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Functional Properties and Seam Puckering on Cotton Shirt Influenced by Laundering

Uporabne lastnosti in nabiranje šivov bombažne srajčevine pri pranju

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Abstract
Plain cotton fabrics of various mass per unit area, commercially available for manufacturing men's shirts, were seamed by applying three types of seams. The seaming was conducted on an industrial sewing machine under the sewing parameters commercially adopted by apparel manufacturers. The selected samples were laundered three times with two different commercially available detergents under the same washing conditions. The seam puckering and fabric properties were analysed before and after the laundering. It was found out that the degree of seam puckering after the laundering was affected by the type of seam and used detergent. The samples treated with a powder detergent showed greater changes in the fabric structure compared to those washed with a liquid detergent.
Keywords: dress shirt, safety seam, French seam, English seam, seam thickness

Izvleček
Komercialne bombažne tkanine različnih ploščinskih mas v vezavi platno, ki so namenjene za izdelavo moških srajc, so bile šivane s tremi vrstami šivov na industrijskem šivalnem stroju pri pogojih, povzetih po proizvajalcih oblačil. Izbrani vzorci so bili trikrat prani pri enakih pogojih z dvema različnima komercialnima detergentoma. Nabiranje šivov in lastnosti tkanin so bile analizirane pred pranjem in po njem. Ugotovljeno je bilo, da sta na stopnjo nabiranja šivov po pranju vplivala vrsta uporabljenega šiva in vrsta detergenta. Vzorci, prani s praškastim detergentom, so izkazali večje spremembe v strukturi tkanin v primerjavi z vzorci, pranimi s tekočim detergentom.
Ključne besede: majica, varnostni šiv, francoski šiv, angleški šiv, debelina šiva

1 Introduction

Shirts represent a traditional piece of men's clothing. A great-looking shirt adds style to any outfit. Slim fit cuts and narrow fit cuts are currently in fashion, both in the business world and for casual wear.

Shirts can be made of different materials and with cuts emphasizing different styles. They are made of 100% cotton, cotton/polyester blends or linen, wool, silk or their blends, woven and dyed in various patterns and colours. Pure cotton is probably the most popular material [1]. The fabric weight varies from 70 to 200 g/m^2. Superimposed and lapped seams are the most frequently used seam classes in shirt manufacturing, ranging from plain, safety, French, to English and other types of seams. Since shirts are usually worn seven or more than seven hours a day, they should be frequently changed and properly cared for. Laundering is a part of the dress shirt care [2]. Shirts have to exhibit good heat and moisture transfer, durability, smoothness, and the ability to recover the shape when washed and ironed.

The overall shirt appearance depends on the characteristics of the shirt style, shirt pattern design,

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fabric, quality of seams, final assembly and finishes. Shirt manufacturing includes choosing a suitable fabric, seam type and sewing parameters.

Seam pucker is one of the major problems the garment industry has been facing with for many years [3, 4]. Seam pucker appears when the sewing parameters and material properties are not chosen properly, thus reducing the garment quality. Factors affecting seam pucker are sewing thread and fabric characteristics, stitch formation, sewing thread tension, fabric feeding and seam type [5]. Seam thread properties, sewing parameters and their compatibility during the sewing have been investigated in several papers [6–12]. The effect of sewing parameters on seam pucker was examined most frequently [13, 14]. Researchers have been investigating the relationship between fabric sewability, optimization of sewing and fabric features to predict seam pucker [15, 16].

People prefer cotton shirts due to their softness and natural feeling; however, the soft-to-touch quality brings along less resilience and durability. The textile hand, hydrophilicity, friction and other properties are affected by the laundering [17, 18]. The shrinkage of a fabric after the laundering may have a considerable influence on seam pucker. To the best of our knowledge, the influence of seam type on seam pucker has been scarcely investigated [9], while the effects of laundering and detergent type on seam puckering were evaluated in our previous paper where the effects of seam type and laundering after 3 washing cycles on seam puckering and functional properties of cotton/polyester shirt fabric were discussed [19]. It was concluded that the seam type and laundering affected seam puckering, irrespective of detergent type. The highest pucker grade (less puckering) after the laundering was noticed on the safety seam followed by the English and French seams.

