ISSN 1392–1320 MATERIALS SCIENCE (MEDŽIAGOTYRA). Vol. 19, No. 3. 2013

The Influence of Chemical Treatment on Cotton Fiber Materials' Mechanical Parameters

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crossref http://dx.doi.org/10.5755/j01.ms.19.3.1684

Received 29 May 2012; accepted 17 January 2013

This paper explores the changes in the mechanical parameters of cotton fiber materials (woven and knitted materials) resulting from the chemical softening using two cationic liquid softeners. It was determined that these changes can be reflected and reliably evaluated using a method based on pulling a disc-shaped specimen through a central nozzle. The research also analyses the changes in textile mechanical parameters determined in pulling process, in material thickness as well as in surface friction coefficient resulting from wet textile treatment. It was determined that the washing of textile material influences the increase in their hand parameters and in thickness. The softening of washed textiles allows regenerating their hand properties similar to those of untreated ones.

1. INTRODUCTION

The purpose of chemical treatment is to give additional handling softness to fiber material [1].

Some instrumental devices were developed to identify as well as to measure objectively textile softness [2 – 10]. One of these instruments is a device based on punching a disc-shaped specimen through a rounded nozzle of device's stand [7 – 10]. During punching a disc-shaped specimen through a rounded nozzle and restricting its sliding under limiting transparent plate, a specimen is complicatedly deformed. It is bended triplexly over a punch, over the edge of nozzle as well as in the space between transparent plate and stand. Additionally, it sustains friction between limiting plates. So, the changes in mechanical parameters resulting from the different chemical treatment also can be seen from the parameters of bending stiffness as well as ones of surface friction. The principal scheme of such device is shown in Figure 1 [9, 10].

Applying this method, the changes in fiber material mechanical parameters resulting from chemical softening can be determined measuring the maximum value of punching force $P_{\max}$, the slope angle tgα of the H–P curves' initial zone punching work A and nondimensional complex parameter Q [11 – 14].

In the punching process the sizes of space between the transparent plate and stand of device h and of stand nozzle radius r is adjusted according material thickness δ from the following equations:

$$r \geq \sqrt{2R\delta}, \tag{1}$$

$$h = \frac{R}{r} \cdot \delta, \tag{2}$$

where the radius of specimen R is equal to 56.5 mm.

The optimal conditions of specimen punching without its' jamming in either stand's nozzle and in space between transparent plate and tester's stand are obtained when thickness δ of material is measured under pressure p, which was equal to 2.5 kPa.

Earlier research works have shown that the type of cationic softener, the kind of fiber polymer and softening conditions influence the essential changes in mechanical parameters determined in pulling process [11 – 17].

On the base of SEM analysis, it was shown that fiber surface became evidently smoother than the surface of washed fibers influencing the changes in both friction and punching parameters ($P_{\max}$, tgα, A and Q) [18].

The aim of this research was to investigate the effect of chemical softening upon the changes in the mechanical parameters of cotton fiber polymer materials differing in their structure applying the experimental methods as well as the simulated parameters.

2. METHODOLOGY

The objects of investigation were two fiber materials, i. e. woven fabric WF and knitted material KM with the initial structure parameters presented in Table 1. The choice of these materials was based on two aspects. One of them was that cotton is in the middle of triboelectric scale [19] and intensively reacts with cationic softeners. The second aspect was the aim to determine the impact of material structure roughness upon the effectiveness of chemical softening.

