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Static Water Absorption in Fabrics of Different Pile Height

Abstract
The static water absorption, fabric thickness and surface density of woven structures were investigated. Samples were woven for this experiment using low, medium and high pile of 6, 9, and 12 mm, respectively. The fabrics were affected by various impacts/finishing like macerating, washing with detergent, washing with detergent and softener, and tumbling. It was found that an increase in pile height in many cases causes an increase in water absorption for grey, macerated, washed with detergent, washed with detergent and softened fabrics. The biggest differences in water absorption between fabrics with low, medium, and high loops were determined for grey fabrics, i.e. from 142.9 to 300.8%. Increasing the tumbling time to 90 - 120 min increased the static water absorption in fabrics with medium and low loops. Treatment with detergent or with conditioner decreased the thickness of the fabric compared with grey and macerated ones. The surface density of the variously treated fabrics generally increased significantly with an increase in pile height.

Key words: *static absorption, surface density, terry woven structures, fabric thickness.*

Introduction

Terry fabrics are produced using weft, ground warp and pile warp yarns. Pile structure has a very important effect on the structure and usage properties of terry fabrics. Cotton and linen yarns are very desirable materials for terry fabrics because of their good water absorption properties, bearing in mind that terry materials are widely used for towels, home textile products, sauna dressing-gowns, headgears, slippers, children's clothes, hygiene products for babies, etc. Although the yarn material is an important parameter in determining the water absorption properties of terry fabrics, pile characteristics also have an effect on them. Unfortunately, the literature available on the water absorption properties of terry fabrics is limited. There is a lack of detailed studies on such questions as how the construction of terry fabric affects the water absorption properties of the material, and the influence of the finishing procedures of the fabrics on their sorption properties. Current mathematical relationships to express the dependencies between the sorption characteristics of fabrics and their structural properties were found wanting.

Absorption properties are determined by the fabric's structure and geometrical characteristics, such as porosity, thickness, pile density, handle etc. as well as by finishing procedures like washing, softening etc.

Static water absorption defines the amount of water the terry fabric can absorb, which is an important property of any terry textile [1]. The high water absorption ability of terry material is due to the loop pile facilitating water absorption, which is thanks to the developed surface. The pile height together with a large density determines the product's full bulky handle [2]. The sorption-desorption process is very important to maintain the microclimate during transient conditions [3]. The behaviour of textile in contact with liquid plays an important role in determining clothing performance and in maintaining body comfort [4]. The thermal comfort of clothing is associated with the thermal balance of the human body as well as with thermal responses to interactions with the textile and environment system [5]. In this case the air permeability of terry textile also plays a significant role [6, 7].

The heterogeneity of pore size, shape and orientation affects the penetration of liquid into the yarn structure and, hence, its liquid retention properties, as exhibited by textured filament yarns [8]. In [2] it was determined how the level of water sorption ability and handle depends on the kind of raw material used, the terry fabric's structure and finishing. Fabrics with cotton, cotton-linen, and cotton-hemp pile were investigated. The average water sorption ability of the fabrics after washing increases by over 10%, but this difference is not statistically significant. The fabric's compression ability was calculated using the free sample thickness after washing and the thickness of the washed sample after compression loading with a force of 1 N/m^2.

The effect of terry fabric parameters on water absorption properties using various fabric constructions without hydrophilic finishes was investigated in [1]. The water absorption properties were analysed with respect to warp density, weft density, pile height, and the type of yarns used for producing them. It was found that an increase in weft density, warp density or pile height causes an increase in static water absorption, but the pile height had the most significant effect. The percentage of water absorption is the lowest for open-end yarn, and the highest for two-ply ring carded yarn. The higher twist values used in the production of open-end yarns are thought to make water penetration inside open-end yarns more difficult. It was concluded that the percentage of water absorption decreases with increasing warp and weft densities as the terry fabric structure becomes dense, whereas it increases with an increase in pile height because of the increased pile warp yarn surface area.

