Changes in sorption properties due to repeated washing processes

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The change in the sorption properties of white cotton fabric used for bed linen in the hospital environment was investigated. For this purpose, the commercially available cotton fabric was subjected to repeated washing cycles in a Wascator FOM71 CLS industrial washing machine (Electrolux) in accordance to ISO 15797:2018. The procedure "Washing of white and delicate coloured material - Peroxyacetic bleach" was carried out at 75 °C with a standard detergent with optical bleach (WFK 88060-A1) with the addition of Proxitane 523, peroxyacetic acid - a mixture of 5 % acetic acid and 20 % H_2O_2, as a bleaching agent successively until the 15th washing cycle. The contact angle was determined on the fabric samples before and after the 1st, 5th, 10th and 15th washing cycle using a KRÜSS DSA30S goniometer. The sorption properties were investigated using standardized methods: by Absorbency of Textiles (so-called Drop test) according to AATCC TM 79-2018; by Vertical and Horizontal Wicking of Textiles according to AATCC TM 197-2018 and AATCC TM 198-2020, and the Moisture Management Capability according to AATCC TM 195-2017 was tested using the Moisture Management Tester (MMT) device, SDL Atlas. The changes in sorption properties were analysed together with the changes in mechanical properties. It has been shown that with repeated washing cycles the finishing agent is removed, which allows greater swelling, but also depletion (damage) of the fabric, so that for these two reasons the cotton fabric had a higher absorbency. The results obtained indicate the possibility of using the selected fabric in a hospital environment.
***Keywords**: washing, sorption properties, contact angle, moisture management capability.*

1. Introduction

One of the most important raw materials for the production of textiles is cotton, i.e. the cotton fiber, which is the largest and most widely used in various areas, including hospital textiles [1].

Textiles undergo repeated washing cycles. Washing is a complex process of removing impurities and soiling in an aqueous medium, the effect of which is the result of mechanical work, chemistry, temperature and time (the so-called Sinner's circle) [2].

Five factors are involved in the washing process: washing machine or industrial washing machine (type of washing machine, washing program and mechanics), textiles (raw material composition, dimensions, yarn characteristics, dyeing, printing), water (hardness, heavy metal content, quantity), detergent or cleaning agent (active, organic and inorganic components) and type and degree of soiling. In addition to aesthetics, textile hygiene is also very important for textiles, which is why attention must be paid to the composition of detergents, bleaching agents and disinfectants at the appropriate temperature. If textiles containing numerous contaminants and microorganisms are not properly disinfected, they can become carriers of infections [2-7].

Water plays the most important role in washing, as it serves as a drain for water-soluble impurities and detergent components and to disperse insoluble detergent components and insoluble impurities. The movement of the water, which is caused by mechanical and thermal influences, separates contaminant particles that fall into the bath. In addition, a higher temperature leads to a better washing effect, although too high temperatures can also have the opposite effect. The temperature should therefore be selected according to the type of textiles and soiling, taking energy efficiency into account. Time and mechanics also achieve better effects the longer or larger they are, but they also have certain limits and it is necessary to optimize the process [2, 8-12].

Numerous components in the composition of the detergent act synergistically in the washing process. The most common chemical bleaching agents in detergent formulations are perborate and percarbonate, and more recently peracetic acid has been added to the industrial process. Peroxyacetic acid or peracetic acid, PAA, is a chemical bleaching agent and disinfectant with bactericidal, fungicidal, virucidal and sporicidal activity, derived from acetic acid and hydrogen peroxide. When it reacts with coloured substances, colourless epoxides are formed [6].

The active ingredient for whitening is the peracetate anion. The decomposition of PAA is accelerated by a pH value above 9 and high temperatures, so that it bleaches at a pH value < 8. In acid, PAA is stable and decomposes very slowly, but some studies have shown that it can be bleached briefly at a pH value of 5-6 to avoid acid damage. The advantage of PAA compared to hydrogen peroxide is a lower pH value (pH 7-8) and a temperature of 60 °C (40-80 °C). During the washing process, PAA breaks down into oxygen and acetic acid, which neutralize the wash bath and are completely biodegradable. It is the most environmentally friendly and does not damage cotton fibers, but is relatively expensive, which is why it is only used in small quantities in the industry [2-14].

The detergent also contains optical brighteners, which increase degree of whiteness during the washing process that is lost during washing and wearing, and mask the grey tone caused by the transition of dirt particles from dirty to clean areas during the washing process [2, 15-17].

Repeated washing cycles change the sorption properties. Moisture passes through textiles in the form of steam and in the form of droplets. Dripping moisture is transferred by wetting and liquid penetration through textiles, while water vapor is transferred by absorption, desorption, diffusion, passage through textile layers, forced convection, migration along the fiber surface and passage through textile layers. Surface wetting can be described by the contact angle (θ), i.e. the wetting angle that occurs when liquid molecules are only adhesively bound to a solid surface but do not react in contact with it. The angle is formed by the tangent of the droplet to the surface of the material. The multidimensional moisture transport properties of the droplet moisture, the so-called moisture management properties, have a considerable influence on the human perception of moisture. The Moisture Management Tester (MMT) was developed to evaluate the moisture management properties of textiles. It is used to quantitatively measure liquid transfer in one step in textiles in repeated directions, where liquid moisture spreads on both surfaces of the textile and is transferred from one side of the surface to the other [18-24].

