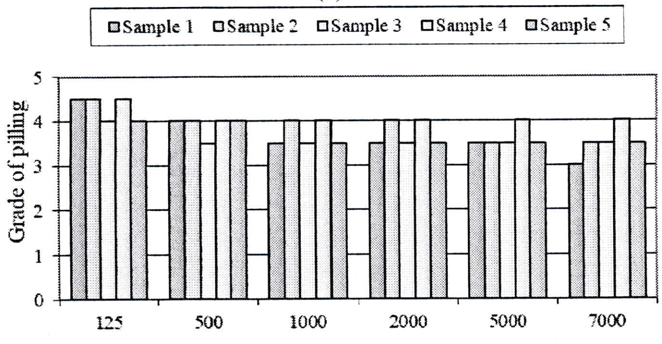
3. RESULTS AND DISCUSSION

3.1. Pilling of the knitted fabrics

The obtained results for the pilling formation over the surface of all investigated flax knitted fabrics, evaluated after a different number of rubs (125, 500, 1000, 2000, 5000, and 7000) using two abrasives, are presented in Figure 1.



(a)



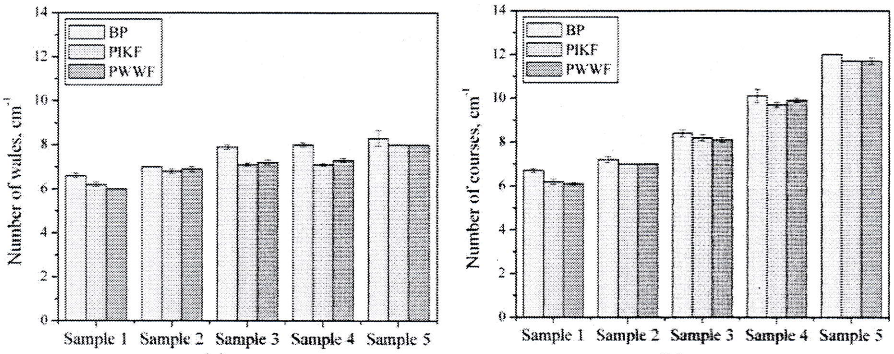
(b)

Figure 1: Grade of pilling of the investigated flax plain weft-knitted fabrics:
(a) pilling caused by the investigated knitted fabric,
(b) pilling caused by the wool woven fabric

The presented results indicate a decrease in the grade of pilling with an increase in the number of rubs from 125 up to 7000 rubs for each sample, when pilling was caused both by the investigated knitted fabric and by the wool woven fabric. The obtained result agrees with the literature [4, 7, 13]. The grade of pilling varied from 4-5 after 125 rubs for Samples 1, 2, and 4 down to grade 1 after 5000 and 7000 rubs for Sample 3. In the first case, pilling was caused by the wool woven fabric (Figure 1b), and in the second case, by the investigated knitted fabric (Figure 1a). The decrease in the grade of pilling with an increase in the number of rubs is a direct consequence of the changes on the surfaces of the investigated knitted fabrics (increased fuzz formation, pill formation, or removal of the formed pills) [4]. Furthermore, the lower grades of pilling were obtained using the investigated knitted fabric as an abrasive. The obtained result indicates higher surface damage of knitted fabrics when pilling was caused by the investigated knitted fabric.

3.2. Structural characteristics of the knitted fabrics

The values of the number of wales and the number of courses for five investigated knitted fabrics, before and after pilling, are shown in Figure 2.



(a) (b)

Figure 2: (a) Number of wales of the knitted fabrics, (b) numer of courses of the knitted fabrics

BP-before pilling, PIKF-pilling caused by the investigated knitted fabric, PWWF- pilling caused by the wool woven fabric

Results presented in Figure 2 show that the number of wales and the number of courses for knitted fabrics increases starting from Sample 1 up to Sample 5, before and after both pillings. The highest differences between Samples 1 and 5, regarding the number of wales and the number of courses, were noticed after pilling caused by the wool woven fabric (25.0%, 47.9%, respectively), and the lowest - before pilling (20.5%, 44.2%, respectively). For all knitted fabrics, before and after both pilling, the number of courses is higher than the number of wales, which can be attributed to the structure of the plain weft-knitted fabric. A statistical analysis, using a t-test (Table 2), was performed to evaluate the differences in structural characteristics of knitted fabrics. The presented results show a statistically significant difference between all investigated samples, independent of the number of wales, number of courses, and pilling (in most cases, level of significance of 0.001). However, there is no statistically significant difference only between the number of wales of Samples 3 and 4 before and after both pilling ($t_{3/4}$=-0.74; 0.00; -0.73, respectively, Table 2), as well as between Samples 2 and 3 after pilling with the wool woven fabric ($t_{2/3}$=-1.95, Table 2). Additionally, the statistically significant difference between the number of wales and the number of courses for Sample 3, Sample 4, and Sample 5, was noticed before and after pilling caused by both abrasives (Table 3).