Regarding water vapour permeability, no correlation of this parameter with the thickness of knitted fabric was noted [9]. There are various test methods used for the evaluation of liquid absorption, such as the aqueous immersion test, the saturation value test, the drop test, etc. [4, 10]. To assess the influence of different washing techniques on denim properties and the washing procedure, during which the textile is affected by a complex of different factors, the changes in thickness and surface thickness were determined [11]. It was found that after simple softening, the thickness increased by 12.5%, whereas after washing with chlorine solution, it increases by some 7%. Enzyme washing conditioned fabric thinning and negligible changes. Enzyme washing removed impurities and loose fibre, smoothening the surface, which caused the thinning. Softener precipitates on the yarns and fibres, consequently the fabric's thickness increases. The highest influence on the change of the surface thickness was found using enzyme washing and silicone softening. After that the greatest reduction in thickness was observed, i.e. from 0.42 mm to 0.27 - 0.28 mm. After simple softening, the surface thickness increased by 17%. The fabric thickness [12] could be measured using the FAST system.

The surface density of any woven materials with special reference to terry and pile fabrics is an important structural property. The relationship between the pile height, surface density, and bending resistance or softness degree was established. Besides this, production parameters such as the type of softener, colouration method and fabric structure were found to significantly affect softness, which was particularly pronounced for velvet fabric; its softness was found to be better than that of un-cut pile structures like terry materials. Since the pile height of velvet fabrics is shorter than that of loop pile fabric, the material's thickness in this case becomes less than that of the others [13].

The aim of this research was to investigate the static water absorption together with the thickness and surface density of various terry woven structures designed with pure linen pile as well as affected by various impact/finishing procedures.

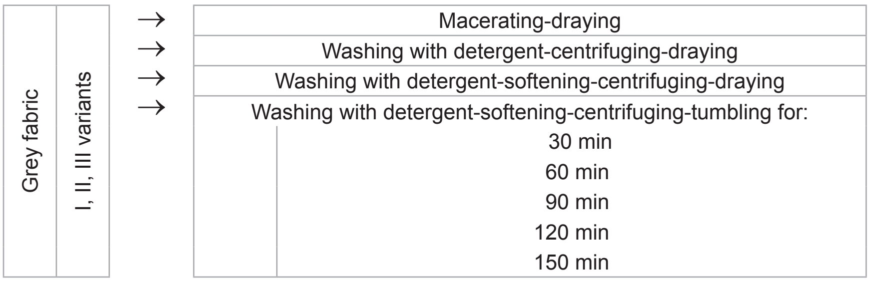

Figure 1. *Scheme of impacting/finishing procedures applied to the fabrics.*

Table 1. *Construction of terry fabrics.*

Fabric variant	Pile height, mm	Material and linear density of pile warp
I	6	Bleached linen yarn, 50 tex
II	9	
III	12	

Table 2. *Determination coefficients of other equations between the S_w, t and d parameters of the fabrics and tumbling duration.*

Parameter	Fabric's variant	Determination coefficient R^2, type of equation
Static water absorption, S_w	I	0.8885, power; 0.8797, logarithmic
	II	0.7368, power; 0.7135, logarithmic
	III	0.1942, linear; 0.1886, exponential
Fabric's thickness, *t*	I	0.500, linear; 0.4813, exponential
	II	0.6113, linear; 0.6096, exponential
	III	0.8516, linear; 0.8500, exponential
Surface density of fabric, *d*	I	0.0239, exponential; 0.0236, linear
	II	0.7192, power; 0.7184, logarithmic
	III	0.9662, exponential; 0.9601, linear

Experimental

Object and method of investigation

The both sided pile formation principle was used in the production of the terry woven structures discussed in this study. There are three systems in terry fabric, namely weft yarn, ground warp yarn and pile warp yarn. The construction of terry fabrics is presented in ***Table 1***. The pile and ground warp density was 250 dm^{-1}, and the weft density 200 dm^{-1}. The ground warps were plied cotton yarns of 25 tex × 2, whereas the ground wefts were cotton yarns of 50 tex. Pile loops were embedded using four picks. The cotton-linen terry fabrics used in the experimental work were woven by joint-stock company "A Grupė" (in Jonava, Lithuania).