The aim of this investigation was to estimate the influence of seam type, laundering and detergent type on seam puckering, on the structural and mechanical properties, and on the air permeability of cotton shirt fabrics.

2 Materials and methods

2.1 Materials

Plain woven fabrics made of 100% cotton or of a cotton/Lycra blend, of white or light colour and various weight, intended for men's shirts were seamed and analysed. The seam types applied were as follows: safety seam, double lap of French seam and English seam (Figure 1). Fabric characteristics are shown in Table 1. The test specimens were prepared in warp direction according to the AATCC Test Method 88B.

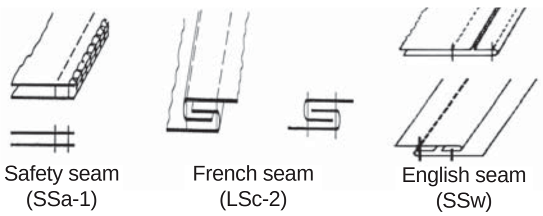

Figure 1: Investigated seam types

Table 1: Structural properties of reference fabrics

No.	Fabric composition	Colour	Fabric weight [g/m²]	Fabric thickness [mm]	Fabric density [cm⁻¹]		Linear density [tex]	
					Warp	Weft	Warp	Weft
A	100% Cotton	White	72.6	0.22	53.3	33.7	7.4	10
B	100% Cotton	White	89.3	0.22	57.0	35.7	9	9
C	100% Cotton	White	97.2	0.24	57.3	31.3	14	10
D	100% Cotton	White	106.7	0.26	50.0	27.7	12.5	12.5
E	100% Cotton	Light colour	108.5	0.24	47.3	29.7	17	14
F	100% Cotton	Stripes	114.2	0.25	48.0	25.0	14	17
G	100% Cotton	Light colour	115.5	0.33	50.0	36.0	12.5	14
H	100% Cotton	Light colour	115.9	0.22	51.7	31.7	14	14
I	100% Cotton	Light colour	122.1	0.24	42.7	23.0	17	20
J	97% Cotton/3% Lycra	Light colour	123.2	0.35	53.3	27.0	14	20
K	97% Cotton/3% Lycra	White	125.8	0.29	57.3	27.0	12.5	17

The sewing was performed using sewing machines with industrial settings. The samples (with and without seams) were subjected to 3 washing cycles, using two detergents with different formulations. The evaluation of seam pucker was made after the washing and drying cycles on non-ironed shirts.

2.2 Laundering procedure

The laundering was carried out using a front loading domestic washing machine with a horizontal axis under the following conditions: total load weight of 1.8 kg at 60 °C for 106 min. The detergents selected for the laundering procedure had different formulations and were commercially available. The declared composition of the powder detergent (P) was anionic (5–15%) and nonionic (5%) surfactants, soap, phosphate, zeolites, enzymes, polycarbonates, bleaching agent, optical brighteners and fragrances. The liquid detergent (L) was composed of anionic surfactant (15–30%), benzyl benzoate, 2-(4-tetra-butylbenzyl) propyl aldehyde, hexyl-cinnamon aldehyde, coumarin, linalool, formaldehyde and fragrance. The quantity of liquid and powder detergents was 160 ml and 150 g per wash load, respectively. The samples were dried in vertical position at room temperature after the laundering. Three laundering cycles were applied.

2.3 Measurements

The structural and mechanical properties, and air permeability as well as the seam characteristics of cotton shirt fabrics were investigated. The structural properties of cotton shirt fabrics were analysed by assessing fabric weight, warp and weft densities, fabric thickness, yarn linear density and shrinkage after 3 washing cycles. The mechanical properties of cotton shirt fabrics were analysed by evaluating tensile strength and elongation at break. Moreover, the seam characteristics of samples, e.g. seam thickness and seam pucker, were analysed. The investigated properties and the standards applied are shown in Table 2.

