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Investigation of the Resistance to Pile Loop Extraction of Linen and Ramie Fabrics

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Abstract

The paper presents an investigation of the resistance to pile loop extraction of terry fabrics in relation to the pile height, impacts/finishing, and weft density. Terry fabrics analysed in the experimental work were made from linen/cotton or ramie/cotton yarns. The pile height of the fabrics was 6 and 12 mm, and the weft density varied from 80 to 200 dm^{-1}*. The samples were affected by impacts or finishing operations. Grey fabrics were also investigated. Analysing a 10 mm pulling distance, the highest resistance to pile loop extraction of grey terry fabrics (1064.2 mN) was determined for linen/cotton fabric with a 6 mm loop pile. It was found that an increase in the weft density of ramie/cotton terry fabrics from 80 to 160 dm*$^{-1}$ *led to an increase in the resistance to pile loop extraction for all pulling distances investigated but with a different intensity: for a 5 mm pulling distance the difference was 3.2 times, and for a 25 mm pulling distance it was in 2.1 times. The decrease in the resistance to pile loop extraction of 18.6 - 38.0% of industrially finished and tumbled linen/cotton fabrics compared with grey ones was determined at a 10 mm pulling distance. The changes in the resistance to pile loop extraction in relation to the tumbling period were not statistically significant.*

Key words: *finishing, extraction resistance, pile loop, terry fabric.*

Introduction

The yarn-pullout behaviour of a woven 100% polyester fibre filament plain-weave fabric is an important indicator of the mechanism of yarn interactions within the fabric [1]. Paper [2] considers the influence of fabric side tension in the single yarn pullout test and associated micro displacements when a single yarn is progressively pulled from a weave. The side tension force per yarn was varied from near zero to values approximately one-half of the value required to completely pull the transverse yarn from the fabric. It was found [3] that the yarn-pullout force in a fabric depends on the geometry thereof, as well as on the fabric treatment type of yarn and fibre. The cationic softening agent also has an effect on the processes involved in pulling out a single warp yarn from a plain weave cotton fabric [4]. This treatment reduces the yarn tensile “modulus” in the weave, the inter yarn adhesion, and the inter yarn sliding friction, as well as increasing the deformability and recoverability of the fabric. Yarn pullout can be an important energy absorption mechanism during the ballistic impact of woven Kevlar fabric [5].

Measurements of the tuft-withdrawal force in machine-made and hand-knotted carpets were performed in [6]. The results show that the tuft-withdrawal force varies with the type and complexity of the knot and, in particular, with the total angle at which a tuft is wrapped around the warp threads. In [7] a new approach to measuring changes in thread interaction at the crossing points due to the fabric structure and yarn irregularity is discussed. A high correlation between the warp-pullout force (static and dynamic), the intensity of thread interaction at the crossing points, the strength of the fabric in the warp direction, and the weft-yarn irregularity was observed. In [8] a theory to characterise the single-fibre pullout behaviour of bonded fibrous systems is presented.

It is evident that the yarn pullout test is a suitable method for investigating the internal mechanical properties of fabric structure performed during weaving or knitting process [9]. The study presents a theoretical model to estimate the stored energy of plain-knitted fabrics which is determined using yarn pullout. This model is based on the knitted fabric dimensional properties, i.e. stitch length and contact angle of yarns, using force balance analysis. Investigation of mechanical properties like tensile, shear, compression of plain jersey weft knitted fabrics in relation to knitting parameters is also presented [10].