Figure 1 presents the scheme of impacting/finishing procedures applied to the fabrics. For the wetting procedure the specimens (300 × 500 mm) were placed into water for 2 - 3 s, which is necessary to complete wetting, and then dried in air. Industrial finishing processes were performed by the joint-stock company "A Grupė". In this research, the detergent NOG CHT R. Beitlich (Germany) was used for industrial washing at 60 °C, which was performed in a rope bath BK (Russia). The tumbling process gives a fuller volume and nice handle to the fabric. For this purpose the samples were washed with detergent, softened, centrifuged, and tumble-dried for different periods: from 30 to 150 min in a tumbler Aipress 15, model Frofix 7126 (Germany). A Tubingal SMF CHT R. silicone conditioner, Beitlich (Germany) was used for softening. After tumbling for 30 and 60 min, the fabrics were dried. If necessary the samples were dried after tumbling for 90 min as well.

The static water absorption was measured according to method [1]. The samples were conditioned in laboratory conditions, cut into pieces (10 × 10) and then weighed (m_d). After that the samples were kept for one minute in distilled water. After being removed from the water, they were hung for three minutes to remove excess water, and the weight of the wet samples (m_w) was measured. An electronic balance was used in the weight measurements. The static water absorption S_w was calculated using the following formula:

$$S_w = (m_w - m_d)/m_d \times 100$$

The fabric's thickness *t* and surface density *d* was measured in accordance with ISO 5084:1996 [14] and LST ISO 3801:1998 [15], respectively.

Results and discussion

To assess the influence of water, mechanics, heat, and chemical treatment on terry woven structures, the changes in static water absorption, fabric thickness and surface density were analysed. The characteristics of the terry fabrics were analysed with respect to pile height as well. The results of static water absorption, thickness and surface density of the terry fabrics are presented in ***Figures 2 - 7*** (see page 62). In order to describe the results, polynomial, linear, logarithmic,

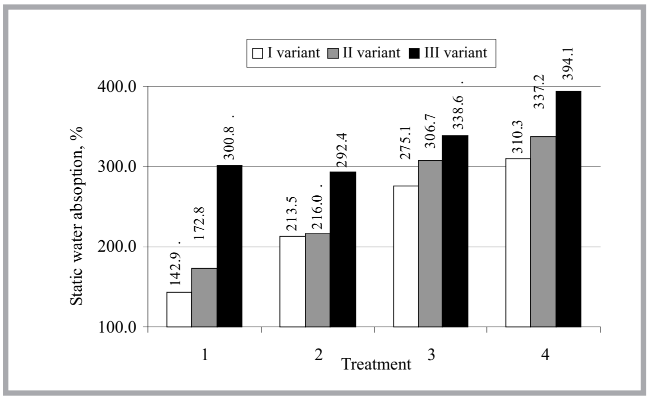

Figure 2. Static water absorption of terry fabrics with respect to treatment: 1 - without finishing (grey fabric); 2 - macerating, 3 - washing with detergent; 4 - washing with detergent and conditioner.

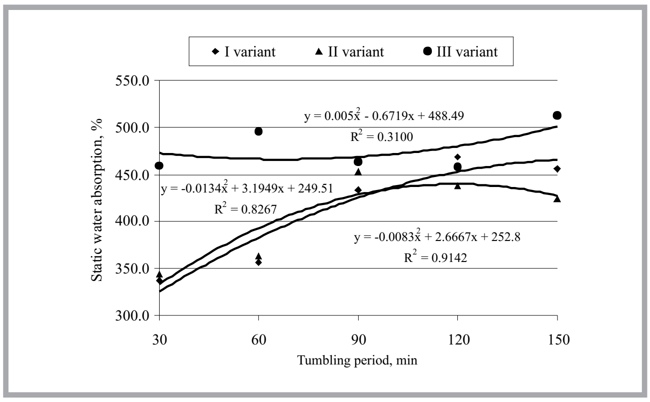

Figure 3. Static water absorption of terry fabrics with respect to the tumbling time.

