(REFEREED RESEARCH)

INFLUENCE OF MULTIPLE LAUNDERING ON COTTON SHIRTS PROPERTIES

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ABSTRACT

White and light colored cotton men's shirts were submitted to multiple laundering with two different detergents under the same washing conditions. Powder detergent contained bleaching agent and optical brightening agents while the liquid one did not. Changes after 25 washing cycles were analyzed through mechanical, comfort and aesthetic properties and ash content. Mechanical properties were studied by measuring tensile strength and tensile elongation, comfort by air permeability and thickness and aesthetic properties by whiteness index and CIELab coordinates. Shirts laundered whith powder detergent showed higher thickness, mechanical properties and ash content and lower air permeability compared to shirts laundered with liquid detergent. White shirts laundered with powder detergent showed higher whiteness index compared to shirts laundered with liquid detergent. Colored shirts laundered with powder detergent were lighter (higher ΔL*) and showed higher fading (higher ΔE*) compared to shirts laundered with liquid detergent.

Keywords: Cotton shirt, detergents, multiple washing, ash residues, mechanical properties, comfort, aesthetic properties

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1. INTRODUCTION

For most people, wearing dress shirt is a comfortable and stylish way to look decent every day. Man's dress shirt includes a diversity of styles, colors, designs and constructions. They are made of cotton or blend of cotton and polyester, sometimes with lycra. Reasons for blend development are economy, durability, comfort and ease of use and care (1). Determining shirt duration expectancy is difficult due to variances in wear frequency. Industry experience shows that, on average, shirts have a two year wear life expectancy during 25 to 30 washing cycles (2). Generally, laundering is most damaging to fabric than its usage or wear, causing fiber modification due to fiber swelling capacity in alkaline detergent bath superimposed by mechanical agitation. These phenomena are followed by changes of fiber surface color, textile hand, comfort and other parameters (3-5).

Laundering process include textile materials, soil, water, detergents and washing machine. Today intention is to use a shorter laundering time and lower temperature. This developed new environmental friendly detergent, based mostly, on their efficiency on lower temperature (6). Laundering processes should not only be tested for their cleaning efficiency (primary effects) but also on their gentleness to shirts during laundering (secondary effects). Primary effects refer to soil and stain removal after one washing cycle, while secondary effects concern different aspects of damages after 25 or 50 washing cycles.

Detergent can be in powder or liquid form. Household detergents are complex formulation containing different compounds among which surfactant is the active ingredient. The other substances being builders, alkali/pH controller, chelating or complexing agents, ion exchangers, fabric softeners, corrosion inhibitors, foam controlling agents, bleaching agents/activators, fluorescent brighteners/ whitening agents, enzymes, fragrances/perfumes, fillers and other additives (7-8). Universal powder detergent for use on 30, 40, 60 and 90 ºC, usually contains anionic and nonionic surfactants, phosphate and/or, zeolits and/or polycarboxylates as sequesters or ion exchange components. It also contains perborate as an oxygen bleaching agent, whitening agent, enzymes, components for re-deposition of soil and others. Liquid detergent for washing dyed fabrics usually contains anionic and nonionic surfactants, zeolites, or polycarboxylate compounds, enzymes, compounds for re-deposition of soils and others. Liquid detergents can be classified into two types: unstructured and structured. Unstructured liquid detergents are isotropic and contain higher quantity of nonionic surfactants and soaps and lower quantity of anionic surfactants and builders. Structured liquid detergents contain higher quantity of anionic surfactants and builders and lower quantity of nonionic surfactants and soaps (3, 9). Liquid detergent components must be easy soluble in water and stable during a long period of time. That is the reason that liquid detergents do not contain perborate because it is not stable in alkali media (9).