The hydrophobicity or hydrophilicity of textiles can be determined qualitatively and quantitatively, e.g. by testing the Absorbency of Textiles (so-called *Drop test*) and by measuring the Vertical and Horizontal Wicking of Textiles. The Moisture Management Tester and the goniometer are instruments for measuring the sorption properties of textiles, e.g. the speed spreading of moisture and the contact angle [18]. In this article, different methods were applied to investigate the change in sorption properties of white cotton fabric used in hospital environments after repeated washing cycles.

2. Material and methods

2.1. Material

In this article, optically brightened white sanforized cotton fabric in plain weave for hospital bed linen, provided by "DM Tekstil krojački obrt" was used. Fabric declared properties by the supplier are listed in tab.1.

2.2. Washing process

The white cotton fabric was subjected to repeated washing cycles in an industrial washing machine, Wascator FOM71 CLS, acc. to ISO 15797:2018 *Textiles – Industrial washing and finishing procedures for testing of workwear*.

Tab.1 Declared properties of the white fabric by the supplier

Product name:	Sanforized embroidery canvas
Country of origin:	Pakistan
Raw material composition:	100 % cotton
Colour:	White
Embroiderment:	Canvas
Surface mass, conditioned [g/m^2]:	176
The fineness of the yarn [tex; Nm]:	Warp: 35 tex x 1; Nm 29/1 Weft: 35 tex x 1; Nm 29/1
Density [threads/cm]:	Warp: 24.5 Weft: 21.5
Breaking force [N]:	Warp: 641 Weft: 549
Breaking strength [%]:	Warp: 13.5 Weft: 22.3
Dimensional changes during washing 95 °C:	After 1st washing cycle Lengthwise: -3.5 % Widthwise: -0.5 %
	After 5th washing cycle -5.0 % -0.5 %

Tab.2 Detergent composition according to ISO 15797:2002 (6.1.1.)

Component	Percentage [%]
Na-dodecylbenzenesulfonate (anionic surfactant)	0.425
Nonionic surfactant (C13/15 7EO)	6.0
Sodium citrate dihydrate (builder)	5.0
Hydroxyethanediphosphonic acid Na salt (HEDP) (builder and corrosion inhibitor)	1.0
Metasilicate anhydrous	42.3
Polymer (polymaleic acid), carrier of dirt	2.0
Foam inhibitor (phosphoric acid ester)	3.0
Sodium carbonate (Na_2CO_3), fillers	39.5
Optical brightener	0.3
Remaining water from raw material	0.475
	100

Tab.3 *Washing procedures for white workwear and/or sensitive coloured trimmings – Peracetic acid bleach* according to ISO 15797:2002

	Cotton
Load ratio	1:12
Agitation during heating, washing and rinsing	normal
Liquor ratio	1:4
Detergents and additives	4 g/l detergent 2 g/l PAA
Temperature	75 ± 2 °C
Time of washing	20 min
Cool down	no
Drain	1 min
Extraction 100 rpm	1 min
Liquor ratio	1:5
Time of rinsing 1	3 min
Drain	1 min
Extraction 100 rpm	1 min
Liquor ratio	1:5
Time of rinsing 2	3 min
Drain	1 min
Extraction 100 rpm	1 min
Liquor ratio	1:5
Time of rinsing 3	3 min
Drain	1 min
Final extraction 350 rpm	6 min

Washing procedures for white workwear and/or sensitive coloured trimmings – Peracetic acid bleach was carried out with a standard detergent with optical bleach (WFK 88060-A1) with the addition of Proxitane 523, Ivero, (peroxyacetic acid – mixture 5 % acetic acid and 20 % H_2O_2), as a bleaching agent at a temperature of 75 °C. The composition of the detergent is shown in tab.2.

15 washing cycles were carried out on white cotton fabric. The fabrics are air-dried between washing cycles. The washing procedure is shown in tab.3.

2.3. Methods

The methods for analysis of the sorption properties before and after 15 washing cycles of white cotton fabric for bed linen are:

- AATCC TM 79-2018 *Absorbency of Textiles*, so-called *Drop test*
- AATCC TM 197-2018 *Vertical Wicking of Textiles*
- AATCC TM 198-2020 *Horizontal Wicking of Textiles*
- AATCC TM 195-2017 *Liquid Moisture Management Properties of Textile Fabrics* on Moisture Management Tester M290 (MMT) by SDL Atlas
- Determination of the contact angle on the goniometer DSA30S by KRÜSS.

Drop test. Absorbency of Textiles according to AATCC TM 79-2018 is a measurement method in which the absorption time of a drop of distilled water in a cotton fabric is measured. A drop of distilled water is released from a burette at a distance of 10 mm from a 200 x 200 mm cotton fabric stretched under the burette. If the drop is absorbed immediately, the absorption time is 0 s, if the absorption time is longer than 60 s, the result is noted as "60+ s". Repeat the measurement at 5 points and take the mean value as the result.

Vertical Wicking of Textiles was measured according to AATCC TM 197-2018. 3 samples with dimensions of 165 x 25 mm are cut along the warp and marked so that the first line is drawn at a height of 5 mm, the second at 20 mm and the third at 150 mm. Distilled water is poured into the Petri dish into which the sample is immersed. The sample is lowered into it so that 5 mm of the sample is immersed in the distilled water.