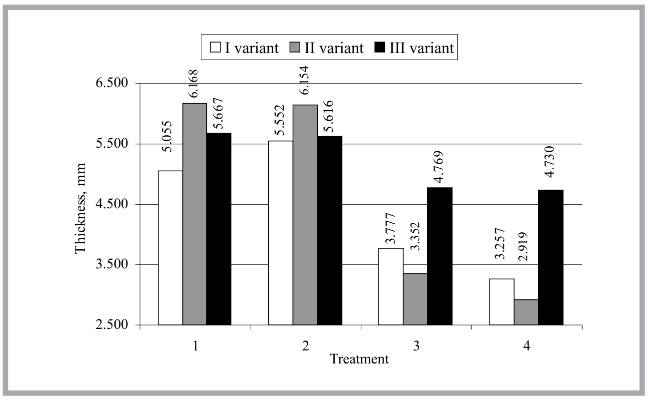

Figure 4. Fabric thickness with respect to treatment: 1 - without finishing (grey fabric); 2 - macerating, 3 - washing with detergent; 4 - washing with detergent and conditioner.

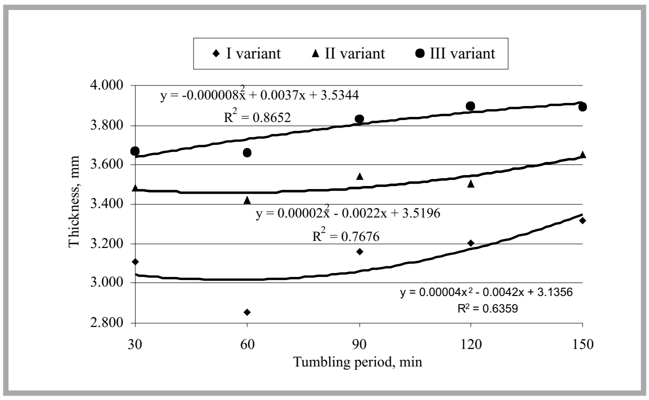

Figure 5. Fabric thickness with respect to the tumbling time.

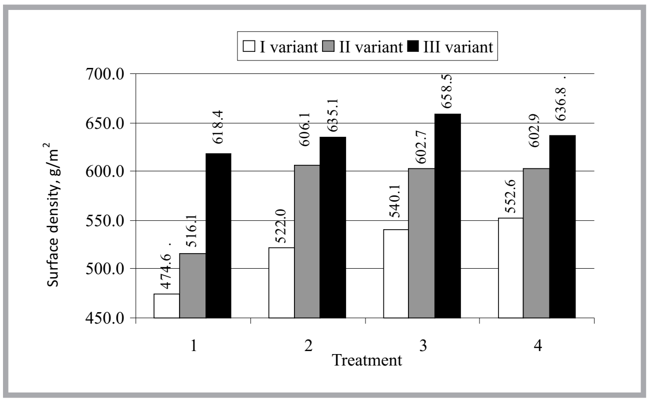

Figure 6. Surface density of the fabrics with respect to treatment: 1 - without finishing (grey fabric); 2 - macerating, 3 - washing with detergent; 4 - washing with detergent and conditioner.