Correct washing should keep shirt look new for a long time. A poorly washed shirt looks very tacky. Laundering temperature, ranges from 40 ºC to 60 ºC, depending on shirt color. Shirts are primarily dyed with reactive or vat dyes. Consumers can understand how to follow care label instructions and prolong life of their garments. Labels may define machine wash, tumble dry, but detergent type and drying temperature are not stated. Care label should recommend use of detergents and bleaches to assist in the removal of soil and stains (10).

The aim of this investigation is to analyze the secondary effects of multiple laundering of white and light colored cotton shirts with two different detergents under same washing conditions. Changes after 25 washing cycles were analyzed through damage (loss of tensile strength), incrustations (deposits of inorganic compounds), graying and color change (reduced whiteness and color change by dye transfer) as well as comfort properties through air permeability.

2. EXPERIMENTAL

2.1. Material

Tested shirt fabrics, were in white or light colours, produced from combed yarns, having fabric weight from 72.64 to 115.46 g/m^{2}. Fibre composition is 100% cotton or blend of 97 % cotton and 3 % elastane. Fabrics were woven in plane, twill, satin or basket weave. These are the most common fabrics for production of man's shirts. After selection of fabrics, shirts were sewn on industrial sewing machine under sewing parameters adopted by apparel manufacturers. Sewing parameters and machine settings were constant during sewing. Fabrics characteristics for shirt production are given in Table 1.

2.2. Laundering procedures

Domestic washing machine, with horizontal axis, front loading type was used for laundering. Washing machine was set as follows: total load weight 1.8 kg, water level high, temperature 60 ºC, 106 min laundering time, and 40 L water content. Recommended detergent quantity in accordance with water hardness, 160 ml of liquid and 150 g of the powder detergent, was added to the washing machine. After laundering shirts were dried in vertical position at room temperature. Washing and drying cycles were repeated up to 3 and 25 times.

2.3. Detergents

Powder and liquid detergents commercial available with different formulations were selected for shirts washing. Washing conditions, such as temperature, number of washing cycles and load of washing products, were kept constant during shirts laundering. Powder detergent contains 5-15 % anionic surfactants, 5 % nonionic surfactants, phosphate, oxygen bleaching agent, enzymes, polycarbonates, soap, zeolites, optical brighteners and fragrances declared for washing on 30, 40 and 60 ºC. Liquid detergent contains 15-30 % anionic surfactant, formaldehyde, fragrance, benzyl benzoate, 2-(4-tetra-butylbenzyl) propylaldehyde, coumarin, hexyl-cinnamon aldehyde and linalool.

Table 1. The characteristics of cotton woven fabrics used for production of dress shirts

Shirt Fabrics Code	Color	Weave	Fibre composition	Fabric weight, g/m^2	Fabric thickness, mm	Yarn count, tex		Yarn density, cm^{-1}		Fabric fractional cover		
						warp	weft	warp	weft	warp	weft	total
1	White	Plane	100 % Cotton	72.64	0.22	7.4	10	53.33	33.67	0.54	0.40	0.73
2	White	Plane	100 % Cotton	115.99	0.22	14	14	51.67	31.67	0.72	0.44	0.85
3	White	Twill	100 % Cotton	117.90	0.26	14	20	48.33	28.00	0.68	0.47	0.83
4	White	Plane	100 % Cotton	122.15	0.24	17	20	42.67	23.00	0.66	0.39	0.79
5	White	Plane	97 % Cotton/ 3 % Elastane	123.21	0.35	14	20	53.33	27.00	0.75	0.45	0.86
6	White	Plane	97 % Cotton/ 3 % Elastane	125.83	0.29	12.5	17	57.33	27.00	0.76	0.42	0.86
7	White	Plane	100 % Cotton	127.40	0.29	12.5	12.5	50.00	27.00	0.66	0.36	0.78
8	White	Twill	100 % Cotton	192.32	0.48	30	30	41.00	21.33	0.84	0.44	0.91
9	Light color	Plane	100 % Cotton	89.25	0.22	9	9	57.00	35.67	0.64	0.40	0.79
10	Light color	Plane	100 % Cotton	106.69	0.26	12.5	12.5	50.00	27.67	0.66	0.37	0.79
11	Light color	Plane	100 % Cotton	108.53	0.24	17	14	47.33	29.67	0.73	0.42	0.84
12	Light color	Plane	100 % Cotton	114.18	0.25	14	17	48.00	25.00	0.67	0.39	0.80
13	Light color	Plane	100 % Cotton	115.51	0.33	12.5	14	50.00	36.00	0.66	0.51	0.83
14	Light color	Satin	100 % Cotton	128.24	0.26	8.3	14	80.67	45.00	0.87	0.63	0.95
15	Light color	Basket	100 % Cotton	139.64	0.42	14	36	48.00	18.00	0.67	0.40	0.81
16	Stripes	Plane	100 % Cotton	97.19	0.24	14	10	57.33	31.33	0.80	0.37	0.88
17	Stripes	Basket	100 % Cotton	115.46	0.25	14	14	50.00	26.67	0.70	0.37	0.81

