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Effects of Knit Structure on the Dimensional and Physical Properties of Winter Outerwear Knitted Fabrics

Abstract
In this study, an experimental work is presented to determine the effects of fourteen different knit structures of 80% Lambswool-20% Polyamide knitted outerwear fabrics, on the dimensional properties; pilling resistance, abrasion resistance, bursting strength, air permeability and bending rigidity. The effect of relaxation condition on the dimensional properties of the fabrics was also studied. From the analyses of variance, it is seen that the effects of knit structure on the properties of the knitted fabrics inspected are highly significant. Specifically, the effect of knit structure on the bursting strength, air permeability, and bending rigidity is highly significant in washed fabrics. Tuck stitch fabrics have the lowest resistance to abrasion. Links-links, seed stitch, and moss stitch fabrics have the highest resistance to pilling.

Key words: *knitted fabric, pilling resistance, abrasion resistance, bursting strength, air permeability, bending rigidity.*

Introduction

Knit fabrics provide outstanding comfort qualities and have long been preferred as fabrics in many kinds of clothing. Since knit fabrics are produced on different machines with different knit stitches and conditions to create different patterns and fabric types, we expect them to have different qualities [1]. The commercial design of knitted garments is a process that shares many important characteristics with other types of aesthetic design and engineering [2]. Although many CAD systems are commercially available for the artistic design of fabrics, none is commercially available for the engineering design of fabrics to meet their end use performance requirements [3].

In apparel design and garment manufacturing, fabric characteristics are usually dictated by a specified end-use. Understanding the relationship between the fabric end-use and fabric properties becomes fundamental for classification, selection, search, and purchase control of apparel fabrics [4]. Tactile (hand) and appearance properties are very important in all classes of fabrics [5]. Appearance retention is directly related to the longevity and serviceability of fabrics. A fabric may loose its aesthetic appeal due to wear, which is a combined effect of several factors like abrasion, repeated laundering, the application of forces in dry and wet states etc. arising from everyday use and service. Surface abrasion is considered perhaps the most important of these factors, and so it has become routine in fabric testing [6]. The effects of various knit structures on the abrasion strength have been analysed by a lot of researchers [7 - 9].

Fabric pilling is a serious problem for the apparel industry. The development of pills on a fabric surface, in addition to resulting in an unsightly appearance, initiate the attrition of the garment and can cause premature wear [10]. The number of pills increases within a certain range of tightness factor but decreases when the tightness factor increases [11]. The effects of knit structure on pilling have been analysed by a lot of researchers [7, 8, 10, 12].

The bursting strength of knitted fabric is extremely important in many ways. The fabric should have sufficient strength against forces acting upon it during dying, finishing and use. However, it is very difficult to predict the bursting strength of knitted fabrics before performing bursting strength tests [13]. Kavuşturan [8] showed that the effect of knit structures on the bursting strength of fabric is highly significant.

Clothing comfort is an extremely complex phenomenon resulting from the interaction of various physical and non-physical stimuli on a person wearing given clothing under given environmental conditions. One of the basic variables that has a great influence on comfort is fabric construction. A lot of thermo-physiological comfort properties, such as air permeability, water vapour permeability, thermal resistance, wick ability, absorbency, drying rate, water resistance and so on, can be altered by fabric construction [14].The air permeability of fabric depends on the shape and value of the pores and the inter-thread channels, which are dependent on the structural parameters of the fabric [15]. The effects of knit structures on the air permeability of fabric have been analysed by Çeken [16] and Kavuşturan [8].

The way in which a fabric drapes or hangs depends largely on its stiffness, i.e. its resistance to bending and its own weight [17]. Fabric bending behaviour has been the focus of many investigations [17, 18]. A fabric's bending characteristics contribute to differences in the way it conforms to the body. Fabrics with higher values of bending rigidity and bending hysteresis will bend less easily [19]. Many researchers have already reported that consumers are consistently able to detect differences in some mechanical properties of knits, such as lateral compression and fabric stiffness, through the subjective assessment of touch [20]. The effects of knit structure on bending behavior have been analysed by some researchers [8, 19].