2.4 ANOVA analysis of variance

The influence of seam type, laundering process and detergent type on seam pucker was then determined using the ANOVA analysis of variance. One- and two-factor designs were used to structure the experiment, wherein the independent (factor) variables were seam type (3 levels: safety, French and English seams), laundering process (2 levels: un-laundered and laundered) and detergent type (2 levels: powder detergent P and liquid detergent L). The response (dependent) variable was the grade of seam pucker determined by the AATCC Test Method 88B. P-values lower than 0.05 show a significant influence of independent (factor) variables on the investigated property.

3 Results and discussion

3.1 Functional properties of reference and laundered fabrics

The structural properties of tested fabrics are given in Table 3. The selected fabrics weighing between 72 and 126 g/m^2 had an unbalanced woven structure with higher thread density in warp direction (Table 3). The fabrics exhibited shrinkage after the laundering with both detergents, in warp and weft direction, ranging between 0.5–9% and 0.5–4%, respectively (Table 3). Higher shrinkage was noticed in warp direction, due to the stress applied to warp during the weaving. Cotton fibres swell by about

Table 2: Investigated properties and used standards

Property	Standard
Fabric weight	ISO 3801
Warp and weft densities	BS EN 1049-2
Fabric thickness	ISO 5084
Linear density	ISO 7211-5
Shrinkage	BS EN 25077
Tensile strength and elongation at break	BS EN ISO 13934-1
Air permeability	ISO 9237
Seam thickness	ISO 5084
Seam pucker	AATCC 88B

40% in volume when immersed in water [2]. This is mostly accounted by radial swelling, while the longitudinal swelling presents only an increase by about 1–2% in fibre length. In a woven structure, wet relaxation caused by fibre swelling leads to an increase in yarn crimp and thickening of the yarn cross-section. As a result, laundered fabrics have higher fabric weight, fabric warp and weft densities, fabric thickness (Table 3), elongation and tensile strength at break (Table 4). The fabric weight after the laundering increases slightly with the increase in warp and weft densities of a fabric resulting from the shrinkage. Fabric weight after the laundering with both detergents increased from 1.12 to 9.31% (Table 3). Fabric elongation at break and tensile strength increase slightly with the increase in fabric weight, resulting from fabric densities and interlacing yarns. The loss of tensile strength of a cotton shirt fabric after 25 washing cycles was evaluated in our previous paper, where the secondary effects of multiple laundering on cotton shirts were analysed through damage (loss of tensile strength), deposits of inorganic compounds and air permeability [20]. Slightly greater increases in fabric weight, fabric thickness and elongation at break were observed at fabrics laundered with a powder detergent, compared to those washed with a liquid detergent (Tables 3 and 4). As the temperature, time and mechanical action during the laundering were the same for both used detergents, the differences in analysed properties came from different washing product ingredients. The powder detergent contained phosphate and zeolites as chelating agents, polycarbonates as soil dispersing agent, bleaching agent for the removal of stains, and optical brighteners and some fragrances commonly used to mask the odour of other chemical ingredients. Calcium ion binding is pH dependent and deteriorates markedly below pH 9.5. Phosphates provide alkalinity for calcium ion binding and activation of the bleaching system. 10% powder detergent solution provides the pH between 10 and 11. The liquid detergent contained a higher amount of surfactant, benzyl benzoate, linalool, coumarin and formaldehyde as preservative and did not contain bleaching agents; hence, the 10% detergent provided pH from 8.1 to 8.6. The swelling of cotton is pH dependable and is thus higher during the washing in a powder detergent solution than in a liquid detergent solution. A higher degree of swelling led to an increase of yarn crimp (weave angle) thickening of yarn cross-section as well as the fabric [2]. Shrinkage by more than 3% can produce undesirable problems [6].