The samples of both investigated materials were washed as well as centrifuged using Whirlpool AWE 6515 washing machine. Later some of the washed W samples were placed horizontally and dried at 22 °C temperature T. The others were kept in the rinsing water solvents with two chemical softeners "Domol" (SD) (producer "Rosmann" from Germany) and "Nature" (SN) (producer "Vilasta" from Lithuania) prepared with 3.8 ml/l H_2O and 12 ml/l H_2O concentrations, respectively, recommended by softener producers. They were rinsed for 20 min after their centrifuging. After rinsing they were also centrifuged and dried. Specimens for punching through a central nozzle test were cut from prepared samples. The number of specimens

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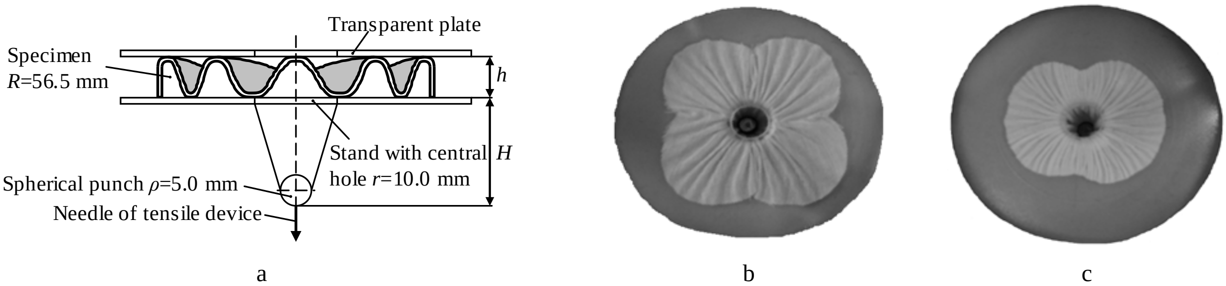


Fig. 1. Principal scheme of textile punching through a central nozzle (a) and the geometrical shapes of specimens cut from woven fabric (b) and knitted material (c); h – the distance between transparent plate and stand, H – pulling deformation

in the groups was 5 – 7. This number warranted the measuring errors ranging from 5 % to 7 %.

The changes in the properties of control specimen (C) resulting from washing (W) or chemical softening with the softeners SD or SN were determined from the measured parameters carrying out both tests: surface friction test and punching through a central nozzle test. P_{max}, tgα, A, H_{max} and Q parameters of punching a specimen through a nozzle (hand parameters) were determined from typical punching curves describing relationship between pulling deformation H and maximal pulling force P (Fig. 2) using KTU-Griff-Tester [9, 10].

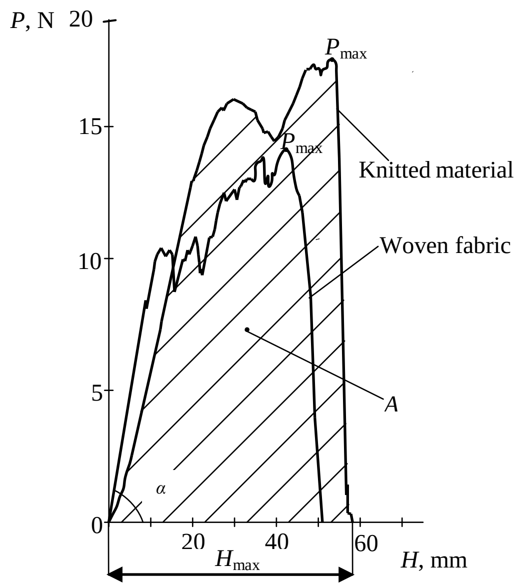


Fig. 2. Typical punching curves H–P and the parameters measu-red from them

Complex parameter Q of resistance to punching was determined from the polar diagrams (Fig. 3) involving the different number of mechanical parameters chosen according to WF woven fabric and KM knitted material structure [9]. Change in the material thickness resulting from pressure applied to material is determined as:

$$\Delta\delta = \frac{\delta_1 - \delta_2}{\delta_1} \cdot 100,\ (\%) \tag{3}$$

where δ_1 is the material thickness under pressure p_1 equal to 0.5 kPa, and δ_2 is the material thickness under pressure p_2 equal to 2.5 kPa.