Knitting can be stated as a complex dynamic technological process. During the knitting process, yarn is exposed to tension, therefore the fabric is in a deformed state. The relaxation process starts after taking the fabric from the machine, which causes a change in the dimensions of knitted fabrics. Dimensional changes in knitted fabrics occur during the actual knitting process as well as in the process of dry and wet relaxation [21]. Fabric shrinkage is a serious problem for knitwear, originating from dimensional changes in the fabric, particularly in the stitches. The effect of the knit structure on fabric shrinkage has not been investigated enough. Most work has focused particularly on some double or single Jersey knits [22].

The effects of various knit structures on the dimensional and/or physical properties of knitted fabrics have been analysed by many researchers [7-10, 12, 16, 19, 22]. To the best of our knowledge, there is no study on different knit types together. In this study, variables were reduced by changing only the knit structure of samples, in order to isolate the effects of other variables. The goals of our research were to study changes in the dimensional and physical properties of 80% Lambswool-20% Polyamide blend knitted fabrics as a function of their structure, and to investigate the relationship between the relaxation condition and dimensional properties of weft knits.

Table 1. *Fabric codes, fabric structures and knitting notations [23].*

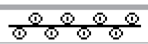
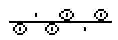
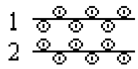
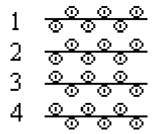
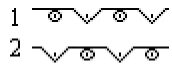
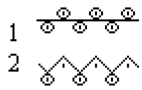
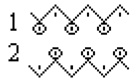
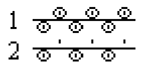
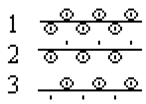
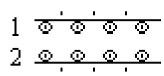
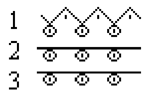
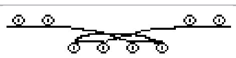
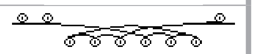
Fabric code	Fabric structure	Knitting notation	Fabric code	Fabric structure	Knitting notation
RL	Plain		RR1	1X1 Rib	
RR2	2x2 Rib		P1	Seed Stitch	
P2	Moss Stitch		L1	Lacoste	
YS	Half Cardigan		TS	Full Cardigan	
YM	Half Milano Rib		TM	Milano Rib	
LL	Links Links		HV	Terry	
S2	2x2 Cable		S3	3x3 Cable	

Table 2. *ANOVA results for weight. course per cm. wale per cm and thickness.*

Source	Weight. g/m²		Courses/cm		Wales/cm		Thickness. mm	
	F-ratio	F-Prob.	F-ratio	F-Prob.	F-ratio	F-Prob.	F-ratio	F-Prob.
Main Level								
Knit Type	334.75	***	279.54	***	59.95	***	261.27	***
Relaxation Type	4.97	*	56.59	***	9.57	***	110.17	***
Interaction								
Knit type x raising	7.59	***	42.78	***	7.59	***	13.98	***

Table 3. *ANOVA results for loop length, bursting strength, air permeability and bending rigidity.*

Source	Loop length		Bursting strength		Air Permeability		Bending rigidity Wale way		Bending rigidity Course way	
	F Ratio	F Prob.	F Ratio	F Prob.	F Ratio	F Prob.	F Ratio	F Prob.	F Ratio	F Prob.
Knit type	48.22	***	33.50	***	139.69	***	15.01	***	19.50	***

Experimental

Our experimental samples were knitted on a E 7 gauge SES 236-S model Shima Seiki flat knitting machine. Fourteen weft knits were produced with different structures. The structures chosen were based on the kinds of stitch structures currently most used in industry. The structures of the knitted fabrics created for the study are shown in Table 1. All the fabric types were knitted at the same machine setting in order to see the effect of their structure on the fabric properties. 80% Lambswool-20% PA blended yarn with a yarn count of 67 tex (Nm 1/15) was used. Three fold yarn was fed into the machine. Three different relaxation processes were applied to the samples. These are:

Dry relaxation:
After having taken the samples off the machine, they were laid on a smooth and flat surface in atmospheric condition for one week.

Wet relaxation:
The above-mentioned dry relaxed samples were immersed in a solution of water+wetting agent (0,5 g/liter) at 50 °C for 24 hours and then dried on a flat surface in an unconditioned atmosphere for one week.

