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Investigation of the Effect of Pile Height and Yarn Linear Density on the Performance Properties of Pile Loop and Cut-Pile Loop Knit Fabrics

DOI: 10.5604/12303666.1172092

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Abstract

This paper investigates the effects of fabric structural parameters such as pile yarn linear density (19.7, 22.7 and 24.6 tex), ground yarn linear density (100 and 78 dtex), sinker height (2.2 sinker; 2.5 sinker and 2.8 sinker) on the performance properties of pile loop and cut-pile loop knit fabrics. The effects of structural parameters on the performance properties of the fabrics, such as abrasion resistance, bursting strength, and air permeability, were analysed. To determine their relationship and significance, ANOVA and Pearson correlation analysis were conducted. A higher pile height increases the fabric surface weight and thickness, thereby improving the abrasion resistance of the fabrics. The bursting strength of the fabrics increases with thicker ground yarn. The thicker pile yarn decreases the air permeability of the fabrics. Pile loop knit fabrics have higher abrasion resistance and lower air permeability compared to cut-pile loop knit fabrics. There is not much difference between the bursting strength of pile loop and cut-pile loop knit fabrics if the linear density of ground and pile yarn is the same.

Key words: *pile loop knit fabric, cut-pile loop knit fabric, abrasion resistance, bursting strength, air permeability.*

Introduction

Single-sided plated pile loop or terry is a popular knitted leisurewear and sportswear structure that has the form-fitting properties of single jersey and can be used in both fabric and sock form. The elongated pile loop sinker loops are formed over a higher knock-over surface than the normal-length ground sinker loops with which they are plated. The pile loop sinker loops show as a pile between the wales on the technical back of the fabric. Cut-pile loop is achieved during finishing, by cropping or shearing the pile loop sinker loops in both directions. This leaves the individual fibres exposed as a soft cut-pile loopy surface whilst the ground loops remain intact [1].

On the sinker top latch needle machine, the ground yarn is fed into the sinker throat and the sinker is then advanced so that the pile loop yarn fed at a higher level (***Figure 1***) is drawn over the sinker nib. A range of pile loop heights from 2 to 4 mm is possible, using different heights of sinkers [1].

Although there are many studies about single jersey fabrics and their derivatives, few studies are available about knitted pile loop knit fabrics in the literature. Ertugrul and Nuray [2] reported that fabric surface weight, yarn breaking strength, and yarn elongation are the major parameters that affect the bursting strength of knitted fabric. Ucar and Karakas [3] determined that the presence of lyocell and cut-pile loop knit fabrics increases the lengthwise shrinkage and widthwise extension after repeated wash and dry cycles, that the fabric thickness decreases with the presence of lyocell and decreases fabric tightness, that lyocell blend and ground-face fabrics have lower drape coefficients, and that spirality tends to increase with the presence of lyocell and pile loop knit fabrics. Das et al [4] observed that the direction of the pile loops (upward/downward) has no effect on the air permeability values of the fabrics and pile loop stability is one of the factors which influence the air permeability value of knitted pile fabrics. Kim et al [5] investigated the effect of chemical splitting on the water absorption and mechanical properties of a split type nylon/polyester (N/P) microfibre pile knit under various alkaline hydrolysis treatment conditions. According to results of the study, they determined that surface weight loss of the hydrolysed pile knit increases as the hydrolysis time, temperature and con-