The stopwatch is started as soon as the sample is immersed and the rise in the water column is observed. The measurement is finished when the water column has not reached 20 mm in 5 minutes or 150 mm in 30 minutes. After 30 minutes, the time and distance that the water has reached on the sample is recorded.

Horizontal absorbency of textiles was measured according to AATCC TM 198-2020. A 200 x 200 mm sample is stretched using a ring placed on 2 l beaker. A circle with a diameter of 100 mm is drawn in the centre of the sample beforehand. The sample is placed under the burette at a distance of 10 mm from the sample surface. 1 ml of distilled water is released from the burette and the migration on the textile is observed. The test should be terminated when the water stops migrating and has not reached the circle within 5 min; in this case, the time and distance the water has reached on the sample are recorded. If the water reaches the circle before the time has elapsed, the specified time is recorded. 5 measurements must be taken and the result is expressed as an average.

Moisture Management Capability was performed according to AATCC TM 195-2017 on a Moisture Management Tester, MMT. This test method is intended for measuring, evaluating and classifying the moisture management properties of the tested textiles. The results obtained with this method are based on the water resistance, water repellency and absorbency of the tested textiles depending on the geometric structure, the macro- and micro-structure of the textile and the capillarity of the fibers and yarns.

The 80 x 80 mm sample is placed on the lower concentric sensors with the back facing the upper concentric sensors. By lowering the upper head, on which the sensors are located, onto the back of the sample, the upper sensors come into contact with the material. The sodium chloride solution (0.22 ml) is dripped onto the back of the textile and the spread of the solution on the sample is monitored for 120 s. The solution is transferred to the material in three directions: outward spread to the top of the textile, transfer through the textile from the top to the underside and outward spread to the underside of the textile. The main types of textiles and a description of their properties are shown in tab.4. The results of 5 consecutive measurements can be presented in a table by displaying the mean value and the coefficient of variation (CV), or by means of a *Finger Print* that is formed in relation to the measurement results. *Finger Print* summarizes the moisture management properties of the tested textiles. The measured values shown in a table are:

Tab.4 The main types of textiles and a description of their properties

Types of fabrics	**Characteristic**
Water Proof Fabric	- Very slow absorption - Slow spreading - No one-way transport, no penetration
Water Repellent Fabric	- No wetting - No absorption - No spreading - Poor one-way transport without external forces
Slow Absorbing and Slow Drying Fabric	- Slow absorption - Slow spreading - Poor one-way transport
Fast Absorbing and Slow Drying Fabric	- Medium to fast wetting - Medium to fast absorption - Small spreading area - Slow spreading - Poor one-way transport
Fast Absorbing and Quick Drying Fabric	- Medium to fast wetting - Medium to fast absorption - Large spreading area - Fast spreading - Poor one-way transport
Water Penetration Fabric	- Small spreading area - Excellent one-way transport
Moisture Management Fabric	- Medium to fast wetting - Medium to fast absorption - Large spread area at bottom surface - Fast spreading at bottom surface - Good to Excellent one-way transport

- Wetting Time, WT_T (top surface) and WT_B (bottom surface),
- Absorption Rate, AR_T i AR_B,
- Maximum Wetted Radius, MWR_T i MWR_B,
- Spreading Speed, SS_T i SS_B,
- Accumulative One-way Transport Capability, R,
- Overall (liquid) Moisture Management Capability, OMMC.

The contact angle was measured with a Drop Shape Analyzer - DSA30S goniometer by KRÜSS according to HRN EN ISO 19403-6:2020 *Paints and varnishes – Wettability – Part 6: Measurement of dynamic contact angle*. The standard configuration of DSA30 is designed for semi-automatic contact angle measurements, including dynamic contact angle measurements and surface free energy determinations. The device is ideal for reliable measurement of the wetting process [25].

The contact angle is measured by placing the sample on a table, which is captured by a camera connected directly to the computer screen. A needle filled with distilled water is lowered onto the sample until it is within the range visible on the screen. Before the liquid is dispensed, the needle must be calibrated manually. Before starting the measurement, the textile should be placed on the table so that a flat surface is visible on the screen in order to set the baseline, i.e. the line indicating the contact of the droplet with the textile, as correctly as possible. Distilled water that falls onto the textile in the form of a drop has a volume of 10 μl. The DSA30S software can start the measuring process automatically and immediately after the liquid is dispensed, while the data is recorded immediately after the drop hits the textile surface.

Mechanical properties. The change in the fabric mass per surface area after washing cycles is calculated gravimetrically in accordance with ISO 3801:1977 *Textile – Woven fabrics – Determination of mass per unit length and mass per unit area*:

$$\Delta m = \frac{m_0 - m}{m_0} \cdot 100\ [\%] \qquad (1)$$

Δm is the change in surface mass [%], m_0 is the mass of the initial fabric [g/m^2] and m is the mass of the fabric after washing [g/m^2].

Yarn count was determined by ASTM D3775-07 *Standard Test Method for Warp (End) and Filling (Pick) Count of Woven Fabrics* [No./cm ≡ cm^{-1}].