An investigation on the dimensional properties of plain knitted fabric produced from cotton yarn and subjected to different relaxation treatments is performed in [11]. The aim of this research was to characterise the internal energy of knitted fabric by using the yarn pullout test method in an ultrasonic relaxation state. Since the nature of internal frictional force is related to yarn interaction at crossing points, the yarn pullout test was a very effective way to examine woven fabric properties [12]. It was determined that the nature of the internal frictional force is mainly related to yarn interaction at warp and weft crossing points. Besides this, the effect of finishing treatments was investigated here. The stick-slip properties of para-aramid woven fabrics were investigated in [13]. The research in [14] concerns the estimation of use properties of terry woven fabrics destined for towels and made with cotton, cotton-flax

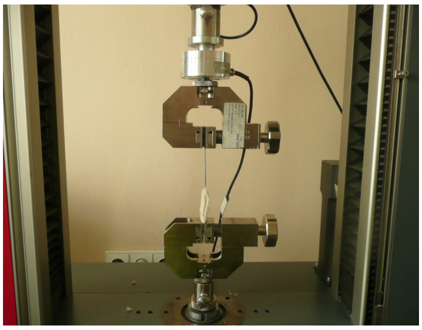

Figure 1. *Terry fabric fixture on the tensile testing instrument ZWICK/Z005.*

or cotton-hemp pile. The friction coefficient of terry fabric determines the fabric's smoothness or roughness.

As is widely known, linen, which is a natural bast fibre, has unique properties such as a feel of freshness, it is very hygienic, and has magnificent brilliance. With the trend of fashion towards natural and comfortable fabrics, linen and blended fabrics have gained prestige. Ramie fibre [15] is classified chemically as cellulosic, just like cotton, linen, etc. There are ramie advantages: Natural lignocellulosic fibres can be used as a substitute to flax and silk; it is resistant to bacteria, mildew, and insect attack, is extremely absorbent, dyes fairly easy, increases in strength when wet, withstands high water temperatures during laundering, has a smooth lustrous appearance improves with washing, keeps its shape and does not shrink, can be bleached and dyed. On the other hand, there are disadvantages too: low elasticity, lacks resilience, low abrasion resistance, wrinkles easily, is stiff and brittle.

Among all textile products, woven fabrics are probably the most used. Terry fabrics have a unique structure which consists of 3 systems of yarns interlaced with each other to form a construction of certain quality. The loop architecture is an essential feature of terry fabric and affects more or less all the fabric properties. Therefore the fabric structure and pile warp interaction with other yarns can be used as indicators of various fabric properties. Moreover such an interaction can also be investigated through the resistance to pile loop extraction of terry fabric. Studying the phenomenon of yarn pullout is an important step toward understanding the fabric's structure and properties as well as toward engineering new qualities of textiles. In spite of the relevance to the usability, aesthetic features, and quality of terry materials, no information is available on the resistance to pile loop extraction in terry fabrics and factors causing it. Hence this paper presents an experimental investigation of this new and unexplored area.

Experimental

Object of investigation

Terry fabrics were woven using linen/cotton and ramie/cotton yarns with pile loops on both sides. The research was performed with grey terry fabrics as well as with fabrics affected by different impacts or finishing operations. Grey fabric samples (see ***Table 1***) of linen/cotton (A6, A12 variants) and ramie/cotton (R(I)6 - R(V)6 variants) were prepared specially for this research in a mill under commercial production conditions. Then the grey linen/cotton fabrics were treated as stated below:

- grey fabric → macerating;
- grey fabric → washing in water → for 10 (or 30, or 120) min → centrifuging;
- grey fabric → industrial washing with detergent for 60 min → softening for 60 min → centrifuging → tumbling for 30 min → drying in air;
  - → tumbling for 60 min → drying in air (if necessary);
  - → tumbling for 90 (or 120, or 150) min.

Table 1. *Details of terry fabric samples.*

Fabric variant			Linen/cotton		Ramie/cotton				
			A6	A12	R(I)6	R(II)6	R(III)6	R(IV)6	R(V)6
Characteristic	Fabric density, dm^{-1}	Pile and ground warp, S_m	250						
		Weft, S_a	200		80				
						100			
							120		
								140	
									160
	Yarn linear density, tex	Pile warp	68, unbleached linen yarn		67, ramie				
		Ground warp	25 × 2, plied cotton yarn						
		Ground weft	50, cotton yarn						
	Pile height, mm		6	12	6				

Our experiments were carried out with 25 variants of terry fabric of 7 structures. The samples were prepared according to ISO 6330:2000 [16] and Methodology of J.S.C. "A Grupė" (Jonava, Lithuania) [17]. The macerating procedure lasted for 2 - 3 seconds, necessary for the complete wetting of the sample. The temperature of the water during macerating was 20 ± 2 °C.