2.4. Testing and Analysis

Fractional fabric cover is defined as the fraction of the fabric area covered by the component yarns (11). Fractional fabric cover in warp (C_1) and weft (C_2) direction are calculated by equations (1):

$$C_1 = d_1/s_1 \text{ and } C_2 = d_2/s_2 \quad (1)$$

Where: d_1 and d_2 are diameters of the warp and weft yarn cross section, and s_1 and s_2 is the spacing that warp and weft thread occupies in the fabric.

Total fractional fabric cover (C_F) is calculated by equation (2):

$$C_F = C_1 + C_2 - C_1 \cdot C_2 \quad (2)$$

Fabric weight was determined according to ISO 3801:1977.

Fabric thickness was determined according to EN ISO 5084.

Mechanical properties were analyzed through tensile strength and tensile elongation in the warp direction according the strip method (BS EN ISO 13934:1-1999) on Tinus Olsen tensile tester, using test speed 100 mm/min and gauge length 200 mm. The loss in the tensile strength (%) was calculated as a percent of the difference between fabrics tensile strengths after 3 and 25 laundering cycles.

Ash content was determined according to DIN 53 919, part 2. Amount of 3 g of sample material is taken from the unwashed and washed shirt, cut, weighed, incinerated in a porcelain crucible, annealed during 60 min at 800 ºC in a muffle furnace, cooled in a desiccators and weighed again. The ash residues are indicated in percent of the fabric weight.

Comfort characteristics were analyzed through air permeability according to BS EN ISO 9237:1995 on M021A Air Permeability Tester using a test area 20 cm^2 and pressure 100 Pa.

Aesthetic properties were analyzed through whiteness index, *CIE Lab* colour coordinates and colour differences measured on X-Rite spectrophotometer with Colour Match colour formulation software v7.0 (D65/10°).

Water hardness was determined in laboratory of PE Water Supply and Sewerage, Skopje, Macedonis.

3. RESULTS AND DISCUSSION

Fabric thickness of tested shirts is given in Figure 1. Shirts laundered with powder detergent, in 12 out of 17 cases showed higher fabric thickness than shirts laundered with liquid one. This increase is between 7 to 48 % for shirts laundered with powder detergent, depending on fabric construction and weight.

During laundering, cotton fibers swell generally in radial direction (the longitudinal swelling accounts only for few percents) and induce shrinkage that led to an increase in yarn crimp and thickening of yarn cross section. Increased yarn crimp in laundered shirts led to increased tensile elongation. Shirts laundered with powder detergent have higher tensile elongation compared to shirts laundered with liquid detergent (Figure 2).