The mechanical damage (U_m) of the fabric during washing was calculated according to ISO 4312: 1989 *Surface active agents – Evaluation of certain effects of laundering – Methods of analysis and test for unsoiled cotton control cloth* using the breaking force [N] of unwashed fabric (F_0) and of the fabric after washing (F) determined using the TensoLab Strength Tester (Mesdan, Italy) according to ISO 13934-1:2013 *Textiles – Tensile properties of fabrics – Part 1: Determination of maximum force and elongation at maximum force using the strip method* with a distance between clamps of 100 mm, a stretching speed of 100 mm/min and a pre-tension of 2 N:

$$U_m = \frac{F_0 - F}{F_0} \cdot 100\ \ [\%] \qquad (2)$$

3. Results and discussion

In this article, the change in the sorption properties of white cotton fabric after repeated washing cycles (W) was researched. The sorption properties were tested using standardized methods.

Drop test results determined according to AATCC TM 79-2018 are shown in tab.5. From the results it can be seen that the unwashed cotton fabric has no absorption time, > 60 s, so it is hydrophobic. White cotton fabric after the first washing cycle absorbs drop after 10 s, and immediately (0 s) after the 5th, 10th and 15th washing cycle, which means that it has become hydrophilic as a result of the washing. It can be assumed that the white fabric had a finishing agent that made it hydrophobic. Washing process removed the finishing agent and the fabric became hydrophilic.

Quantitative methods for determining sorption properties are, in addition to the drop test, the measurement of the vertical and horizontal wicking of textiles. It depends on the subjective assessment of the rate of rise of the water column.

When measuring the rate of rise of the water column in a vertically positioned sample, the sample is positioned vertically and gravity acts on it, whereas in a horizontally positioned sample, gravity has no influence. It should be noted that the rise of the water column is influenced by capillary forces in both measurements.

The results of the measurement of the rate of rise of the water column in a vertically positioned sample are shown in tab.6, which contains the following values: mean liquid penetration distance $\bar{d}$ [mm], mean liquid penetration time $\bar{t}$ [s] and mean capillary absorption rate $\bar{W}$ [mm/s]. The graphical representation of the liquid penetration distance as a function of time can be seen in Fig.1. The results indicate the water column increases with the increment of number of washing cycles. The unwashed fabric shows the smallest increase in water column, only 10 mm in 5 minutes. After the first washing cycle, the fabric reaches a distance of 19 mm in 5 minutes, which is still slightly more than the unwashed fabric. After the 5th, 10th and 15th washing cycle, the water column of the fabric increases more, namely by 108 mm, 116 mm and 125 mm in 30 minutes. The curves in Fig.1 clearly show that the absorbency increases with each washing cycle and that the rate of liquid penetration is highest after 15 washing cycles.

Table 7 shows the results of vertical wicking of white cotton fabric expressed by the speed of water penetration, t (s), and the distance of water column, d (mm). The results show that there is no movement of water column on the unwashed fabric within 300 s.

Tab.5 Absorbency of cotton fabric expressed as drop absorption time t [s]

	t [s]				
Sample	0W	1W	5W	10W	15W
	60+	10	0	0	0

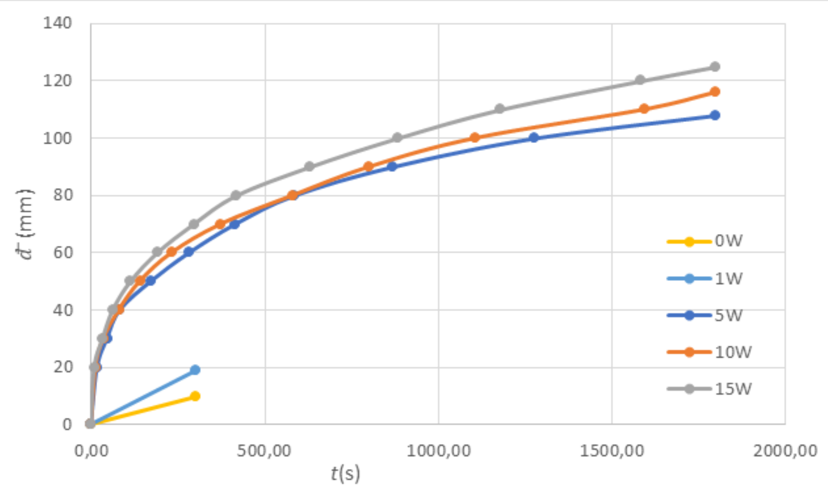

Fig.1 Vertical wicking of white cotton fabric

Tab.6 Vertical wicking of white cotton fabric, mean water penetration time, *t* [s], mean penetration distance, *d* [mm], and mean speed of capillary absorption, $\overline{W}$ [mm/s]

Sample	$\bar{d}$ [mm]	$\bar{t}$ [s]	$\overline{W}$ [mm/s]
0W	10	300.00	0.033
1W	19	300.00	0.063
5W	20	17.28	1.157
	30	45.95	0.653
	40	82.53	0.485
	50	171.48	0.292
	60	281.90	0.213
	70	415.19	0.169
	80	586.20	0.136
	90	869.46	0.104
	100	1277.14	0.078
	108	1800.00	0.060
10W	20	12.93	1.547
	30	35.49	0.845
	40	79.87	0.501
	50	140.35	0.356
	60	231.98	0.259
	70	373.83	0.187
	80	581.00	0.138
	90	801.68	0.112
	100	1106.34	0.090
	110	1592.57	0.069
	116	1800.00	0.064
15W	20	9.35	2.139
	30	33.42	0.898
	40	62.75	0.637
	50	113.79	0.439
	60	191.38	0.314
	70	296.30	0.236
	80	419.44	0.191
	90	631.34	0.143
	100	883.66	0.113
	110	1179.42	0.093
	120	1582.27	0.076
	125	1800.00	0.069

After the 1st washing cycle, within 300 s, it reached a distance of 33 mm. Further washing (5th, 10th and 15th washing cycle) results in reaching the maximum distance of 100 mm almost in the same period of time.