Method of investigation

The resistance to pile loop extraction (F) was measured according to EN 15598:2008 [18] using a computerised tensile testing machine ZWICK/Z005. The testing parameters were as follows: sample size – (120 ± 5) mm × (25 ± 2) mm, and speed of the moving clamp - 100 mm/min. The resistance to pile loop extraction was obtained from the recorded graph at the point where the pulling distance (distance between jaws) *z* was 5 - 25 mm. The terry samples were conditioned for 24 hours before being tested. Testing was carried out under standard atmosphere conditions of 20 ± 2 °C and 65 ± 4% relative humidity. ***Figure 1*** shows the fixture of the sample and pile loop pullout test carried out in the testing instrument.

Results and discussion

In this work, the resistance to pile loop extraction of terry woven fabrics in relation to fabric raw material, structure, and impacts/finishing is discussed.

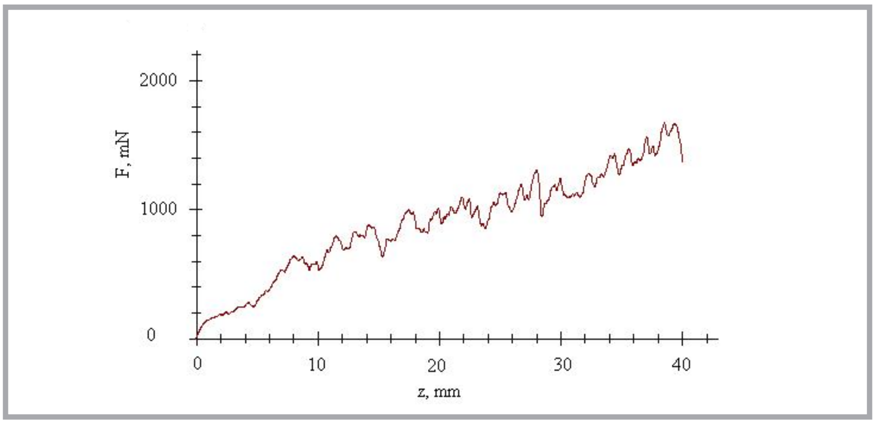

Figure 2. *Stick-slip character of pile loop pullout force-pulling distance curve of R(V)6 variant.*

Table 2. *Results of investigation of grey terry fabrics; F– resistance to pile loop extraction, Δ – absolute error of F.*

Fabric variant	Pulling distance	Resistance to pile loop extraction	
		F, mN	Δ, mN
R(I)6	*5*	151.7	27.3
	10	328.3	27.7
	15	485.0	44.8
	20	618.3	59.5
	25	810.8	98.3
R(II)6	*5*	212.5	33.3
	10	342.5	40.4
	15	535.8	42.8
	20	673.3	50.6
	25	822.5	66.6
R(III)6	*5*	229.2	22.6
	10	402.5	58.6
	15	561.7	60.4
	20	708.3	74.4
	25	900.0	117.1
R(IV)6	*5*	261.7	25.1
	10	503.3	61.5
	15	708.3	73.6
	20	993.3	53.7
	25	1321.7	159.1
R(V)6	*5*	481.7	53.5
	10	813.3	45.4
	15	1171.7	68.4
	20	1341.7	107.1
	25	1728.3	154.0

Loop pile yarn pullout tests were carried out on the fabric samples investigated. Regression analysis was made using a Microsoft Excel Analysis Tool Pack. Factorial designs were made. The informativity of the experiment was proved using the criterion of R. A. Fisher. In order to describe the results for which the informativity of experiment was proved by mathematical equations, the linear type of regression was analysed.