Friction test was carried out according DIN EN ISO 8295 [20] standard using glass (G) and organic glass (OG) surfaces. The sliding distance was 200 mm. By this way the sliding conditions were ascertained similarly as in the specimen punching through a central nozzle of KTU-Griff-Tester having changeable stands made from both glass and organic glass (Fig. 1). The velocity of slider was 100 mm/min. The number of specimens in the groups was 5. The measuring errors ranged from 1 % to 10 %. The tests were carried out at temperature $T = 20\,^{\circ}C \pm 2\,^{\circ}C$ and humidity φ = 65 % ±2 º%.

3. RESULTS AND DISCUSSION

The obtained results have shown that washing and chemical softening significantly influence the changes in fiber materials thickness δ (Fig. 4). The thickness of WF woven fabric increased in about 1.3 times as well as the one of KM knitted material increased only in 1.12 times because of the washing out of finishing materials from textile structure and because of fiber swelling [21]. The type of chemical softeners was not significant. Knitted fabric was in 1.8 times thicker and in 1.24 times lighter than the woven fabric. Thus, the changes in knitted fabric thickness resulting from the wet technological treatment were the smaller than the ones of woven fabric.

The analysis of hand test's results has shown that the type of wet technological treatment influenced the changes in all determined parameters: P_{max}, tgα, A and Q (Fig. 5). The first difference between the WF woven and KM knitted materials was evident analyzing the shapes of typical punching through a central hole curves (Fig. 2).

The initial part of curves recorded for WF specimens is short. Later, it followed by the variation of P force influenced by brakes of specimen waves between stand and supporting plate of KTU-Griff-Tester. This is

Table 1. Characteristics of investigated materials

Material and its code	Content	Weave/knit type	Thickness δ, mm when p = 0.5 kPa	Area density, g/m^2	Linear density, tex
Woven fabric WF	100 % cotton	Plain	0.33	145.4 ±1.0	28.3/30.3
Knitted material KM	100 % cotton	Weft-knitted	0.59	117.1 ±2.0	24.0

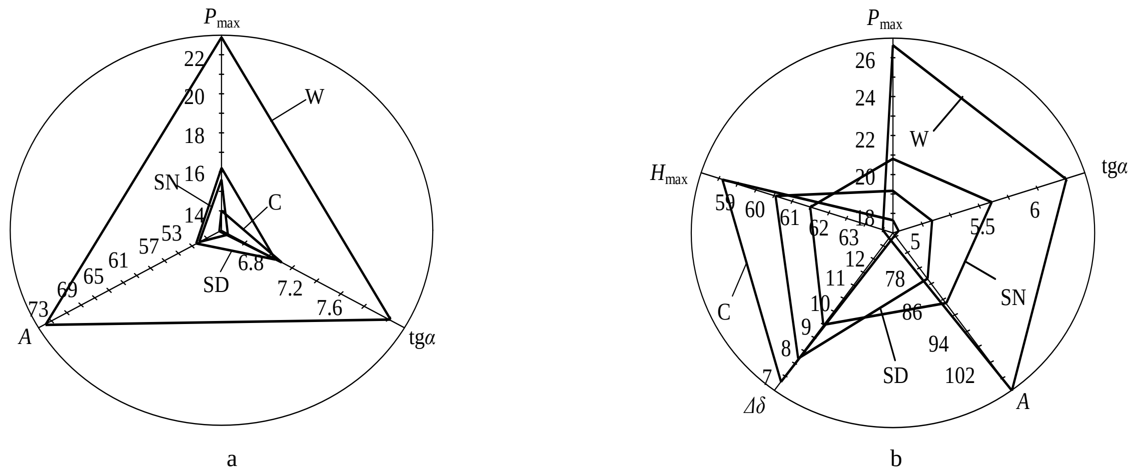


Fig. 3. Schemes of Q complex parameter determination for: a – woven fabric, b – knitted material