Quantitative parameters used to determine moisture management capability were measured on the MMT according to AATCC TM 195-2017. The results of the moisture management test on unwashed cotton fabric are shown in Tab.8. The results of measurements on washed white cotton fabric in repeated washing cycles are shown in Tabs.9 and 10. Labels in Tabs.8-10 are: coefficient of variation (CV); top surface (T); bottom surface (B); Wetting Time (WT); Absorption rate (AR); Maximum wetted radius (MWR); Spreading speed (SS); Accumulative One-way Transport Capability (R); Overall (liquid) Moisture Management Capability (OMMC).

The time period of wetting of the upper and lower surface of the fabric is expressed by the wetting time, which can be compared with the drop test. It can be seen that the unwashed fabric has the longest wetting time, while it decreases with the number of washing cycles. This indicate that the fabric has become hydrophilic. This results are comparable to the drop test, but they are quantified and accurate, for the difference of subjective measure- of drop test. From the maximum wetted radius, it can be seen that the unwashed fabric was not wetted, which is a sign of the hydrophobicity of the fabric, while the radius is already 10 mm during the first washing cycle. A further increase in the washing cycle (5th, 10th and 15th washing cycle) leads to an even larger wetting radius, which is the same for all three washing cycles and amounts to 24 mm, or 23 mm for the 10th washing cycle.

Tab.7 Horizontal absorbency of cotton fabric – penetration time, *t* [s], and penetration distance, *d* [mm]

Sample									
0W		1W		5W		10W		15W	
t [s]	d [mm]	t [s]	d [mm]	t [s]	d [mm]	t [s]	d [mm]	t [s]	d [mm]
300	0	300	33	102.33	100	102.67	100	102.67	100

Tab.8 Moisture management results according to AATCC TM 195-2017 for white cotton fabric

Sample		0W	
		Mean	CV
WT [s]	T	120.0	0,0
	B	6.9452	0,1084
AR [%/s]	T	0.0	0,0
	B	60.5968	0,0937
MWR [mm]	T	0.0	0,0
	B	5.0	0,0
SS [mm/s]	T	0.0	0,0
	B	0.707	0,1001
R [%]		927,8558	0.0513
OMMC		0,6405	0.0246
Type		*Water Penetration Fabric*	

Tab.9 Moisture management results according to AATCC TM 195-2017 for white cotton fabric after 1st and 5th washing cycle

Sample		1W		5W	
		Mean	CV	Mean	CV
WT [s]	T	36.879	1.1895	3.0326	0,1302
	B	6.2152	0.3565	3.1822	0,1081
AR [%/s]	T	14.3856	0.6332	71.9953	0,0117
	B	48.704	0.5403	65.2284	0,0178
MWR [mm]	T	10.0	0.5	24.0	0,0932
	B	10.0	0.5	22.0	0,1245
SS [mm/s]	T	0.6375	0.7417	4.6789	0,0597
	B	0.964	0.2566	4.4008	0,0498
R [%]		635,522	0.3457	-5.2238	2.7913
OMMC		0,6137	0.1248	0.4532	0.038
Type		*Water Penetration Fabric*		*Fast Absorbing and Quick Drying Fabric*	

Tab.10 Moisture management results according to AATCC TM 195-2017 for white cotton fabric after 10th and 15th washing cycle

Sample		10W		15W	
		Mean	CV	Mean	CV
WT [s]	T	2.995	0.0384	2.939	0,0364
	B	3.1262	0.0268	3.1262	0,0453
AR [%/s]	T	69.2941	0.0075	68.8861	0,0142
	B	63.4546	0.0096	62.0989	0,0209
MWR [mm]	T	23.0	0.1191	24.0	0,0932
	B	23.0	0.1191	25.0	0,0
SS [mm/s]	T	4.4284	0.0492	4.6405	0,0369
	B	4.2738	0.0428	4.5074	0,033
R [%]		5,2284	2.1868	3.2305	3.2394
OMMC		0,4596	0.0308	0.4539	0.0311
Type		*Fast Absorbing and Quick Drying Fabric*		*Fast Absorbing and Quick Drying Fabric*	

The overall moisture management capability is an index for the overall ability of the fabric to transport droplets of moisture. The index is obtained by calculating the absorption rate on the underside, the highest moisture spreading speed on the underside and the ability to transfer moisture in one direction. It can be seen that as the number of washing cycles increases, the overall ability to absorb moisture also decreases, which is consistent with the previously mentioned measurements. Unwashed cotton fabric is characterized as a "water penetration fabric", having a small spreading area and excellent one-way transport. The same characterization applies to the fabric after the first washing cycle. By increasing the washing cycle, the fabric is characterized as a "fast absorbing and quick drying fabric", and it is characterized by medium to fast wetting, medium to fast absorption, large spreading area, fast spreading, poor one-way transport.