Table 2: Statistical results of the determination of knitted fabric structural characteristics using *a t-test*

Tested para-meter	Values of parameter *t* between two different samples (df=n_1+n_2-2=18 for number of wales, number of courses, and thickness; df=n_1+n_2-2=8 for mass per unit area)									
	$t_{1/2}$	$t_{1/3}$	$t_{1/4}$	$t_{1/5}$	$t_{2/3}$	$t_{2/4}$	$t_{2/5}$	$t_{3/4}$	$t_{3/5}$	$t_{4/5}$
Before pilling										
n_w	-4.00 (***)	-9.20 (***)	-4.30 (***)	-11.40 (***)	-9.01 (***)	-11.13 (***)	-11.75 (***)	-0.74 (/)	-2.68 (*)	-2.11 (*)
n_c	-3.26 (**)	-10.19 (***)	-27.09 (***)	-69.83 (***)	-6.01 (***)	-17.39 (***)	-35.97 (***)	-9.49 (***)	-24.22 (***)	-19.01 (***)
m	-1.63 (/)	-5.96 (***)	-12.16 (***)	-21.43 (***)	-5.55 (***)	-14.98 (***)	-29.38 (***)	-3.93 (**)	-12.16 (***)	-14.82 (***)
τ	-1.02 (/)	-4.89 (***)	-5.46 (***)	-7.83 (***)	-3.67 (**)	-4.30 (***)	-6.61 (***)	-0.91 (/)	-3.44 (**)	-2.37 (*)
After pilling with the investigated knitted fabric										
n_w	-3.88 (**)	-7.14 (***)	-7.63 (***)	-16.84 (***)	-2.30 (*)	-2.45 (*)	-10.72 (***)	0.00 (/)	-13.49 (***)	-18.01 (***)
n_c	-7.23 (***)	-11.54 (***)	-22.36 (***)	-32.17 (***)	-8.99 (***)	-24.39 (***)	-36.07 (***)	-8.65 (***)	-18.77 (***)	-11.70 (***)
m	-3.63 (**)	-7.68 (***)	-6.36 (***)	-23.57 (***)	-2.86 (*)	-1.42 (/)	-11.32 (***)	1.50 (/)	-8.79 (***)	-11.18 (***)
τ	-1.58 (/)	-3.39 (**)	-3.92 (**)	-7.97 (***)	-2.30 (*)	-3.06 (**)	-10.22 (***)	-1.08 (/)	-7.53 (***)	-7.15 (***)
After pilling with the wool woven fabric										
n_w	-8.42 (***)	-10.84 (***)	-15.94 (***)	-632.4 (***)	-1.95 (/)	-2.97 (**)	-10.29 (***)	-0.73 (/)	-7.22 (***)	-8.57 (***)
n_c	-18.01 (***)	-17.90 (***)	-34.01 (***)	-35.44 (***)	-11.01 (***)	-29.02 (***)	-31.35 (***)	-12.73 (***)	-15.72 (***)	-9.99 (***)
m	-1.81 (/)	-8.41 (***)	-10.10 (***)	-11.37 (***)	-1.50 (/)	-2.16 (/)	-4.54 (**)	-1.81 (/)	-6.00 (***)	-4.86 (**)
τ	-1.36 (/)	-4.86 (***)	-7.88 (***)	-9.61 (***)	-3.54 (**)	-6.25 (***)	-8.15 (***)	-0.45 (/)	-4.04 (***)	-0.67 (/)

Legend: n_w – number of wales, n_c – number of courses, m – mass per unit area, τ – thickness, (*) - 0.05 level of significance, (**) - 0.01 level of significance, (***) - 0.001 level of significance, (/) - no statistically significant difference, df - degrees of freedom, n_1 and n_2 are sample sizes.

Pilling leads to changes in the number of wales and courses in all knitted fabrics (Figure 2). The presented histograms indicate a decreas of the number of wales and courses when pilling causes both the investigated knitted fabric and the wool woven fabric. Sample 4, after pilling caused by the investigated knitted fabric, poses the highest decrease in the number of wales (~11%). On the other hand, Sample 1 has the highest decrease in the number of courses after pilling caused by the wool woven fabric (~9%). Conducted *t*–test (Table 4) shows that pilling led to a statistically significant decrease in the number of wales for all samples, except for Sample 2, after both pillings (1.64, 1.40, respectively, Table 4). However, a statistically significant decrease in the number of courses after pilling with the investigated knitted fabric was noticed only for Samples 1, 4, and 5. The same phenomenon was observed in the case of Samples 1 and 5 after pilling with the wool woven fabric.