When we observe the cells in the stick-slip stages of the pile loop pullout force-pulling distance curve in ***Figure 2***, there is a function which has periodic decreases and increases. When the maximum pullout force display was finished, the first decreasing stage passed. Such a pullout phenomenon has a repeating character.

The resistance to pile loop extraction of grey terry fabrics is presented in ***Table 2* and *Figure 3.*** Analysing grey linen/cotton fabrics, it was determined that the resistance to pile loop extraction depends on the pile height. When analysing the 5 - 25 mm pulling distance, the resistance to pile loop extraction of variant A6 varied from 507.5 to 1641.7 mN, whereas analysing variant A12, this index changed in the 632.7 - 1966.4 mN interval. Besides this it was found that the changes in *F* were not statistically significant for the majority of values of the pulling distances examined.

As was determined by the author of [13], the stick-slip force and accumulative retraction force depend on fabric density. The stick-slip force and accumulative retraction force in dense fabric in single- and multiple-yarn pullout tests were higher than those of loose fabric. We also found the evident influence of weft density on the resistance to pile loop extraction analysing the results of grey ramie/cotton terry fabrics. The increase in *F* is strongly conditioned by that of the weft density of terry fabrics from 80 to 160 dm^{-1} for all pulling distances (see ***Table 2*** and ***Figure 3.a***). The terry fabric of 80 dm^{-1} weft density (R(I)6 variant) had the lowest resistance to pile loop extraction of all the variants: 151.7 mN (z = 5 mm) – 810.8 mN (z = 25 mm). The resistance to pile loop extraction of the fabrics of 160 dm^{-1} weft density (R(V)6 variant) varied from 481.7 mN (z = 5 mm) to 1728.3 mN (z = 25 mm). Besides this, the consistent decrease in power of the weft density was determined: with an increase in S_a the resistance to pile loop extraction for z = 5, 10, 15, 20 & 25 mm increased 3.2, 2.5, 2.4, 2.2 & 2.1 times, respectively. Authors analysing pile carpets in [6] confirm that differences in the static withdrawal force can be attributed to the increased angle of the wrap of pile yarn around the warp thread and to the number of times the pile passes through the backing fabric. A semi-empirical model [5] is also presented for predicting the yarn pullout force and energy as a function of the pullout distance for Kevlar fabrics. Our experimental results of *F* in relation to the pulling distance are described by linear equations. The determination coefficient R^2 = 0.9095 - 0.9967 (see ***Figure 3.a***) indicated the existence of an excellent relation between the parameters investigated. Besides this, the comparative analysis of grey A6, A12 and R(II)6 variants showed that variation in the resistance to pile loop extraction was related to fabric structure and raw material. It was found that the values of *F* for R(II)6 fabric variant (S_a = 100 dm^{-1}) are 2.0 - 3.1 and 1.9 - 3.0 times lower compared with these indices determined for variants A6 and A12 (S_a = 200 dm^{-1}), respectively.

Table 3. *Results of investigation of terry fabrics macerated or washed in water; F– resistance to pile loop extraction, Δ – absolute error of F.*

Fabric variant	Impact/ finishing	Pulling distance	Resistance to pile loop extraction	
			F, mN	Δ, mN
A12	Macerated	*5*	667.1	171.4
		10	771.4	118.9
		15	1014.3	188.6
		20	1150.0	114.7
		25	1317.1	249.0
A6	Washed in water for 30 min	*5*	708.2	92.9
		10	1370.0	134.4
		15	1698.3	248.2
		20	2141.8	223.9
		25	2518.3	385.1
A12		*5*	675.0	89.4
		10	856.7	121.5
		15	1585.8	271.3
		20	1800.8	220.9
		25	1960.8	93.1
	Washed in water for 120 min	*5*	516.0	100.2
		10	698.7	138.9
		15	1139.3	274.1
		20	1321.3	304.8
		25	1501.3	306.3