The contact angle, expressed as the mean value of the contact angle of the droplet immediately after the first contact with the cotton fabric, CA (m) [°C], is shown in tab.11 and Fig.2.

It can be seen that the contact angle on the unwashed cotton fabric has the highest value, while the angle value decreases significantly after the 1st washing cycle. The contact angle after the 5th, 10th and 15th washing cycle could not be measured, as the droplet was absorbed immediately after the liquid came into contact with the fabric. The reason for the greater absorption of water and moisture in repeated washing cycles can be twofold: 1. swelling, 2. damage to the cotton cellulose. Cotton fibers swell up to 40 % of their volume in water, usually in the radial direction, whereas they only swell by 1-2 % in the longitudinal direction.

Tab.11 The contact angle, expressed as the mean value of the contact angle of the droplet immediately after the first contact with the cotton fabric, CA (m) [°C]

CA (m) [°C]				
0W	1W	5W	10W	15W
105.67	50.35	0	0	0

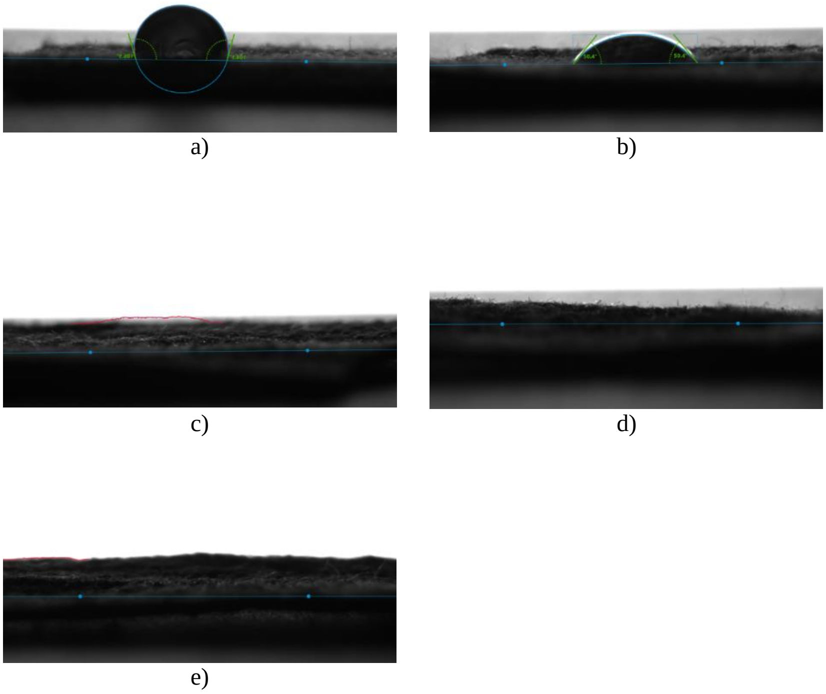

Fig.2 Screenshots from the DSA30S software when determining the contact angle on a white cotton fabric: a) unwashed, and after b) 1st, c) 5th , d) 10th , and e) 15th washing cycle

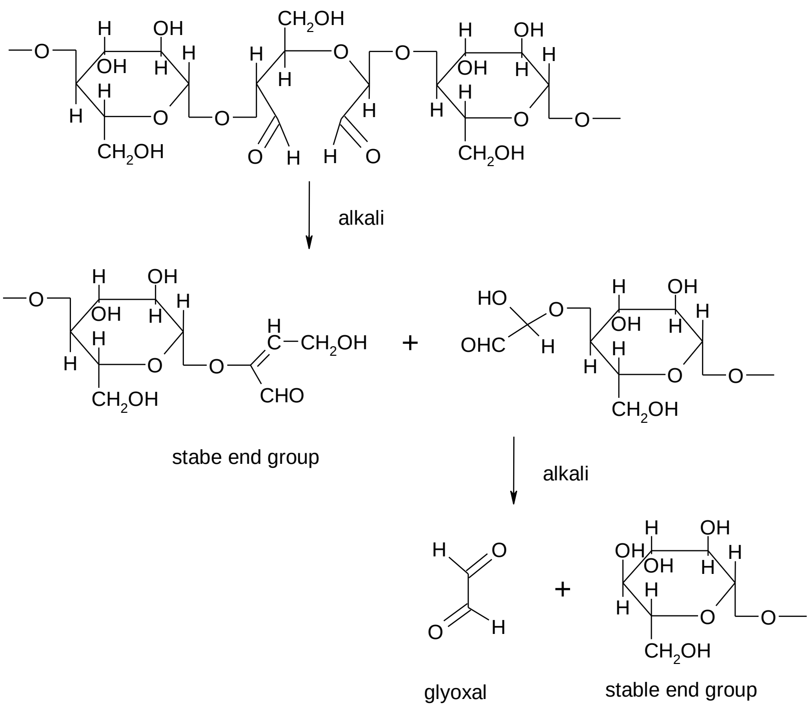

Fig.3 Alkaline hydrolysis of oxycellulose

This extremely anisotropic swelling behaviour is explained by the fact that the water cannot penetrate the crystalline micro-fibril structure of the cellulose, but the swelling in the fibers only takes place between the micro-fibrils. During chemical bleaching, in addition to the decomposition of pigments, partial oxidation of the cellulose can occur, so that in addition to hydroxyl groups (–OH), carboxyl groups (–COOH) are possible, and sometimes the oxidation of secondary alcohols leads to the formation of aldehyde and keto groups [26, 27]. Aldehyde groups are particularly sensitive to alkalis (Fig.3), so that alkaline hydrolysis or decomposition of the cotton cellulose can occur during washing in an alkaline medium, resulting in chemical and mechanical damage to the cotton fabric [17, 26].