Table 4. SNK ranking at 5% significance level after single factor of the ANOVA model.

Relaxation Type	Weight, g/m2	Courses/cm	Wales/cm	Thickness, mm
Dry	a	C	b	a
Wet	b	B	b	c
Washing	b	A	a	b

Table 5. SNK ranking at %5 significance level after single factor of the ANOVA model.

Fabric code	Weight	Courses per cm	Wales per cm	Thick-ness	Loop length	Bursting strength	Air perme-ability	Bending rigiditiy	
								Wale way	Course way
RL	h	c	c	j	de	b	d	e	cd
RR1	f	g	b	cd	b	efg	b	cde	d
RR2	d	f	a	c	bcde	def	c	bc	d
LL	ef	f	c	g	e	b	d	de	bcd
YS	gh	i	e	g	bc	gh	b	cde	cd
TS	gh	i	f	fg	bcd	efg	ab	cde	cd
L1	g	h	e	h	e	bc	e	cde	cd
YM	c	a	b	ef	f	b	e	bc	bcd
TM	b	b	a	b	g	a	f	a	b
S2	de	e	b	c	bcde	def	d	bc	cd
S3	de	cd	b	de	cde	bcd	d	bcd	bc
P1	i	d	d	i	bc	fgh	b	e	cd
P2	i	cd	d	i	bc	h	a	de	cd
HV	a	c	d	a	a	cde	g	b	a

Table 6. Effect of relaxation treatment and fabric structure on pilling and abrasion resistance.

Fabric code	Pilling rate wale way	Pilling rate course way	Abrasion resistance (Number of rubs required to produce a hole)
RL-R	4 - 5	4	After 100,000 rubs
RL-L	4	3 - 4	After 100,000 rubs
RR1	4	3 - 4	After 100,000 rubs
RR2	5	4 - 5	After 100,000 rubs
LL	5	5	After 100,000 rubs
YS	4	5 - 4	70,000 - 75,000 rubs
TS	3 - 4	4	75,000 - 80,000 rubs
YM	4	3 - 4	After 100,000 rubs
TM	4 - 5	4	After 100,000 rubs
L1	3 - 4	4	80,000 - 85,000 rubs
S2	4	4	After 100,000 rubs
S3	5	4 - 5	After 100,000 rubs
P1	5	5	After 100,000 rubs
P2	5	5	After 100,000 rubs
HV	-	-	After 100,000 rubs

Wash relaxation:
Wet relaxed samples were washed in a household washing machine at 30 °C with Perwoll™ on the wool program. The samples were dried on a flat surface in an unconditioned atmosphere for one week.

The following properties of the fabrics were measured after every relaxation state in accordance with relevant standards: Course and wale per cm, ISO 7211-2; fabric weight in g/m2, ISO 3801; fabric thickness in mm, ISO 5084. Loop length in mm measurements were taken only while the fabric was in its dry relaxed condition. This was because Postle [24] and Kurbak [25] suggested that the course length of conventionally knitted fabric did not change after relaxation treatments. The length of ten unrowed courses, each of which contained one hundred wales, was measured on a Hatra-like tester by putting a 10 g weight on the underside as suggested by Smirfitt [26] & Munden [27], and then the average was calculated. This average value was divided by hundred to find the length of one loop [28]. The following properties of the fabrics were measured only after the wash relaxation, in accordance with the relevant standards: pilling resistance, ISO 12945-1; abrasion resistance ISO 12947, bursting strength ISO 13938-1; air permeability in l/(m2s) ISO 9237; bending rigidity, BS 3356.