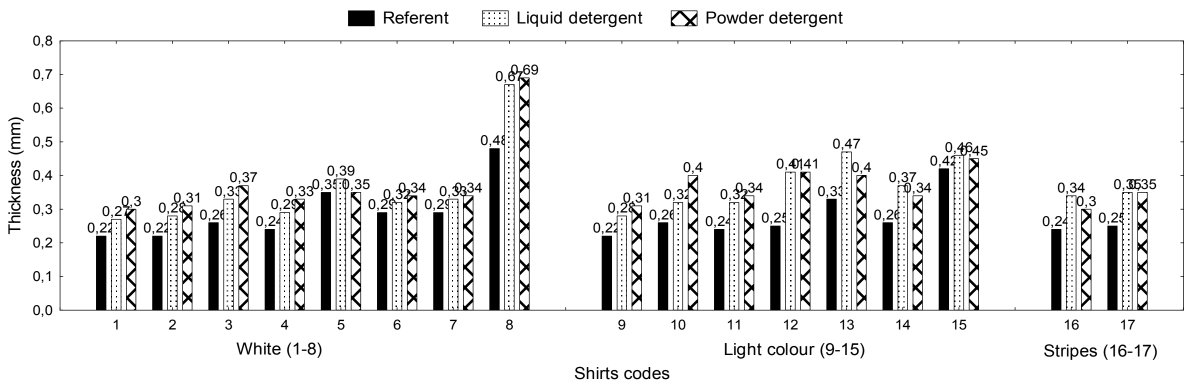

Figure 1. Thickness of shirts laundered with powder and liquid detergent after 25 washing cycles

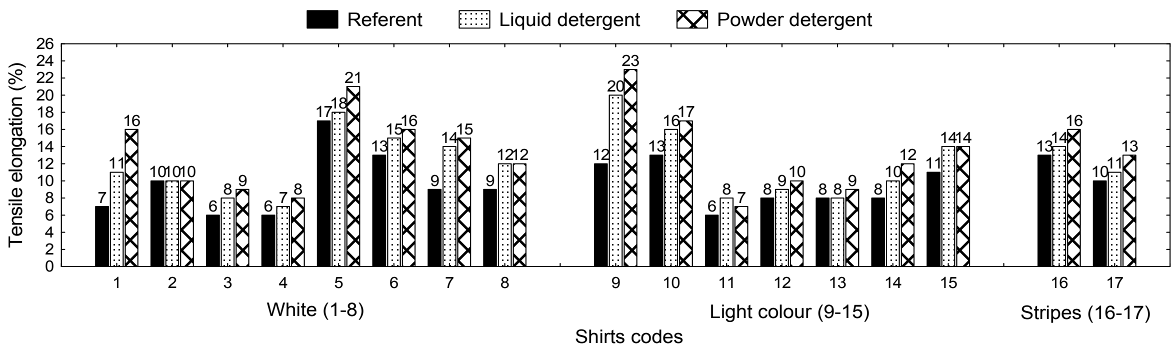

Figure 2. Tensile elongation of shirts laundered with powder and liquid detergent after 25 washing cycles

Increase of the tensile strength, in most of the analyzed cases, was found for shirts washed with powder detergent (Figure 3). This is due to increase of fabric weight, tensile elongation and thickness. Higher loss of tensile strength was noticed on shirts washed with liquid detergent. Highest loss of tensile strength (higher than 15 %), was noticed on shirts with lower fabric weights 1, 9, 10, 13.

Loss in tensile strength higher than 15 % according to RAL-GZ 992 (Quality label for proper textile care, RAL-GZ 992, recognized by the German Institute for Quality Assurance-RAL) is over the margin of tolerance (12). These shirts have lower swelling in liquid detergent, lower increase of thickness and lower tensile elongation compared to those laundered with powder detergent. Although washing was done in a domestic washing machine with high amount of liquid and low weight of textile (only 1.8 kg, while the optimum weight for regular washing is 4 to 5 kg fabrics), fabric to fabric friction was more severe for shirts with low fabric weights, resulting in higher degree of abrasion and loss of tensile strength higher than 15 %. Loss of tensile strength of other tested shirts was lower than 15 %.