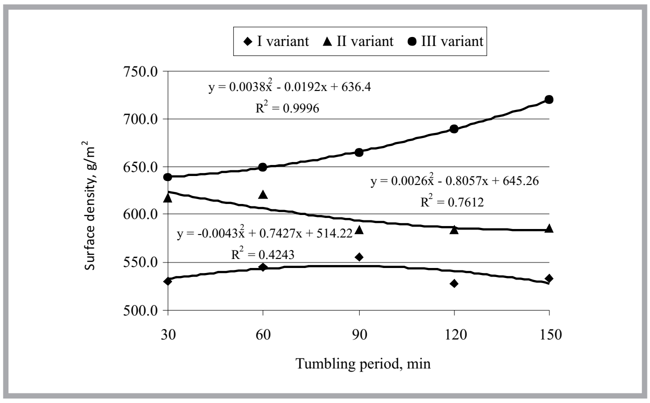

Figure 7. Surface density of the fabrics with respect to the tumbling time.

power, and exponential types of regression, were analysed. In ***Figures 3, 5*** & ***7*** the equations with the highest determination coefficients are shown. Some other types of regressions and coefficients of determination are presented in ***Table 2*** (see page 61).

Figure 8 shows microscopic surface views of the terry structures investigated. It was found that an increase in pile height causes an increase in water absorption for grey, macerated, washed with detergent and softened fabrics (the difference between macerated sample variants I and II is the only one not statistically significant), which is due to an increase in the surface density of the fabrics. This tendency confirms data presented in ***Figure 6***. As is seen from ***Figure 2*** the biggest differences in water absorption between I, II, and III variant were determined for grey fabrics: 2.1 times (comparing variants I and III) and 1.7 times (comparing variants II and III), i.e. from 142.9 to 300.8%. Meanwhile the smallest differences were obtained for fabrics washed with detergent: 23.1% (comparing variants III and I) and 10.4% (comparing variants III and II). As is seen from ***Figure 6*** grey fabrics with a pile height of 12 mm, compared with the 6 and 9 mm, demonstrate the biggest differences in surface density compared with analogous macerated fabrics or with fabrics washed with detergent or washed with detergent and softened ones. Hence our data are in agreement with those obtained by other researchers [1]: the increase in the weight of dry pure cotton terry fabrics of higher pile is suggested as a reason for the increase in water absorption ability. Besides, these authors stated that the pile height had the most pronounced effect on static water absorption compared with other characteristics investigated.

Macerating is a very passive procedure compared with industrial finishing operations as it only includes the impact of water. Yet such an impact increased the static water absorption by 49.4 - 25.0% for fabrics with low and medium loops compared with grey ones, respectively. The difference between macerated variants III and I-II is less compared with the analogous difference in grey fabrics.

Intensive industrial treatments like washing with detergent or washing with detergent and softener changes the fabric's structure much more because during the whole washing cycle, the fabric is affected by a complex of factors like the washing solution, heat, abrasion, compressive deformation, etc. The important changes in the fabric's structure lead to intensive transformation of its physical and mechanical properties as well as usage peculiarities, such as the fabric's handle. Softening solution acts as an additional factor for the fabrics which were softened after the washing procedure. It was determined that the difference in water absorption is 1.9 and 1.8 times for fabrics washed with detergent and even 2.2 and 2.0 times for those washed with detergent and softened compared with grey ones of I and II variants, respectively. Besides this the water absorption reached highest values in fabrics washed with detergent and softened, i.e. 310.3% (I variant) - 394.1% (III variant) compared with all other variants presented in ***Figure 2***. The water absorption of fabric washed with detergent and softened with a loop pile of 12 mm is 31.0% higher compared with grey fabric; however, the difference was 95.1-117.1% for fabrics II and I. To our mind, fibre swelling and the decrease in pore size could be the main reasons for the increase in water absorption of intensively treated fabrics. The loop pile in grey fabric is stiff and of regular geometry; the loops are perpendicular to the fabric's base. The water impact during the macerating procedure or more intensive finishing operations changed the pile structure of the fabric, resulting in it being more filled with loops. Softening conditioned the loss of stiffness of the loops throughout, in which the terry fabrics became soft and bulky. Such a structure could provide an easier uptake of water.