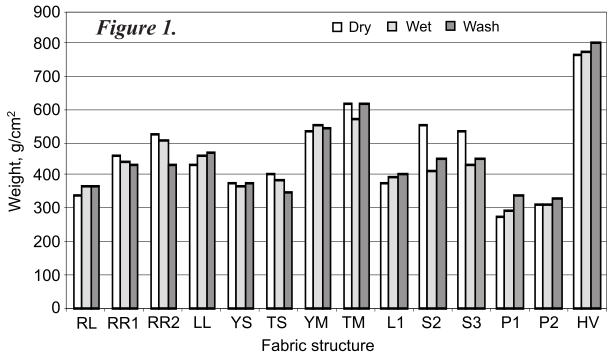
A two factor, completely randomised ANOVA model (Table 2) was used to establish the weight, course and wale per cm, and thickness of the fabrics, in order to demonstrate the importance of each variable. Also, a single factor, completely randomised ANOVA (Table 3) model was used to establish the loop length, bursting strength, air permeability and bending rigidity of the fabrics, in order to demonstrate the importance of knit structure (* and *** demonstrate the importance of each variable i.e., *** shows the most important variable). The results were evaluated at a 5% significance level. The means were compared by the Student-Newman-Keuls (SNK) test for rejected hypothesis. (Tables 4 and 5). The treatment levels were marked in accordance with the mean values, and any levels marked by the same letter showed that they were not significantly different.

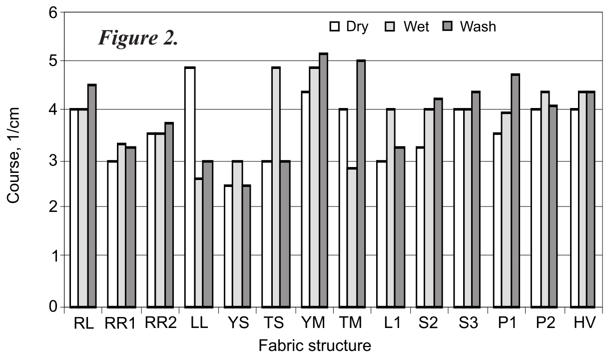
Results and discussion

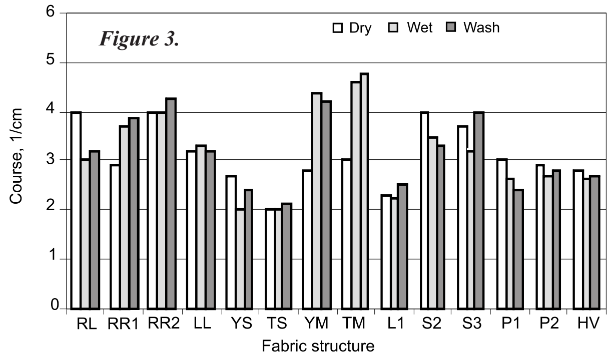
Fabric weight
The results of the analysis of variance for fabric weight reveal that the effect of knit structure is rather more significant than the type of relaxation processes. The SNK test for the comparison of relaxation processes revealed that the fabric weight of dry relaxed samples differs significantly from wet relaxed and washed samples.

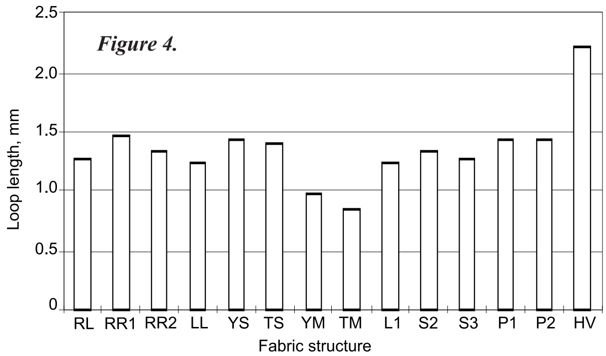
Course per cm and wales per cm
The results of the analysis of variance for course per cm and wale per cm reveal that the effect of knit structure and relaxation processes are highly significant.. Whereas knit structure has the greatest effect, the. SNK test for the comparison of relaxation processes revealed that the course per cm of dry, wet and wash relaxed samples differs significantly from each other. The SNK test for the comparison of relaxation processes revealed that the wales per cm of washed samples differ significantly from dry and wet relaxed samples.