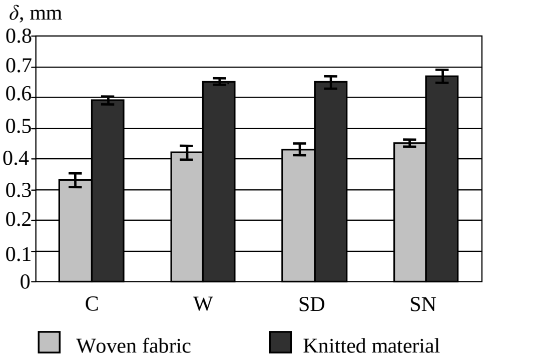


Fig. 4. Changes in the thickness of investigated materials resulting from technological treatment

influenced by the higher stiffness of WF compared with KM due its looser loop structure. For KM material the initial part of curve *H–P* is longer. Here, the material is compressed and slides gradually in the space between transparent plate and stand. The influence of wet treatment on the parameters P_{max}, tgα, A and Q is significant. The highest increase in the hand parameters was determined after material washing.

Chemical softening of washed specimens influences the decrease in punching parameters but they still remain higher compared with those of control specimens, except tgα of woven fabric [11 – 13]. For this case, tgα became lower than the one of control specimen

The highest changes were determined in the values of complex parameter Q (Figs. 3 and 5). It can be seen that the

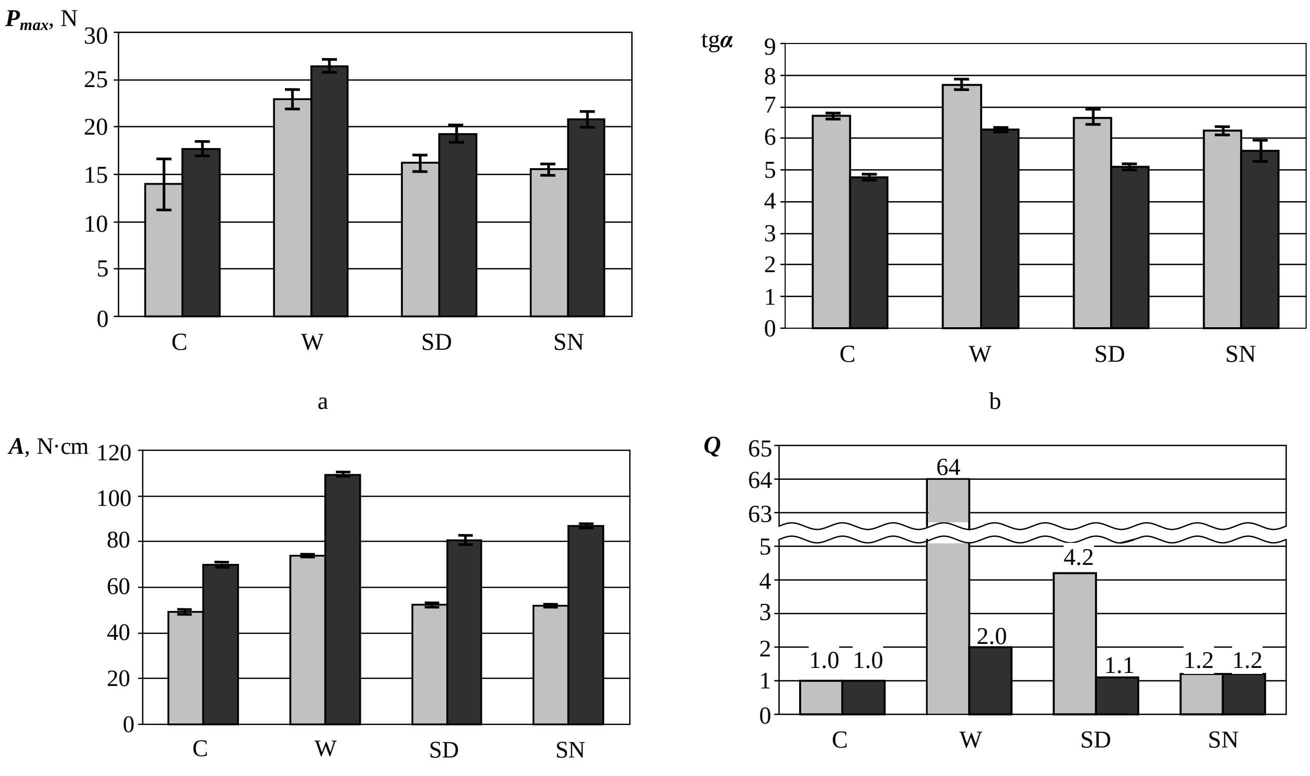
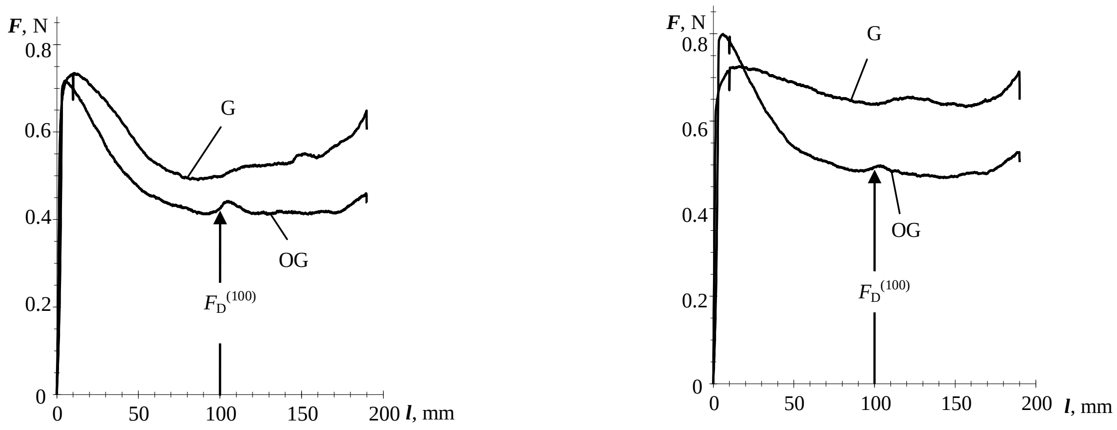