Increasing the tumbling time to 90 - 120 min increased the static water absorption in variants with medium and low loops. The polynomial relationships with the highest determination coefficients, $R^2 = 0.9142$ and $R^2 = 0.8267$, were determined for water absorption with respect to the tumbling time for fabrics of variants I and II, respectively (see ***Figure 3***). Such coefficients indicate a very good match between the experimental data and polynomial curves. Other kinds of regression also distinguish sufficiently high determination coefficients for variants I and II; whereas for the fabric with high loops, the relation between the experimental data and mathematical expression is weak throughout (see ***Table 2***). It was found that during the tumbling period investigated, the water absorption of the fabrics increased from 337.1 – 512.5%. Tumbling for 30 min increased the absorption ability of the fabrics compared with the samples affected by washing and softening procedures (except variant II, for which the increase is statistically insignificant). Meanwhile, increasing the tumbling time to 90 min determined the increase in water absorption of the fabrics investigated by 17.7 - 39.6% compared with samples washed with detergent and those softened. The increase in water absorption with respect to the tumbling time could be explained by substantial changes in the fabric's structure after such intensive and numerous finishing procedures: washing with detergent-softening-centrifuging-tumbling. Warp pile yarns became very bulky and fluffy in the tumbled fabrics. A certain amount of fly slipped from the yarns and got trapped in the fabric, increasing the ability of water uptake. Very significant increases in water absorption were determined comparing fabrics tumbled for 90 - 120 min and grey ones, for example, the water absorption increased 1.5 - 3.3 times in the above-mentioned samples.

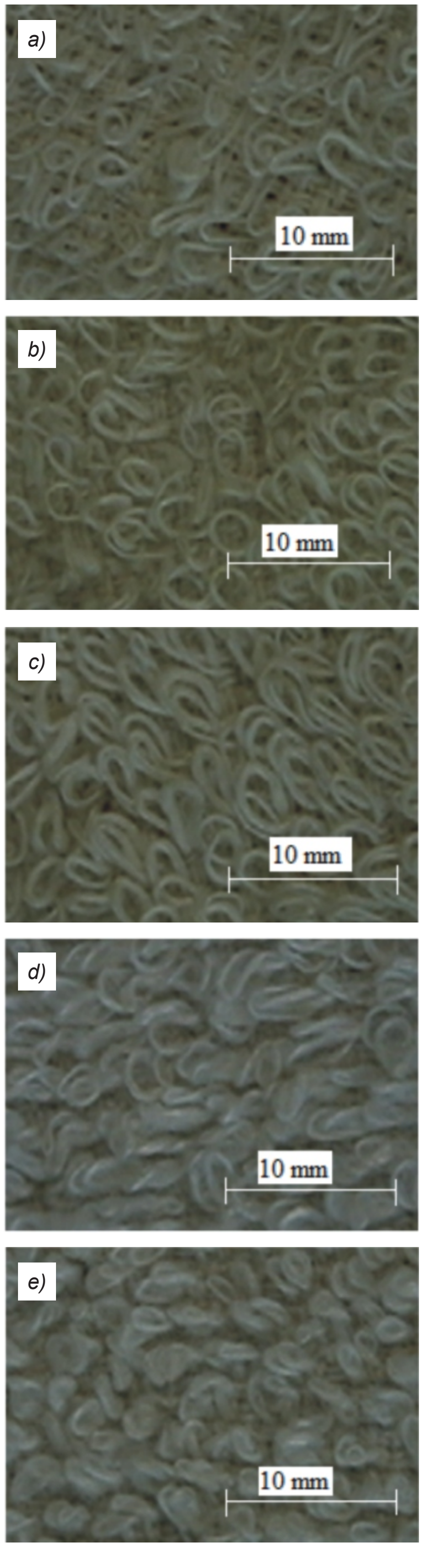

Figure 8. *Microscopic views of terry fabrics of variant I: a) grey, b) macerated, c) washed with detergent, d) tumbled for 60 min, e) tumbled for 90 min.*

By increasing the tumbling duration to 150 min, compared with the duration of 120 min, the increases in water absorption were not conditioned (except for a slight increase for fabrics with high loops). Furthermore, it is necessary to bear in the mind that prolonged

Table 3. Relative and absolute errors of experimental data for the S_w, t and d parameters of terry fabrics.