Loop length
The results of the ANOVA for the loop length revealed that the effect of knit structure is highly significant. The order of the loop length of the fabrics from large to small is terry, 1×1 Rib, seed









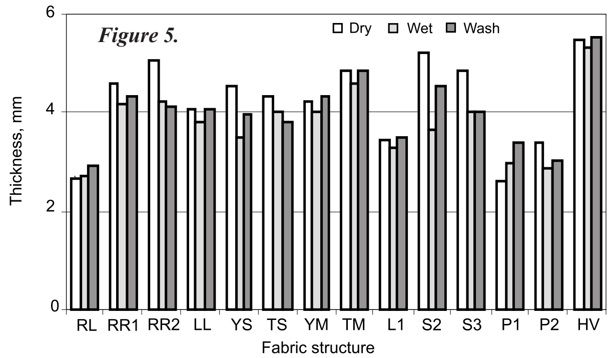


Figure 1. *Effects of fabric structure and relaxation process on the weight of knitted fabrics; all fabric codes by which the bar-graphs in Figures 1 - 5 are marked, are explained in Tables 5 and 6.*

Figure 2. *Effects of fabric structure and relaxation process on the course per cm of knitted fabrics.*

Figure 3. *Effects of fabric structure and relaxation process on the wales per cm of knitted fabrics.*

Figure 4. *Effects of knit structure on loop length for dry relaxed fabrics.*

Figure 5. *Effects of fabric structure and relaxation process on fabric thickness.*

stitch, moss stitch, half cardigan, full cardigan, 2×2 cable, 2×2 Rib, 3×3 cable, single jersey fabrics "plain, links-links, lacoste", and float stitch fabrics "half Milano and Milano".

Thickness

The results of the ANOVA for fabric thickness revealed that the effect of knit structure, relaxation processes and their interactions is highly significant, although knit structure has the greatest effect. The order of thickness of the fabrics from large to small is terry, Milano, 2×2 Rib, 2×2 cable, 1×1 Rib, 3×3 cable, half Milano, full cardigan, half cardigan, and single jersey fabrics "links-links, lacoste, moss stitch, seed stitch, plain" The SNK test for the comparison of relaxation processes revealed that the thickness of samples differs significantly from each other. Figures 1-5 show the effects of fabric structure and the relaxation process on the weight, course/cm, wale/cm, stitch length and thickness of knitted fabric.

Abrasion resistance

In order to evaluate the resistance of the samples to abrasion, the fabrics were subjected to 100,000 rubs or until a hole occurs. Abrasion tests were performed for both faces of the fabrics. The weight loss percent of the fabrics were also measured every 5,000, 10,000, 20,000, 30,000 and 40,000th rubs. For washed fabrics, after 40,000 rubs, the highest value of weight loss was for moss stitch followed by seed stitch fabrics, tuck stitch fabrics "full cardigan, half cardigan and Lacoste", and the technical face of plain fabric. In terry fabric, the weight loss percent was the least, but when the appearance of this fabric was visually evaluated, it was observed that terry fabric exhibited the worst surface characteristics. Figure 6 shows the effects of knit structure on the weight loss (in percent) of the fabrics. At the end of the test, the fabrics were examined for the presence of a hole. Tuck stitch fabrics "half cardigan, full cardigan and Lacoste" have the lowest resistance to abrasion. (Table 6) The photos of these fabrics taken before and after the abrasion test are presented in Figure 7.

Pilling resistance

Pilling tests were performed for both faces of the fabrics. A comparative study of the results reveals that links-links, seed stitch and moss stitch fabrics have the highest resistance to pilling (pilling rate: 5). In these samples, pill formation was not observed. Lacoste, full cardigan,