Table 3: Statistical results of the determination of knitted fabric number of wales and courses using *t*–test

Sample	Values of parameter *t* between the number of wales (n_w) and courses (n_c) in the same sample (df=n-1=9)		
	Before pilling	After pilling with the investigated knitted fabric	After pilling with the wool woven fabric
Sample 1	-0.16 (/)	0.00 (/)	-2.0 (/)
Sample 2	-1.50 (/)	-1.79 (/)	-0.94 (/)
Sample 3	-2.79 (*)	-7.37 (***)	-6.04 (***)
Sample 4	-15.63 (***)	-27.41 (***)	-20.15 (***)
Sample 5	-33.43 (***)	-28.40 (***)	-24.68 (***)

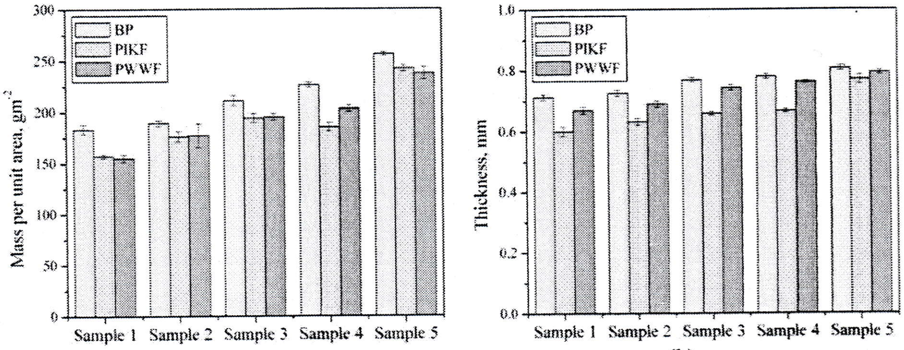
Legend: n_w – number of wales, n_c – number of courses, (*) - 0.05 level of significance, (**) - 0.01 level of significance, (***) - 0.001 level of significance, (/) - no statistically significant difference, df - degrees of freedom, n - sample size.

Table 4: Statistical results of the determination of the influence of pilling on the knitted fabric structural characteristics using *a t-test*

Tested parameter	Values of parameter *t* regarding the influence of pilling on the structural characteristics of knitted fabrics (df=n-1=9 for number of wales, number of courses, and thickness; df=n−1=4 for mass per unit area)									
	Pilling caused with the investigated knitted fabric					Pilling caused with the wool woven fabric				
	$t_{1BP/1PIKF}$	$t_{2BP/2PIKF}$	$t_{3BP/3PIKF}$	$t_{4BP/4PIKF}$	$t_{5BP/5PIKF}$	$t_{1BP/1PWWF}$	$t_{2BP/2PWWF}$	$t_{3BP/3PWWF}$	$t_{4BP/4PWWF}$	$t_{5BP/5PWWF}$
n_w	2.59 (*)	1.64 (/)	7.24 (***)	9.00 (***)	2.35 (*)	6.00 (***)	1.40 (/)	4.12 (**)	6.09 (***)	2.35 (*)
n_c	3.22 (*)	1.50 (/)	1.10 (/)	2.71 (*)	2.69 (*)	4.40 (**)	1.50 (/)	1.65 (/)	1.80 (/)	2.33 (*)
m	5.65 (**)	3.71 (*)	2.28 (*)	9.48 (***)	4.60 (**)	4.30 (*)	1.06 (/)	2.80 (*)	11.96 (***)	2.91 (*)
τ	8.28 (***)	8.85 (***)	15.09 (***)	14.22 (***)	2.41 (*)	3.45 (**)	2.12 (/)	2.85 (*)	2.27 (*)	1.04 (/)

Legend: n_w – number of wales, n_c – number of courses, m – mass per unit area τ – thickness, BP-before pilling, PIKF- pilling caused with the investigated knitted fabric, PWWF- pilling caused with the wool woven fabric, (*) - 0.05 level of significance, (**) - 0.01 level of significance, (***) - 0.001 level of significance, (/) - no statistically significant difference, df - degrees of freedom, n - sample size.

Figure 3a shows the mass per unit area, and Figure 3b the thickness of five investigated knitted fabrics before and after pilling caused by two different abrasives.