Fig. 5. Changes in punching parameters: P_{max} (a), tgα (b), A (c) and Q (d) (■ – woven fabric, ■ – knitted material)



a b

Fig. 6. Curves *l–F* of friction of the woven fabric (WF) (a) and knitted material (KM) (b) sliding on glass (G) and organic glass (OG) surfaces

values of complex parameters became the largest after materials' washing (W). The complex parameters of control materials (C) were the lowest. The values of complex parameters of chemically treated (SD and SN) specimens were slightly higher than the ones of control materials, but lower than the ones of washed specimens. The results presented in Figure 5 show that the complex parameter is the most suitable to determine the changes in material mechanical properties resulting from technological treatment. The effectiveness of the type of chemical softener can not be evidently seen from the changes in punching parameters as they vary in the range of measuring errors. But according to the tendencies of their variations, it is obviously, that SN softener was the more effective for WF fabric and SD softener – for KM material.

The parameter P_{max} of WF fabric increased in 1.64 times due to its washing compared with the control specimen. The softening of washed fabric's specimens with softeners "Domol" (SD) and "Nature" (SN) influenced the increase of P_{max} in 1.16 times and in 1.11 times, respectively. Parameter tgα increased in 1.15 times after WF fabric washing. The softening of washed specimens retains almost unchanged tgα values compared them with the ones of control specimens. The pulling work *A* increased in 1.50 times after WF fabric washing and remained almost unchanged after followed softening. The pulling force P_{max} of KM material increased in 1.49 times. It decreased in 1.08 times (SD) and in 1.18 times (SN) after softening. The parameter tgα changed in 1.31 times (W), in 1.07 times (SD) and in 1.18 times (SN). Due the wet treatment, the extraction work *A* of KM material increased in 1.57 times (W), 1.16 times (SD) and 1.25 times (SN).