Air permeability is an important property of fabric since clothing ventilation determines its comfort. However, air permeability is significantly influenced by yarn and fabric properties, e.g. yarn crimp, yarn cross-section, shape of fabric pores [21]. In the

Table 3: Structural properties of reference fabrics (R), and fabrics laundered with powder (P) and liquid (L) detergents

No.	Fabric weight [g/m²]			Density [cm⁻¹]						Fabric thickness [mm]			Shrinkage [%]			
				Warp			Weft						P		L	
	R	P	L	R	P	L	R	P	L	R	P	L	Warp	Weft	Warp	Weft
A	72.6	75.9	74.8	53.3	60.5	57.7	33.7	40.5	39.0	0.22	0.29	0.25	4	1.5	3	2
B	89.3	97.6	93.5	57.0	64.0	62.3	35.7	44.0	42.3	0.22	0.30	0.27	9	3.5	4	2.5
C	97.2	120.5	116.0	57.3	64.0	63.0	31.3	35.5	34.7	0.24	0.30	0.30	3	3	1	2.5
D	106.7	109.5	107.9	50.0	56.0	54.0	27.7	33.5	32.3	0.26	0.31	0.32	4	1.5	3	0.5
E	108.5	116.3	115.3	47.3	60.0	58.3	29.7	34.5	33.0	0.24	0.30	0.30	1	1	1	1
F	114.2	116.8	117.0	48.0	55.0	53.3	25.0	29.0	28.0	0.25	0.31	0.29	1	2	1	2.5
G	115.5	119.7	120.4	50.0	61.0	60.0	36.0	42.0	40.7	0.33	0.43	0.40	1.5	3	0.5	4
H	115.9	118.7	118.2	51.7	60.0	58.0	31.7	37.0	34.7	0.22	0.29	0.26	2	1.5	1.5	2.3
I	122.1	124.2	122.1	42.7	55.5	47.0	23.0	30.0	25.0	0.24	0.33	0.29	2	1	0	0.5
J	123.2	129.3	124.6	53.3	62.0	60.0	27.0	34.0	31.7	0.35	0.39	0.42	4	1	2.5	0
K	125.8	129.4	130.7	57.3	70.0	67.7	27.0	31.0	29.3	0.29	0.33	0.34	1.5	3	1	3

Table 4: Mechanical properties and comfort of reference (R) fabrics, and fabrics laundered with powder (P) and liquid (L) detergents

No.	Tensile strength $_{(warp)}$ [N]			Elongation at break $_{(warp)}$ [%]			Air permeability [l/(m²/s)]		
	R	P	L	R	P	L	R	P	L
A	463	469	469	7.3	9.9	9.3	466	283	353
B	680	568	632	12.3	18.5	16.3	543	167	280
C	743	789	745	12.8	14.3	13.2	125	81	127
D	504	441	524	12.8	15.6	14.7	273	142	200
E	435	466	435	5.8	6.6	6.2	488	372	472
F	592	634	601	8.3	9.2	8.7	357	285	334
G	683	679	667	7.7	8.0	7.7	474	299	318
H	636	596	641	10.0	10.1	9.9	196	167	200
I	535	529	562	5.8	6.9	6.6	465	409	506
J	600	577	602	16.8	10.1	18.8	75	49	61
K	990	893		13.4	14	14.3	94	61	61

present study, air permeability decreased with an increase in fabric weight. Lighter fabrics, i.e. fabrics A and B, had higher air permeability (Table 4). The increase in shrinkage, fabric weight, and warp and weft densities, and probably the thickening of yarn cross-section and formation of smaller pores after the laundering as well led to lower air permeability. A greater alteration in the structural properties of the fabrics laundered with a powder detergent suggests more intensive changes in the yarn cross-section and pore shape, which determined a decrease in air permeability, compared to the properties of the fabrics washed with a liquid detergent.

The changes in the structural characteristics discussed above may have an influence on seam puckering as well.

3.2 Seam puckering of reference and laundered samples

The results of subjectively evaluating the seam pucker for the analysed seam types at the initial stage of fabrics are shown in Table 5. Grade 5 represents the best

Table 5: Seam pucker and seam thickness of reference (R) samples, and samples laundered with powder (P) and liquid (L) detergents as function of seam type