(a) (b)

Figure 3: (a) Mass per unit area of the knitted fabrics, (b) thickness of the knitted fabrics
BP-before pilling, PIKF-pilling caused by the investigated knitted fabric,
PWWF-pilling caused by the wool woven fabric

The increase in the knitted fabrics mass per unit area starting from Sample 1 up to Sample 5, before and after both pilling (Figure 3a), was noticed. The deviation is registered only in the case of Sample 4 after pilling with the investigated knitted fabric, where the value of mass per unit area was lower in comparison to Sample 3. The highest differences in mass per unit area were between Samples 5 and 1, both before and after pilling (~29% before and ~ 35% after pilling with both abrasives). The increase in mass per unit area from Sample 1 up to Sample 5 is a consequence of an increase in the number of wales and courses (Figure 2), thus an increase in the amount of yarn in the knitted fabric. In most cases, a statistically significant difference in mass per unit area between investigated samples before and after pilling was registered (Table 2). The absence of a statistically significant difference in mass per unit area was noticed only between Samples 1 and 2, before and after pilling with the wool woven fabric, between Sample 2 and Sample 3 after pilling with the wool woven fabric, as well as between Sample 2 and Sample 4 and between Samples 3 and 4 after both pillings (Table 2).

The mass per unit area of all investigated samples decreased after pilling with two different abrasives. Samples 1 and 4 had the highest decrease in mass per unit area (Figure 3a). The decrease in mass per unit area after pilling arises due to the removal of pills from the knitted fabric surfaces during pilling. Based on the results presented in Table 4, pilling leads to a statistically significant decrease in the mass per unit area almost in all samples independent of the type of abrasives used for pilling. After pilling with the wool woven fabric, a statistically significant decrease in the mass per unit area, only for Sample 2 ($t_{2BP/2PWWF}$ = 1.06, Table 4), was not noticed.

The investigated knitted fabrics are also different in the values of thickness. The thickness of knitted fabrics increases from Sample 1 up to Sample 5, both before and after pilling (Figure 3b). The thickness increase is a result of the increase in number of wales and courses. Namely, during the increases in the number of wales and courses, the compactness of knitted fabrics increases, therefore the spaces between the loops become

lower. Because of that, the yarn loops cannot be easily flattened under the applied pressure, resulting in higher fabric thickness [4]. The statistical analysis using *t*–test (Table 2) shows, in most cases, a statistically significant difference in the thickness between two samples independent on the type of abrasives used for pilling. However, there is no statistically significant difference between the thickness of Sample 1 and Sample 2 and between the thickness of Sample 3 and Sample 4, before and after both pilling, as well as between the thickness of Sample 4 and Sample 5 after pilling with the wool woven fabric.
The histograms in Figure 3b show a decrease in knitted fabric thickness after pilling with both abrasives. In the case of using investigated knitted fabric as an abrasive, a higher thickness decrease occurs, probably due to a greater damage of the knitted fabric surface. Namely, the knitted fabrics were evaluated with a lower grade after pilling with the investigated knitted fabric compared to the knitted fabrics after pilling with the wool woven fabric (Figure 1). A conducted *t–test* shows that pilling led to a statistically significant decrease in the thickness of all investigated knitted fabrics, except for Samples 2 and 5, when pilling was caused with the wool woven fabric (Table 4).

4. CONCLUSION

In this work, the influence of pilling caused by two different abrasives (investigated knitted fabric and wool woven fabrics) on the structural characteristics (number of wales, number of courses, mass per unit area, and thickness) of plain weft-knitted fabrics obtained from the same folded flax yarn, were examined.
The grade of pilling of all investigated knitted fabrics decreases with increasing the number of rubs (from 125 up to 7000) after pilling caused by both abrasives. Additionally, the knitted fabrics after pilling caused by the investigated knitted fabric have a higher degradation and, thus, lower grade values.
Before and after both pilings, the values of all investigated structural characteristics between the two samples are statistically significantly different, except for the number of wales, mass per unit area, and thickness between some adjacent Samples. The statistically significant difference between the number of wales and the number of courses was established, for three Samples with higher values of structural characteristics, before and after pilling caused by both abrasives.
Pilling caused by both abrasives leads to a decrease in all investigated structural characteristics. All tested structural parameters of Samples 1, 4, and 5 statistically significantly decreased after pilling caused by the investigated knitted fabric. The same conclusion is valid for Sample 1, after pilling induced with the wool woven fabric. Furthermore, pilling induced with the wool woven fabric did not lead to a statistically significant decrease in none of the examined structural characteristics of Sample 2.

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