Powder detergent contains oxygen bleaching agent. This detergent contains sodium perborate as source of hydrogen peroxide. Hydrogen peroxide activation is at 70 ºC or higher temperatures and it is effective on the broad spectrum of stains. Activation can be activated at lower temperature in presence of enzymes catalase and transitive-metal ions such as copper and iron (13). On the other hand, catalase is a heamoprotein which contains four Fe^{3+} ions per molecule, which is produced by many organisms as a defense against hydrogen peroxide generated by various oxidizes. It therefore occurs and varies widely, and is present on naturally soiled wash loads at concentrations which depend on: level of soiling, composition of load, and storage time of soiled clothes before washing (2). Due to fact that in our experiment we did not use soiled shirts, this enzyme that was not in detergent formulation, can be excluded. Moreover, copper and iron can be found in supply waters and textile themselves as well as in detergent. These ions can catalyze decomposition of hydrogen peroxide, and products of hydrogen peroxide decomposition attack to hydroxyl groups converting them to aldehydes, ketones or carboxyl groups (14). When aldehyde groups are created at the C2 and C3 positions, cellulosic fibers become sensitive to alkaline hydrolyses (the washing is in alkaline media) and in presence of metal-catalyzed oxidation this can lead to degradation followed with loss in tensile strength. Fortunately it did not happen in our experiment, though quantity of sequestering agent in powder detergent is low as can be seen from discussion that follows. It can be concluded that supply water did not contain high amount of copper and iron ions and washing machine used in experiment was new and therefore did not emit Fe^{3+} and Cu^{2+}.

Experiment was done in water with high hardness ºdH 17 to 18. It has long been recognized that calcium and magnesium hardness ions, present in supply waters, are deleterious to textile washing processes (8). Washing in water with high hardness results in waste of soaps and anionic detergents by their insoluble calcium and magnesium salts. These salts are often deposited on textile fibers, causing graying or yellowing, and development of rancid fatty odors (8). All shirts washed in water with high hardness at the end of washing after rinsing contain hardness ions which are potential sites for attachment of anionic soils during use. Ash content of tested shirts after 25 washing cycle is given in Figure 4. Higher ash content was found on shirts laundered with powder detergent (1.2 to 4.4 %) compared to laundered with liquid detergent (0.3 to 0.8 %). Powder detergent contains phosphate as sequestration and zeolits as ion exchange agents, while chelating compound in liquid detergent it was not declared but it is probably polycarboxylate. Phosphate forms a soluble 1:1 calcium complex that is responsible for its excellent sequestrate building performance. When there is a molar excess of polyphosphate over hardness, no insoluble phosphates are precipitated, but in marginally built conditions calcium ortho- and pyro-phosphate occur. Higher ash content on shirts laundered with powder detergent may suggest that amount of sequestering agent in powder detergent is not enough to be able to bind all ions of hardness metals from water used for washing of tested shirts, and therefore can not prevent formation of inorganic salts and prevent their deposition on shirts. Higher ash content founded on dyed shirts washed with powder detergent suggesting that additional negatively charged groups from used dyes are centers for bounding calcium ions in deficit of sequestering agent.