Impact/ finishing	Fabric's variant	Relative error			Absolute error		
		S_w, %	t, %	d, %	S_w, %	t, mm	d, g/m^2
Grey fabric (without finishing)	I	3.1	4.3	1.6	4.4	0.219	7.7
	II	6.2	1.5	2.0	10.8	0.095	10.2
	III	5.4	3.9	3.8	16.2	0.223	23.5
Macerating	I	3.7	3.7	2.2	9.2	0.208	11.4
	II	3.8	3.9	2.5	8.2	0.240	15.4
	III	3.9	2.7	1.6	11.4	0.152	10.5
Washing with detergent	I	5.5	4.7	1.9	15.1	0.176	10.0
	II	4.5	6.1	1.6	13.6	0.206	9.5
	III	3.7	6.2	2.2	12.5	0.294	14.4
Washing with detergent and conditioner	I	2.6	3.8	2.6	8.2	0.124	14.2
	II	2.5	2.9	1.7	8.5	0.084	10.0
	III	3.1	2.1	2.7	12.0	0.100	17.0
Tumbling in 30 min	I	5.0	4.3	1.5	16.7	0.134	7.8
	II	3.9	5.4	1.8	13.3	0.189	11.0
	III	1.7	2.5	2.2	7.9	0.090	14.1
Tumbling in 60 min	I	4.5	5.6	4.4	16.1	0.160	24.2
	II	5.2	2.8	1.5	18.7	0.096	9.1
	III	6.3	1.9	8.2	31.4	0.071	53.6
Tumbling in 90 min	I	2.0	3.5	1.8	8.5	0.110	9.7
	II	2.7	2.4	1.2	12.2	0.086	6.9
	III	4.2	1.5	3.1	19.3	0.059	20.9
Tumbling in 120 min	I	0.7	4.1	0.5	3.5	0.132	2.4
	II	2.6	1.8	2.3	11.5	0.064	13.3
	III	2.8	2.2	1.7	12.3	0.086	11.8
Tumbling in 150 min	I	2.1	3.2	1.8	9.5	0.104	9.7
	II	5.9	1.3	7.1	25.2	0.048	41.3
	III	4.4	1.2	3.3	22.4	0.047	24.0

tumbling could over dry the textile, and therefore the recommendation to extend the tumbling procedure to no longer than 120 min could be substantiated.

As is seen from ***Figure 4*** (see page 62), the fabric's thickness did not change after the macerating procedure compared with grey fabrics, except the variant with low loops, but here the difference is slight. Treatment with detergent and/or conditioner decreased the thickness of the fabric by 15.8 to 52.7% compared with the grey ones. The authors in [2] stated that the shrinkage of treads occur during washing, followed by pile flattening, which consequently decreases the fabric's thickness. Our results confirmed this opinion. Of course, such changes in fabric thickness may valuably influence the handle of the textile.

The tendency of a fabric's thickness to increase during tumbling is noticeable, but in many cases the changes were found to be statistically insignificant after the fabric had been analysed following the tumbled periods (see ***Figure 5*** see page 62). The data showed that generally the thickness is bigger with a higher pile, confirming the effect of terry fabric construction. If we compare grey fabrics and those tumbled for 30 min, the decrease in fabric thickness could be explained by the changes in loop pile structure: the loops are rigid and range perpendicularly to the base of the fabric in grey textile; the loops are bulky and in some cases of spiral or snarl configuration in tumbled fabrics. Until the tumbling procedure, i.e. analysing macerated, washed with detergent, washed with detergent and conditioned samples, the thickness of the fabric continuously decreased for all variants, except in some cases. The remains of small particles and amounts of fly are removed during washing by decreasing the fabric's thickness.