Macerating is a very passive procedure and has only a water impact on the fabric. From the data presented in ***Table 3*** and ***Figure 3.b***, it can be seen that after the macerating impact, the changes in resistance to pile loop extraction mainly are not statistically significant compared with grey fabrics. A linear relationship (R^2 = 0.9898) was observed between the resistance to pile loop extraction and the pulling distance for variant A6 (see ***Figure 3.b***). It was found that F changed from 538.8 mN (z = 5 mm) to 1975.0 mN (z = 25 mm) for the macerated A6 variant and from 667.1 mN (z = 5 mm) to 1317.1 mN (z = 25 mm) for the macerated A12 variant.

Washing with water as well as a complex of factors like water, heat, abrasion, etc. impacted the structure of the fabric much more than the macerating procedure. Results of investigation of fabrics that were washed in water are presented in ***Table 3*** and ***Figure 3.c***. Analysis of fabrics washed in water for 30 min showed that the resistance to pile loop extraction was higher for the fabric with a lower loop pile (6 mm) compared with that with a higher loop pile (12 m); however, only in some cases were these changes statistically significant. The highest resistance to pile loop extraction for z = 25 mm was determined for the fabrics washed in water for 30 min: 2518.3 mN for variant A6 and 1960.8

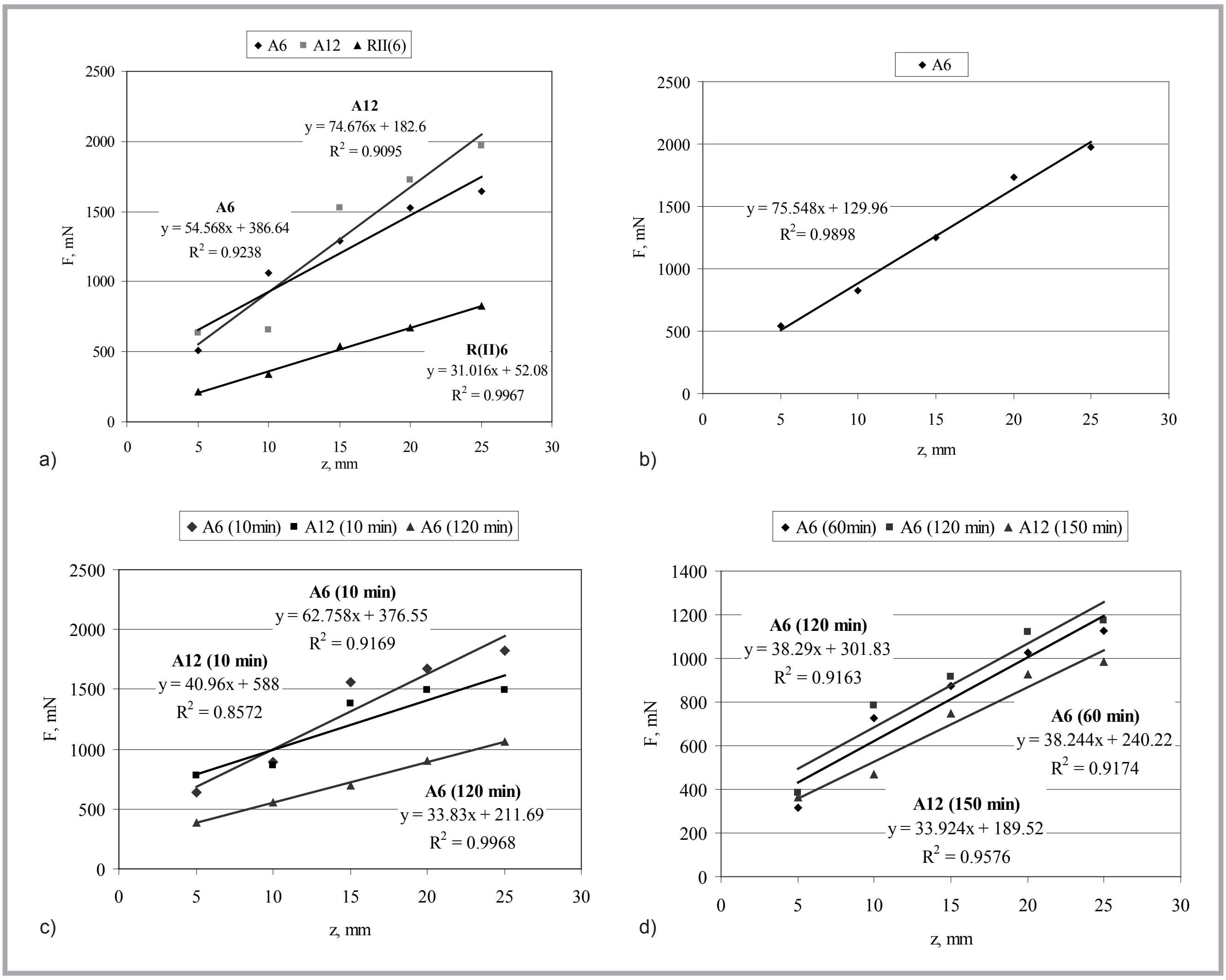

Figure 3. *Resistance to pile loop extraction of: a) grey fabrics of A6, A12, R(II)6 variants, b) macerated fabrics of variant A6, c) washed in water of fabrics of variants A6 and A12 and d) industrially finished and tumbled A6 and A12 variants.*

mN for variant A12. The *F* of the fabrics after 120 min of the washing procedure decreased by 24.0 and 35.4% for variant A6 and by 18.4 and 23.7% for variant A12 for pulling distances 5 and 25 mm compared with grey fabrics. The proven informativity of experiments of industrially washed, softened and then tumbled A6 and A12 fabrics is presented in ***Table 