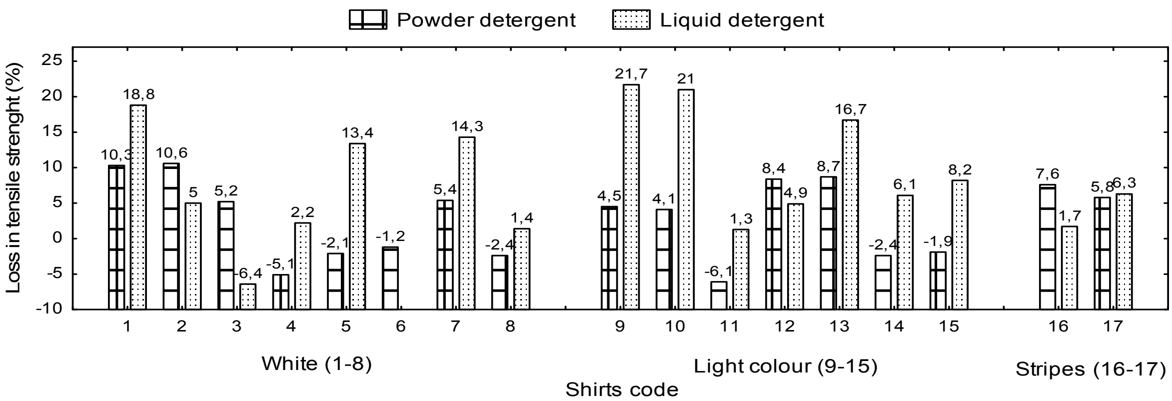

Figure 3. Loss in tensile strength of shirts laundered with powder and liquid detergent after 25 washing cycles

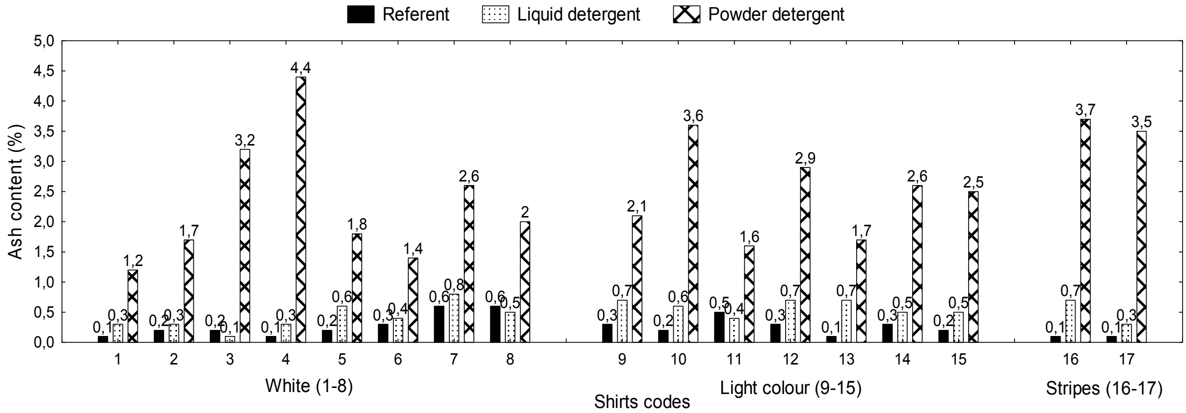

Figure 4. Ash content of shirts laundered with powder and liquid detergent after 25 washing cycles

Better results were received on shirts laundered with liquid detergent (in most of the cases lower than 0.7 %). It probably contained sequestering agent in adequate quantities. Inorganic salt deposits could affect the stiffness, air permeability or mechanical properties. Change in air flow also gives information of fabrics change due to laundering and detergent type. Air permeability of tested shirts is given in Figure 5. Three of referent shirts: 5, 6, and 14 have low air flow. These shirts have among the highest total fractional fabric cover of 0.86, 0.86 and 0.95, respectively. Beside, shirts 5 and 6 contain elastane that keep them tight and shirt 14 is in satin weave heaving high degree of tightness. Air flow of other shirts was between 125 to 476 $l/m^2/s$. There is high correlation between fractional fabric cover in warp direction (-0.75) and air permeability and between total fractional fabric cover and air permeability (-0.72). This correlation applies to shirts air permeability in relaxed state, and it can be used as an indication of fabric comfort performance. After laundering these correlation drops. Multiple laundering decreased shirts air permeability. Laundered shirts with liquid detergent were more comfortable, had higher air permeability, than those laundered with powder detergent. As discussed previously, higher degree of swelling, thickness and yarn crimp of shirts laundered with powder detergent results in more intensive changes of pores shape and value which subsequently lead to lower air permeability.