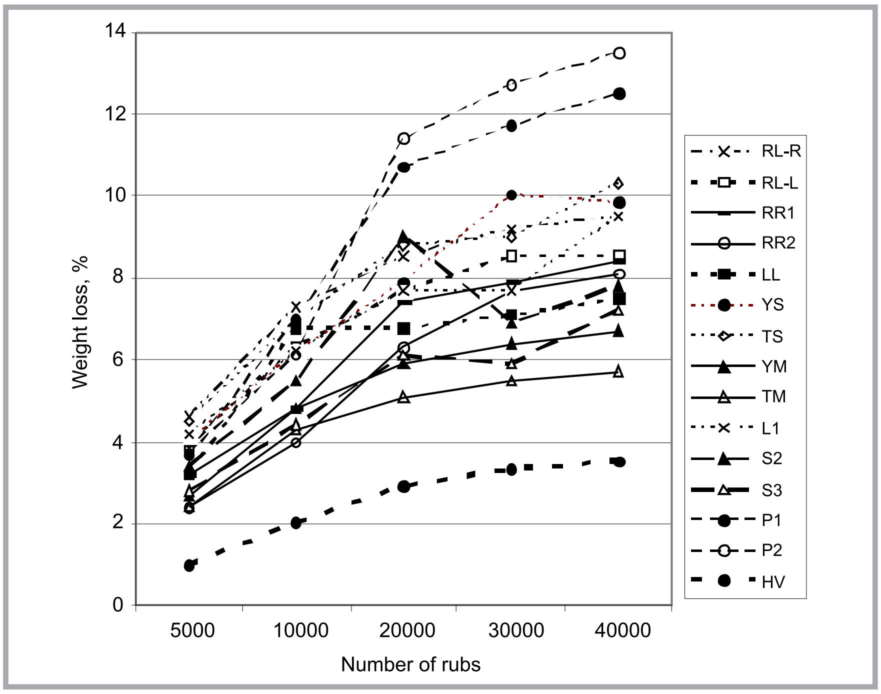


***Figure 6.** Effects of knit structure on weight loss (%) for washed fabrics after 5,000, 10,000, 20,000, 30,000, 40,000 rubs (RL-R: technical face of plain knitted fabric; RL-L: technical back of plain knitted fabric).*

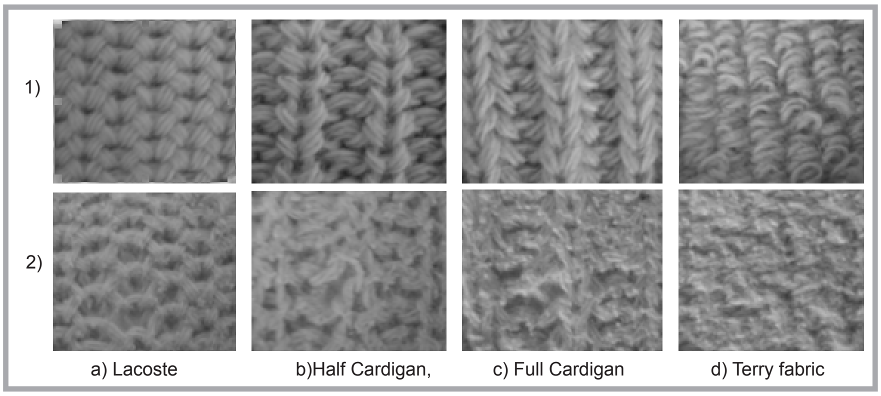


***Figure 7.** Effects of knit structure on abrasion resistance for washed fabrics (1)before and (2) after 40,000 rubs.*

half Milano, the technical back of plain fabric and 1x1 rib fabric have the lowest resistance to pilling (pilling rate: 3 - 4 and 4).

Bursting strength

The results of the ANOVA for bursting strength revealed that the effect of knit structure is highly significant in washed fabrics. Moss stitch and half cardigan fabrics have weaker bursting strength performance. Half Milano, links-links and plain fabrics have the strongest bursting strength performance (Figure 8).

Air permeability

The results of the ANOVA for air permeability revealed that the effect of knit structure is highly significant in washed fabrics. Moss stitch and full cardigan fabrics are the most permeable to air, and terry and Milano fabrics are the least (Figure 9). The most adequate choices from the studied knit structures for manufacturing garments for windy and cold winter periods are terry, Milano, half Milano and Lacoste.

Bending behaviour

The results of the ANOVA for wale and course way bending rigidity revealed that the effect of knit structure is highly significant in washed fabrics. Milano is the most rigid fabric in wale way bending. Single jersey structures have lower wale way bending rigidity. Terry is the most rigid fabric in course way bending. 2×2 rib fabric is the least rigid fabric in course way bending. (Figure 10).

Conclusions

- The effect of knit structure and relaxation processes on the dimensional properties of fabric is highly significant. Knit structure has the greatest effect. The effect of knit structure on bursting strength, air permeability, bending rigidity is highly significant in washed fabrics.