No.	Seam pucker grade									Seam thickness [mm]								
	Safety			French			English			Safety			French			English		
	R	P	L	R	P	L	R	P	L	R	P	L	R	P	L	R	P	L
A	2	2	2.5	2.33	1	2	3.33	2	3	0.78	0.69	0.66	0.86	0.80	0.90	0.90	0.88	0.99
B	1.66	3	3	3	2.67	3	3.66	3	3	0.78	0.68	0.66	0.91	0.94	1.05	0.96	1.07	1.02
C	3.33	4	4	4	2.67	3.33	4	3	3.33	0.93	0.83	0.84	1.02	1.06	0.98	1.18	1.31	1.13
D	2.33	4	3.5	4	2.33	3.67	4	2.67	3.67	0.86	0.76	0.75	1.06	1.06	1.02	1.18	1.26	1.21
E	3.17	3.5	4	3.33	2	3	4	2.33	3	0.96	0.84	0.76	1.06	1.11	0.95	1.20	1.20	1.06
F	2.66	3	3	2.33	2	2	4	3	3	0.94	0.83	0.89	1.09	1.05	1.03	1.19	1.17	1.19
G	2.67	3	3	4	2.67	2.33	4.33	3	2.33	0.85	0.79	0.85	1.05	1.09	1.15	1.25	1.36	1.32
H	2.66	3	3	3.33	1.33	2	4	2	3	0.88	0.74	0.70	1.09	1.05	0.99	1.20	1.10	1.08
I	3.33	2	3	3	1	3	3.33	2	3	0.90	0.79	0.80	1.10	1.14	1.07	1.34	1.29	1.22
J	2.66	3	4	3.6	3.33	3	4.66	3	3	0.82	0.74	0.74	1.03	1.05	1.02	1.27	1.33	1.31
K	2.75	3	3	4	2.5	4	4	3	2.5	0.80	0.69	0.73	0.97	1.01	1.00	1.16	1.21	1.18

level of seam appearance, while grade 1 represents the poorest one. In general, fabrics react differently to sewing due to their nonlinear structure [22]. The increase in fabric weight and fabric thickness for the reference fabrics resulted in smaller seam puckering for all seam types. Yarns in light fabric weight are aligned in very thin layers that could easily compensate for the sewing thread as it is introduced into the seam. In the case of thin fabrics, there could be sufficient space to accommodate a sewing thread with displacement of yarns. Hence, stitching along a straight line will distort and push adjacent yarns in the fabric, which will cause seam pucker. It is known that thicker and more rigid fabrics crease less [6]. Some dependence was found between fabric weight and seam pucker for the reference samples, and a positive linear correlation between fabric thickness and seam pucker for the English seam (correlation coefficient 0.78). Dependence between fabric thickness and seam pucker was also found for the French seam; however, not for the safety seam.

The average values of seam pucker for the analysed seam types are presented in Figure 2. The results in Figure 2 show that the English seam determined the smallest seam puckering, followed by the French and safety seams. The significant influence of seam type on seam pucker was confirmed by the analysis of variance (ANOVA) (Table 6).

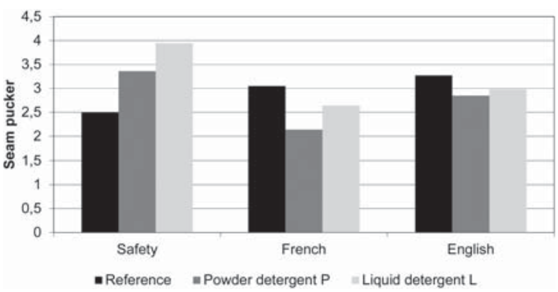

Figure 2: Average values of seam pucker of reference samples, and samples laundered with powder (P) and liquid (L) detergents as function of seam type

The thickness of analysed seam types is shown in Table 5, which reveals that the English seam has the highest seam thickness, followed by the French and safety seams. Furthermore, fabrics of higher weight show higher seam thickness. However, seam thickness also varies within the same type of seam due to the increased fabric weight. A positive linear correlation between the fabric weight and seam thickness was found for the English and French seams (correlation coefficients of 0.87 and 0.74, respectively).