Air permeability is in opposite correlation with tensile elongation (-0.69, -0.60 and -0.70 for referent, washed with powder and liquid detergents, respectively). Insoluble phosphates are precipitated inside fiber additionally reducing air permeability of shirts laundered with powder detergent.

Multiple laundering may cause reduction of shirts aesthetic properties, which can shorten wear life. Whiteness index and *CIELab* coordinates, especially color difference are important critera for evaluation of changes in aesthetic properties. Detergent that contains bleaching and optical brightening agents with its specific action should give brilliance and freshness of white washed shirts. But this detergent can damage dyes on dyed shirts too. Tendency of any detergent bleaching system to damage dyes is strongly dependent on washing temperature and product concentration selected by consumer. At recommended wash temperature for a particular dyed shirts, and recommended detergent product dosages, potential for bleaching systems to cause damage increases with increasing catalyzed reactivity of hydrogen peroxide at lower temperature. In our experiment we tested changes that occurred on white and dyed in light color shirts after 25 washing cycles with powder and liquid detergents with and without oxidative bleaching agent and optical brightening agents. Shirts were dyed in light color probably with reactive or vat dyes for shirts in stripe design. Laundering of white shirts with powder detergent resulted in lower reduction of whiteness index (less graying) than shirts laundered with liquid detergent (Figure 6). As washing was done on 60 °C and oxidative agent was not activated, as was shown in previous discussed results, higher whiteness index is due to the optical brightening agent.

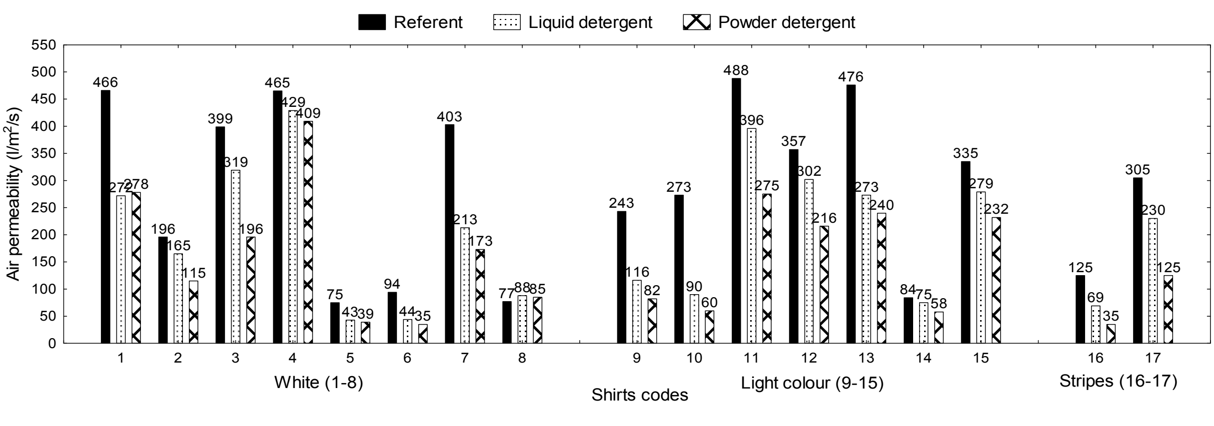

Figure 5. Air permeability of shirts laundered with powder and liquid detergent after 25 washing cycles