4***; other results are presented in ***Figures 3.c, 4*** (see page 58). Washing with detergent, softening and then the tumbling procedure changed the fabric's structure because during the industrial washing cycle the fabric is affected by washing and softening solutions, as well as by the mechanical impact, heat and water. Consequently the spaces between loops and yarns changed - the loop became bulky and the fabric became fluffy. Since such intensive finishing removes most of the surface fibres and protruding fibres of the pile loop are mainly removed due to mechanical action, it is demonstrated that these operations also cause resistance to pile loop extraction. It was found that there is a tendency of *F* to decrease for industrially finished and tumbled terry fabrics compared with grey ones. Furthermore, analysing fabrics A6 and A12, which were industrially finished and tumbled for 30 - 150 min, the increase in *F* was 2.5 - 3.9 times and 1.9 - 2.7 times, respectively, when z = 5 - 25 mm. Experimental work [3] verifies the connections between fabric properties and yarn pullout behaviour: for different fabric weave structures and yarn types, yarn pullout behaviours are also different. We found an irregular change in the resistance of pile loop extraction from 698.2 mN (tumbling lasted for 90 min) to 866.4 mN (tumbling lasted for 30 min) for variant A6 and a 10 mm pulling distance. Whereas for variant A12 and a 10 mm pulling distance, it was determined that *F* increased from 468.2 mN (tumbling lasted for 30 min) to 517.3 mN (tumbling lasted for 90 min) and then decreased (tumbling lasted for 120 - 150 min). Moreover it was found that the changes in *F* in relation to the tumbling period were not statistically significant, while the relationships showed that the resistance to pile loop extraction in relation to the pulling distance had a linear character for variant A6 tumbled for 60 and 120 min as well as for variant A12 tumbled for 150 min (R^2 = 0.9163 - 0.9576, see ***Figure 3.d***).