For this reason, the changes in the mechanical properties of the fabric due to repeated washing cycles were researched. In Tab.12 the results of the yarn count and in tab.13 of the mass per surface area of the cotton fabric before and after repeated washing cycles are presented, and the changes in mass are calculated according to (1). In Tab.14 the results of the tensile properties are shown, and the mechanical damage of the cotton fabric before and after repeated washing cycles was calculated according to (2). From the results in Tabs.12-14 can be observed that the fabric shrunk after the first washing cycle, so the yarn count, the mass per surface area and breaking force are higher. The reason for fabric shrinkage is high swellling capacity of the cellulose materials under the washing conditions. The yarn count increased in both directions increasing the mass per unit area. As the number of washing cycles increases, the fabric continues to shrink and

Tab.12 Yarn count of cotton fabrics before and after repeated washing cycles

Sample	N_o [cm^{-1}]	CV [%]	N_p [cm^{-1}]	CV [%]
0W	26.00	4.45	22.00	0.00
1W	26.67	3.85	22.00	0.00
5W	29.33	2.56	22.67	2.33
10W	29.33	3.03	22.67	2.67
15W	29.33	2.67	23.33	3.02

N_o – warp count [cm^{-1}]; N_p – weft count [cm^{-1}]; CV - coefficient of variation

Tab.13 Mass per unit area and changes in the mass per unit area of cotton fabric before and after repeated washing cycles

Sample	m [g/m^2]	CV [%]	Δm [%]
0W	177.98	0.01	-0.00
1W	187.95	1.31	-5.60
5W	188.88	2.05	-6.12
10W	200.66	0.23	-12.74
15W	200.27	0.51	-12.52

m – mass per unit area [N]; CV – coefficient of variation; Δm – change in mass [%]

Tab. 14 The breaking force in warp direction and mechanical damage of cotton fabric before and after repeated washing cycles

Sample	F_o [N]	CV [%]	U_m [%]
0W	553	8.124	0
1W	615	2.642	-10.08
5W	655	5.744	-15.57
10W	622	3.646	-11.09
15W	542	7.445	2.03

F_o – mean value of breaking force, warp direction [N]; CV – coefficient of variation; U_m – mechanical damage [%]

the mass increases. However, after the 10th cycle it reaches its maximum mass. The results of the breaking force (F) shown in Tab.13 show an improvement in the mechanical properties. Due to the shrinkage of the fabric, the number of threads in the test increased, resulting in higher breaking force values. Up to the 10th washing cycle, the breaking force increased with increasing mass. After the 15th washing cycle, however, the breaking force decreased, which can be attributed to the increase in mass as a possible effect of the oxidizing agent. The observed decrease in tensile strength can therefore be attributed to the mechanical damage to the cotton fabric during repeated washing cycles, with increased swelling and a greater number of available groups leading to greater moisture and water absorption.

Studies on the cumulative effects of washing on the properties of cotton fabrics and their blends [17] have shown that washing causes changes in cotton due to the strong swelling in an alkaline medium, the influence of bleaching agents and mechanics, and that a damaged (repeatedly washed) fabric is much more susceptible to soiling than an undamaged one. The MMT results indicate that the fabric is characterized as a "fast absorbing and quick drying fabric", which indicates a shift in charge towards the positive and thus a higher susceptibility to soiling.

4. Conclusion

In this study, the sorption properties of white sanforized cotton fabric was investigated after repeated washing cycles. The results of measuring the sorption properties with different standard methods gave very similar results.

The original cotton fabric has hydrophobic properties and is described by MMT as "water penetration fabric". This means that it has water-repellent properties but allows dripping moisture to pass through - it "breathes". This is confirmed by all methods: a clear drop forms on the surface with the possibility of measuring the contact angle, there is no drop absorption, no water penetration into the fabric by vertical or horizontal wicking.

Washing increases the hydrophilicity of the cotton fabric. After the first washing cycle, the contact angle decreases, which is smaller but still measurable. A low water penetration by horizontal and vertical wicking into fabric is observed. The results of the MMT show that the wetting radius has increased to 10 mm, but the fabric still has the same characterization as "water penetration fabric".

The fabric has become hydrophilic after repeated washing cycles. The sorption properties changed with each washing cycle. After the 5th washing cycle, there is a clear increase in absorption, and this increase stagnates in repeated washing. The penetration speed is visible in all methods, especially in the contact angle measurement, which could not be measured. These fabrics are characterized as "fast absorbing and quick drying fabric".

It can be said that the unwashed cotton fabric was finished and has a water-repellent effect. Repeated washing cycles lead to the removal of the finishing agent, therefore allowing better swelling. The fabric damage occurred as well, so the cotton fabric has a higher absorbency for these two reasons.

The obtained results indicate the possibility of using the selected fabric in a hospital environment, however to confirm whether the fabric damage occurred during oxidative bleaching in repeated washing, secondary effects in washing should be researched as well.