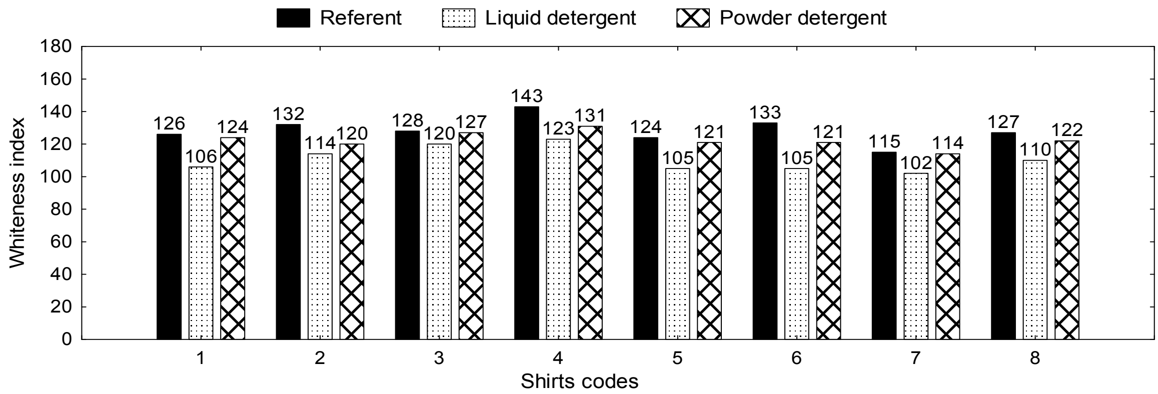

Figure 6. Whiteness index of shirts laundered with powder and liquid detergent after 25 washing cycles

Optical brightening agents are direct dyes with absorption maximum at UV between 300 and 400 nm and which re-emit the absorbed energy as violet or blue visible light at about 400 and 440 nm. Color coordinates differences (Δ*L**, Δ*b**, Δ*a**) and Δ*E** were determined between the referent (not washed) and twenty fifth washed shirts (Table 2). Dyed shirts washed with powder detergent were lighter compared to shirts laundered with liquid detergent (Δ*L** has positive values on all shirts laundered with powder detergent compared to washed with liquid). If Δ*E** value is over 1 it means that color of washed shirts is very different from the not washed shirts. Dyed shirts laundered with powder detergent showed higher fading (higher Δ*E** values) than shirts laundered with liquid detergent (Table 2). Δ*a** of shirts 13 and 15 dyed in light color after washing with powder detergent is positive meaning shirts become reddish. Shirts color coordinates in stripes could not be tested because they were too tight.

4. CONCLUSIONS

The results of the experimental investigations can be summarized as follows:

- Shirts laundered with powder detergent with oxidative bleaching agent have higher thickness, greater increasing of yarn crimp that led to increased tensile elongation, higher increase of tensile strength, higher ash content and lower air permeability compared to shirts laundered with liquid detergent.
- White shirts laundered with powder detergent with oxidative and optical brightening agents showed higher whiteness compared to shirts laundered with liquid detergent without optical brightening agents.
- Shirts in light colors laundered with powder detergent with oxidative and optical brightening agents showed washed out look compared to shirts laundered with liquid detergent.

Table 2. Differences in color coordinate Δ*L**, Δ*a**, Δ*b** and Δ*E** of dyed shirts laundered with powder and liquid detergent after 25 washing cycles

Shirts codes	Δ*L** Powder	Δ*L** Liquid	Δ*a** Powder	Δ*a** Liquid	Δ*b** Powder	Δ*b** Liquid	Δ*E** Powder	Δ*E** Liquid
9	0.75	-1.89	2.33	2.42	-0.78	1.02	2.57	3.24
10	3.42	-0.45	1.21	1.21	2.96	5.06	4.68	5.22
11	0.75	-0.32	-0.45	-0.27	-1.93	-1.22	2.12	1.29
12	1.57	-0.18	-1.68	-1.13	-2.91	-1.20	3.71	1.66
13	4.77	0.80	0.09	-0.01	3.22	3.52	5.76	3.61
14	3.59	-0.06	3.19	2.91	-7.08	-5.82	8.56	6.51
15	3.41	-0.51	1.00	-0.01	-0.50	0.25	3.59	0.57

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