Table 4. *Proved informativity of experiments of F of industrially finished and tumbled variants A6 and A12.*

Fabric variant	Tumbling period, min	F criterion	
		Calculated F_C	Tabular F_T
A6	60	2.88	2.61
	120	6.40	3.48
A12	150	5.04	3.48

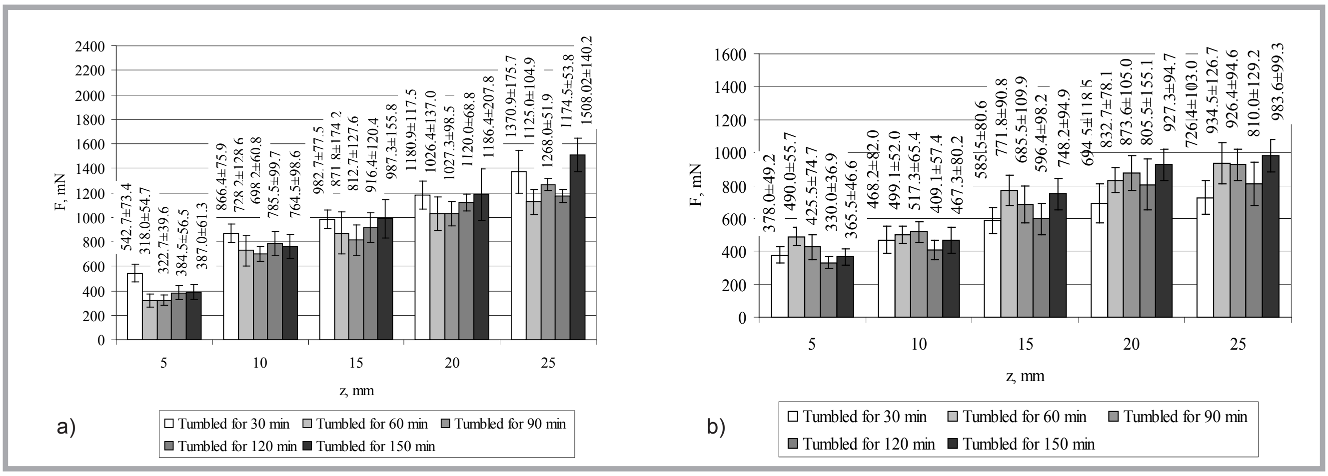

***Figure 4.** Resistance to pile loop extraction of industrially finished and tumbled fabrics of variant a) A6 and b) A12.*

Conclusions

1. The pile height of linen/cotton terry woven fabrics had an effect on their resistance to pile loop extraction. The resistance to pile loop extraction of grey fabrics with a lower loop pile (6 mm) varied from 507.5 to 1641.7 mN, while for fabrics with a higher loop pile (12 mm) this index was 632.7 - 1966.4 mN.

2. It was found that there was an evident influence of the weft density of terry fabrics on the resistance to loop pile extraction. The ramie/cotton terry fabric with a 80 dm^{-1} weft density was significant for the lowest resistance to pile loop extraction (151.7 - 810.8 mN) of all the fabrics investigated.

3. Analysis of linen/cotton fabrics washed in water for 30 min showed that the resistance to pile loop extraction was higher for the fabric with a lower loop pile compared with that with a higher loop pile; however, only in some cases were these changes statistically significant. It was found that the resistance to pile loop extraction of the fabrics washed in water for 120 min decreased up to 18.4 and 35.4% (for pulling distances 5 and 25 mm) compared with grey fabrics.

4. The changes in the resistance to pile loop extraction in relation to the fabric's tumbling period were not statistically significant.

5. The resistance to pile loop extraction of linen/cotton and ramie/cotton terry fabrics in relation to to the pulling distance could be described by linear equations. The determination coefficients of the equations obtained are 0.8572 - 0.9968, indicating the existence of a good or excellent relation between the parameters investigated.

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