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References:

[1] Čunko R., M. Andrassy: Vlakna, Zrinski d.d. Čakovec, Zagreb 2005.
[2] Soljačić I., T. Pušić: Njega tekstila, Čišćenje u vodenim medijima, Sveučilište u Zagrebu Tekstilno-tehnološki fakultet, 2005.
[3] Kitis M.: Disinfection of wastewater with peracetic acid: a review, Environment International 30 (2004) 1, 2004, 47-55
[4] Hickman W. S.: Peracetic acid and its use in fibre bleaching, Rev. Prog. Color. 32 (2002), 13-27
[5] Forte Tavčer P.: Impregnation and Exhaustion Bleaching of Cotton with Peracetic Acid, Textile Research Journal 80 (2010) 1, 3-11
[6] Forte-Tavčer P., P. Križman: Bijeljenje pamuka za sanitetske proizvode s peroctenom kiselinom, Tekstil 52 (2003) 7, 309-315
[7] Forte-Tavčer P. i sur.: Obrada pamuka pektinazama i peroctenom kiselinom, Tekstil 53 (2004) 3, 110-118
[8] Roessler A., X. Jin: State of the art technologies and new elektrochemical methods for the reduction of vat dyes, Dyes Pigm. 59 (2003) 3, 223-235
[9] Pušić T.: Ekološki profil procesa pranja, Sveučilište u Zagrebu Tekstilno-tehnološki fakultet, Dan otvorenih vrata Znanstveno-istraživačkog centra za tekstil, 25. rujna 2019.
[10] Pušić T.: Higijensko pranje, Sveučilište u Zagrebu Tekstilno-tehnološki fakultet, Poticanje društvenog poduzetništva, Probudi kreativnost – izlaganje, GDCK Vrbovec, 2019. Dostupno na: https://gdck-vrbovec.hr/probudi-kreativnost/
[11] Pušić T., B. Iskerka, B. Vojnović: Istraživanje jodnog broja pamučne tkanine nakon pranja, Tekstil 63 (2014.) 1-2, 41-48
[12] Lovreškov V.: Utjecaj aditiva u deterdžentu na svojstva opranih materijala, Diplomski rad, Sveučilište u Zagrebu Tekstilno-tehnološki fakultet, 2019. https://repozitorij.ttf.unizg.hr/islandora/object/ttf%3A556/datastream/PDF/view
[13] Papić S.: Deterdženti, Interna skripta, 2015. Sveučilište u Zagrebu Fakultet kemijskog inženjerstva i tehnologije, https://www.fkit.unizg.hr/_download/repository/DETERDZENTI.pdf
[14] Pušić T., K. Grgić, I. Soljačić: Peracetic acid effectiveness in laundering of cotton fabrics, Engineering Power, Bulletin of the Croat. Academy of Eng. 11 (2016) 1, 2-5
[15] Tarbuk A., T. Pušić, T. Dekanić: Postupci proizvodnje, uzorkovanja i analize deterdženata, Tekstil 62 (2013.) 7-8, 319-328
[16] Pušić T., I. Soljačić: Changes in shade and ultraviolet protection of pastel dyed cotton fabrics during laundering with fluorescent compounds, Colourage 56 (2009) 1, 43-48
[17] Pušić T., I. Soljačić, T. Dekanić: Cumulative effects of washing on properties of cotton fabrics and their blends, H&PC Today 9 (2014) 7/8, 26-33
[18] Dekanić T. i sur.: Određivanje sposobnosti upravljanja vlagom vodoodbojne pamučne tkanine kondenzirane pri niskoj temperature, Tekstil 67 (2018) 7-8, 176-188
[19] Grancarić A. M., A. Tarbuk, E. Chibowski: Slobodna površinska energija tekstila, Tekstil 57 (2008.) 1-2, 28-39
[20] Hubbe A. M., J. D. Gardner, W. Shen: Contact angles and wettability of cellulosis surfaces: A review of proposed mechanisms and test strategies, BioResources 10 (2015) 4, 8657-8749
[21] Mazloompour M., N. Ansari, N. Hemmatinejad: Wetting behaviour of raw and water-repellent cotton fabrics using

wetting kinetic measurements, Indian Journal of Fibre and Textile Research 32 (2007), 93-98

[22] Wiener J., P. Dejlova: Wicking and wetting in textiles, AUTEX Research Journal 3 (2003), 64-71

[23] Mayur B. et al.: Moisture management properties of textiles and its evaluation, Current Trends in Fashion Technology & Textile Engineering 3 (2018) 3, 50-55

[24] Junyan H. et al.: Moisture Management Tester: A method to characterize fabric liquid moisture management properties, Textile Research Journal 75 (2005) 1, 57-62

[25] KRÜSS: DSA30. Dostupno na: https://www.kruss-scientific.com/products/drop-shape/dsa30/drop-shape-analyzer-dsa30s/, pristupljeno: 3-2021.

[26] Bishop D. P.: Physical and chemical effects of domestic laundering processes, In: Carr C.M. (eds) Chemistry of the Textiles Industry, Springer, Dordrecht. (1995) https://doi.org/10.1007/978-94-011-0595-8_4

[27] Stana-Kleinschek K., S. Strand, V. Ribitsch: Surface Characterization and Adsorption Abilities of Cellulose Fibers, Polymer Engineering and Science 39 (1999) 8, 1412-1424.