As was hoped, the surface density of the fabrics generally increased with an increase in pile height for variously treated fabrics (see ***Figure 6*** and *7* - page 62). The differences in surface density of grey fabric of variant III were 143.8 g/m^2 and 102.3 g/m^2 compared with those of I and II, respectively. After treatments like macerating, washing with detergent and washing with detergent and conditioner, these differences remained but did not exceed the above-mentioned values.

The polynomial relationships with the highest determination coefficients, $R^2 = 0.7612$ and $R^2 = 0.9996$, were determined between the surface density and tumbling duration for fabrics II and III. Other kinds of equations investigated (exponential, linear) also demonstrate high determination coefficients. However, only the polynomial regression showed a slight match with experimental data for variant I (see ***Figure 7*** - page 62).

The experimental results were statistically evaluated at a confidence level of 95%. Full statistical analysis was performed and the standard deviation, coefficient of variation, absolute error, and relative error were calculated. Relative errors and absolute errors of the experimental data are presented in ***Table 3***. Statistical analysis of the experimental data showed that the coefficients of variation for the static water absorption of terry fabrics and the surface density of the fabrics generally did not exceed 5.0%, except for isolated instances in which they are higher, whereas the coefficient of variation of the fabric's thickness varied from 2.1 to 11.8%. The relative errors of all parameters investigated varied within the range of 0.5% to 5.0%, except in some cases where the values gowent up to 8.2 %.

Conclusion

The pile height of terry woven fabrics had a significant effect on their static water absorption. The biggest differences in static water absorption between variants investigated were determined for grey fabrics. This was due to the increase in the surface density of the fabric.

Some changes in the static water absorption were determined even after a passive procedure like the macerating one. Compared to the grey samples, an increase in water absorption of up to 1.8 - 2.2 times was found for terry fabrics washed with detergent, for those washed with detergent and softened ones with low (6 mm) and medium (9 mm) loops. The increases for washed and softened fabrics were 310.3 - 394.1% compared with grey and macerated as well as those washed with detergent. Fibre swelling and the decrease in pore sizes could be the main reasons for the increase in static water absorption in more intensively treated fabrics.

In tumbled fabrics the static water absorption increased from 337.1 to 512.5 % when the tumbling time was increases from 30 to 150 min. The increase in water absorption with respect to the tumbling time could be explained by substantial changes in the fabric's structure after the following operations: washing with detergent-softening-centrifuging-tumbling. Very significant increases in water absorption were observed when comparing the fabrics tumbled for 90 - 120 min and greys ones: the water absorption increased 1.5 - 3.3 times.

The polynomial relationships with the highest determination coefficients, $R^2 = 0.9142$ and $R^2 = 0.8267$, were determined for water absorption with respect to the tumbling time of terry fabrics with low and medium loops, respectively. Such coefficients indicate a very good match between the experimental data and theoretical curves.

Treatment with detergent and/or conditioner decreased the thickness of the fabric by 15.8 to 52.7% compared with grey ones.

The tendency of the fabric's thickness to increase tumbling is noticeable, however, analysing the fabrics after the tumbled periods, in many cases the changes are not statistically significant. The data showed that the thickness is bigger with a higher pile, confirming the effect of terry fabric construction. The decrease in fabric thickness for grey fabrics and those tumbled for 30 min, could be explained by the changes in loop pile structure.

In many cases the surface density of the variously treated fabrics increased significantly with an increase in pile height, which varied from 474.6 to 719.7 g/m^2. The differences in surface density of grey fabric with high loops was 143.8 g/m^2 and 102.3 g/m^2 compared with the fabric designed with low and medium ones, respectively.

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