- The fabric weight of the dry relaxed samples differs significantly from the wet relaxed and washed samples. The course per cm of the dry, wet and washed relaxed samples differs sig-

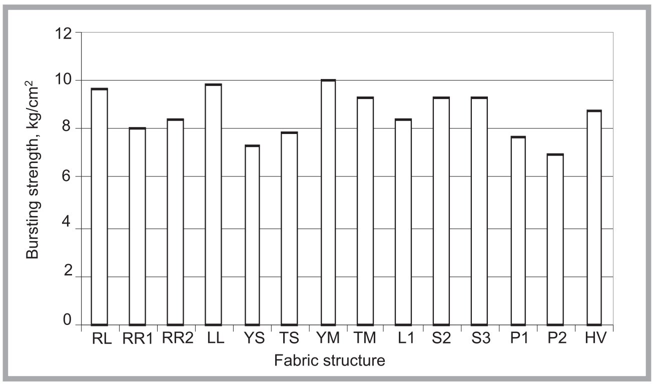


***Figure 8.** Effects of knit structure on bursting strength for washed fabrics (fabric codes according to Tables 5 and 6).*

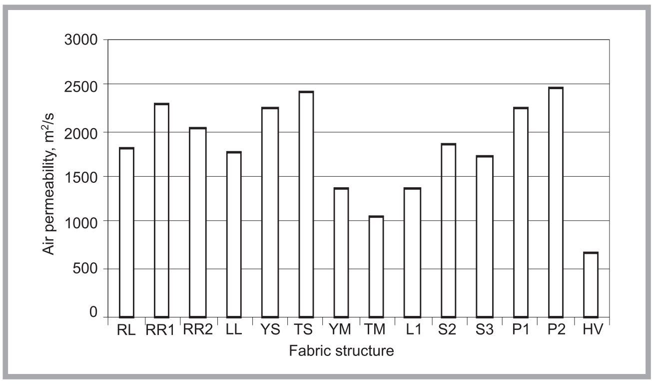


***Figure 9.** Effects of fabric structure on air permeability for washed fabrics (fabric codes according to Tables 5 and 6).*

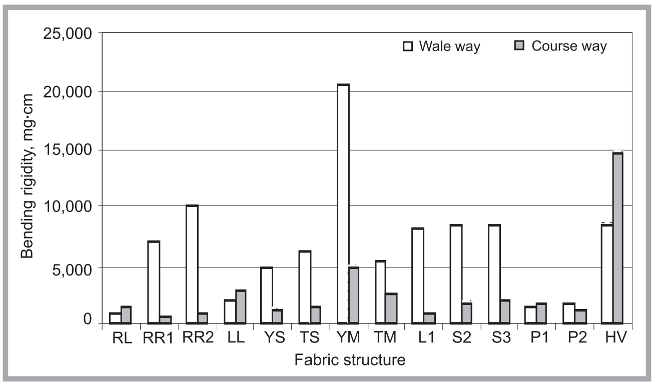


Figure 10. *Effects of fabric structure on wale way and course way bending rigidity for washed fabrics (fabric codes according to Tables 5 and 6).*

nificantly from each other. The wale per cm of the washed samples differs significantly from the dry and wet relaxed samples. The order of thickness of the fabrics from big to small is terry, double jersey fabrics and single jersey fabrics. The order of loop length of the fabrics from big to small is terry, 1×1 Rib, seed stitch, moss stitch, half cardigan, full cardigan, 2×2 cable, 2×2 Rib, 3×3 cable, single jersey fabrics, and float stitch fabrics.

- Tuck stitch fabrics have the lowest resistance to abrasion. For washed fabrics, the highest value of weight loss is for moss stitch followed by seed stitch fabrics, and tuck stitch fabrics. Links-links, seed stitch, moss stitch fabrics have the highest resistance to pilling. Lacoste, full cardigan, half Milano, the technical back of plain fabric and 1×1 rib fabric have the lowest resistance to pilling. Moss stitch and half cardigan fabrics have weaker bursting strength performance. Half Milano, links-links, and plain fabrics have the strongest bursting strength performance. Moss stitch and full cardigan fabrics are the most permeable to air, and terry and Milano fabrics are the least.

Milano is the most rigid fabric in wale way bending. Single jersey structures have lower wale way bending rigidity. Terry is the most rigid fabric in course way bending. 2×2 rib fabric is the least rigid fabric in course way bending.

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