The analysis of friction curves *l–F* (displacement–force) (Fig. 6) recorded during the sliding of investigated materials on the surfaces of glass (G) and organic glass (OG) surfaces shows the evident variations in the values of dynamic friction force F_D.

Table 2. Summary of friction parameters

Material code	Technological treatment	Stand	$\mu_D^{(100)}$	Variation coefficient, %
WF	Control (C)	Glass (G)	0.24	7.39
		Organic glass (OG)	0.14	1.75
	Washed (W)	Glass (G)	0.17	1.77
		Organic glass (OG)	0.18	9.49
	Softened with „Domol“ (SD)	Glass (G)	0.14	5.34
		Organic glass (OG)	0.12	8.86
	Softened with „Nature“ (SN)	Glass (G)	0.20	9.89
		Organic glass (OG)	0.19	2.21
KM	Control (C)	Glass (G)	0.27	5.15
		Organic glass (OG)	0.19	7.84
	Washed (W)	Glass (G)	0.30	4.24
		Organic glass (OG)	0.17	6.09
	Softened with „Domol“ (SD)	Glass (G)	0.25	6.44
		Organic glass (OG)	0.13	5.37
	Softened with „Nature“ (SN)	Glass (G)	0.29	4.92
		Organic glass (OG)	0.14	8.99

The lowest value of dynamic friction force F_D is in the middle part of the friction curve *l–F* recorded during WF fabric sliding on glass surface (G) and it increases in the remained part of curve. The force of dynamic friction F_D decreases regularly during sliding of woven and knitted materials on organic glass (OG) surface (Fig. 6). The different tendencies were seen in dynamic friction variation during KM knitted material's sliding on glass surface where the lowest value of dynamic friction is achieved at the end of sliding process (Fig. 6). Supposedly, the shapes of friction curves were dependent on the generation of electrostatic charges between the elements of friction pair [22]. From the friction test's results presented in Table 2 it can be seen that the average values of friction coefficients were the higher during the specimens' sliding on surface G than the ones during their sliding on surface OG. The changes in dynamic friction coefficient μ_D resulting from material technological treatment were not significant. The dynamic friction coefficient $\mu_D^{(100)}$ was the lowest during the sliding of woven fabric treated with softener SD on glass (G) or organic glass (OG) surfaces. It is higher in the friction contact of W and SN woven fabric to organic glass. The treatment of KM material with softener SD influences the decrease in $\mu_D^{(100)}$ for surface G case. The other types of wet treatment does not influence significant changes in $\mu_D^{(100)}$.

The relationships between material thickness (δ), friction coefficient ($\mu_D^{(100)}$) and hand parameters were also investigated, but the correlation between them was low.

4. CONCLUSIONS

1. The research's results had shown that the behavior of the investigated cotton woven and knitted materials depends on wet treatment. It can be examined analyzing the changes in hand (punching) parameters: P_{max}, tgα, A, and Q for woven fabric as well as P_{max}, tgα, A, $\Delta\delta$, H_{max} and Q for knitted material.
2. The analysis of the determined results had shown that the washing of control materials influences the increase in hand parameters and in material thickness. The softening of washed specimens allows regenerating the hand properties similar to those of untreated ones.
3. The determined correlations between the examined materials' parameters: thickness (δ), dynamic friction coefficient ($\mu_D^{(100)}$) and hand parameters (P_{max}, tgα, A and Q) were very low, thus the mathematical dependencies were not presented in this research.

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Presented at the National Conference "Materials Engineering 2012" (Kaunas, Lithuania, November16, 2012)