Seam pucker may be acceptable after the sewing, but under the impact of laundering, as the fabric shrinks, puckering may worsen. The results of evaluating the seam pucker of laundered samples with powder and liquid detergents as a function of seam type are shown in Table 5. The influence of seam type on the seam pucker of the samples laundered with a powder detergent P is shown in Figure 2. It may be noted that the safety seam led to the least seam puckering, followed by the English and French seams. A single row of stitches in the safety seam, compared to the French seam, which contains two close rows of stitches and more fabric layers in the seam cross-section (Figure 1), [23] can lead to the least distortion of the material. Thus, it may be concluded that the French seam is more inclined to cause seam pucker. Despite the English seam also containing more rows of stitches (in the first stage two parallel rows and in the second stage an additional one), compared to the French seam, this seam shows less puckering due to the longer distance between the first two rows of stitches. The analysis of variance (ANOVA) confirmed that the seam type is an influencing factor for seam puckering (Table 6). A similar behaviour was found for cotton/polyester shirt fabrics – the safety seam exhibited a higher pucker grade (less puckering), followed by the English and French seams [19].

The influence of seam type on seam puckering for the samples laundered with a liquid detergent L is shown in Figure 2. The safety seam shows the least seam puckering, followed by the English and French seams. This trend could also be observed on the samples subjected to the laundering with a powder detergent P. However, ANOVA confirmed that the seam type did not have a significant influence on the seam pucker for the samples laundered with a liquid detergent L (Table 6). The changes in the structural properties of the laundered samples had a great influence

Table 6: Influence of seam type on seam pucker analysed by p-value (ANOVA analysis of variance)

ANOVA outputs	Dependent variables (responses) – seam pucker grade		
Independent variables (Factors)	Reference	Powder detergent P	Liquid detergent L
Seam type	0.000	0.008	0.185

on the seam thickness. A positive linear correlation between the fabric weight and seam thickness was found for the French (correlation coefficient 0.83) and English (correlation coefficient 0.83) seams subjected to the laundering with a powder detergent P.

The influence of the laundering process and seam type on seam pucker is shown in Figure 2. The seam pucker of the samples washed with a powder detergent P followed the same evolving trend as that for the samples laundered with a liquid detergent L. The safety seam showed the least seam puckering, followed by the English and French seams. The laundering with both detergents affected the seam pucker grades for the English and French seams, while the safety seam was not affected. ANOVA analysis confirmed that the laundering process with both detergents and seam types, as well as their combined effects has a significant influence on seam puckering (Table 7).

However, analysing the influence of the detergent and seam type on seam pucker (Figure 2), a significant difference in seam pucker can be observed. Higher seam puckering was observed when laundering with a powder detergent P, compared to the liquid one. The significant influence of detergent type and seam type on seam pucker was also confirmed by ANOVA analysis (Table 8). The differences in seam pucker on the samples laundered with the two detergent types could be explained by the fact that the samples undergo some quality changes during the laundering, which are also related to the detergent formulation.

4 Conclusion

The present study revealed that the structural and mechanical properties, and air permeability of cotton shirt woven fabrics were affected by laundering after 3 washing cycles because of shrinkage and by detergent type. The laundering with a powder detergent induced a greater increase in fabric weight, fabric thickness and elongation at break, and decreased its air permeability. These changes also influenced seam pucker and seam thickness. Seam type had a significant influence on seam pucker both before and after the laundering; however, generally, laundering increased seam pucker. The safety seam demonstrated the least seam puckering after the laundering, followed by the English and French seams. The reference samples exhibited the opposite trend.

In conclusion, determining the relation between seam pucker, seam type, laundering process and detergent type can help apparel manufacturers in the selection of fabrics.

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Table 7: Influence of laundering process and seam type on seam pucker analysed by p-value (ANOVA analysis of variance)

ANOVA outputs	Dependent variables (responses) – seam pucker grade	
Independent variables (Factors)	Powder detergent P	Liquid detergent L
Laundering process	0.000	0.035
Seam type	0.007	0.009
Laundering process*Seam type	0.000	0.000

Table 8: Influence of detergent and seam type on seam pucker analysed by p-value (ANOVA analysis of variance)

ANOVA outputs	Dependent variables (Responses)
Independent variables (Factors)	Seam pucker grade
Detergent type	0.004
Seam type	0.001
Detergent type*Seam type	0.369

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