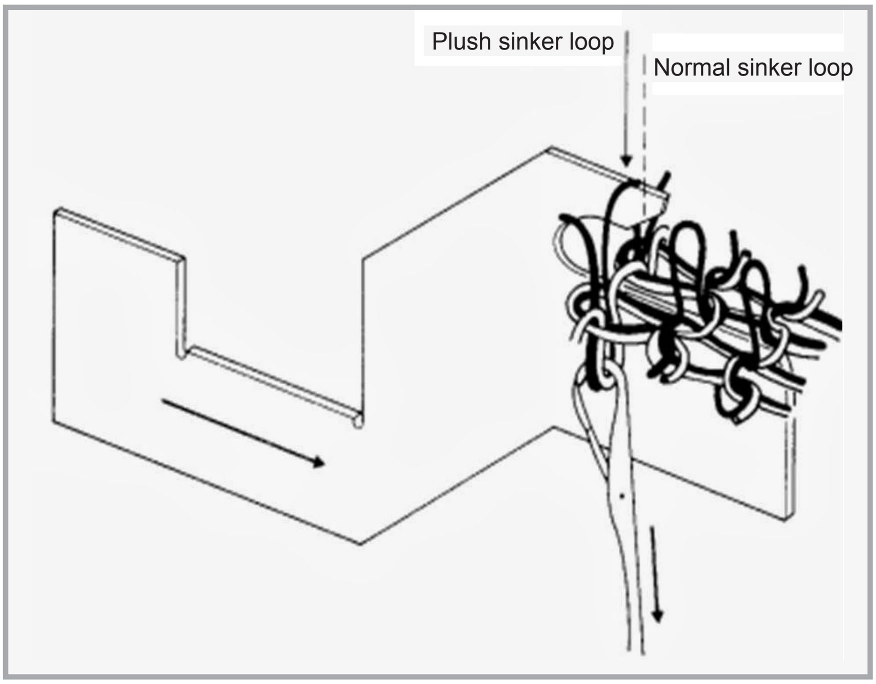

Figure 1. *Action of the pile loop sinker [1].*

***Table 1.** Pile yarn properties.*

Yarn properties	Yarn number, dtex		
	19.7	22.7	24.6
USTER, %	12.1	11.3	11.3
Thin -50%/1000 m	13	3	2
Thick +50%/1000 m	182	102	107
Neps +200%/1000 m	251	104	91
Hairiness	7.1	6.8	7.7
Strength, r.k.m.	15.4	16.9	18.3
Elasticity, %	4.6	4.6	5.0
Twist, t.p.m.	820	768	733

***Table 2.** Knitting machine properties.*

Model	Sinker height, mm	Diameter, inch	Gauge, n.p.i.	Number of feeds	Number of needles
Orizio JSVRN	2.2	30	20	44	1856
Keumyong KM-3SV	2.5				1896
Keumyong KM-3SV	2.8				

centration of sodium hydroxide increase, and that the deformation of the shape of the knit is easy due to decreased tensile strength. Besides this, they observed that bending and shearing values diminish, which leads to increased drapability and flexibility, with surface properties varying with changes in surface weight loss.

Besides pile woven fabric, there are a lot of studies on terry fabrics in literature. In these, the water absorption properties of terry fabrics are investigated especially. Petrulyte and Baltakyte [6] determined that the character of the wetting process depends on the fabric′s characteristics, kind of impact and its lasting period e.g. a macerating impact shortens the absorption process and the wetting process is affected by washing operations. In the other study of Petrulyte and Baltakyte [7], they determined that the liquid drop and liquid transport depends on the structural characteristics of the terry material, as well as on the kind of impact or finishing operation and its intensity, and they suggested that the results of the research could be used for creating new textiles with desired properties as the results determined the dynamics and character of the sorption process in woven terry fabrics. Once again, in another study of Petrulyte and Baltakyte [8] they found that an increase in pile height in many cases causes an increase in water absorption for grey, macerated, washed with detergent, and softened fabrics. Petrulyte and Nasleniene [9] stated that the pile height of terry woven fabrics had a significant effect on their liquid retention capacity and that their liquid retention capacity depends on the kind and intensity of the impact/finishing applied to them.

In this present study, pile loop knit fabrics were produced by using three different pile yarns and two different ground yarns at three different sinker heights. The aim was to investigate the effects of yarn linear density and pile heights on the fabric properties. In addition, after dying, cut-pile loop knit fabrics were produced by shearing of the pile loop knit fabrics with enough pile heights to compare the pile loop and cut-pile loop knit fabrics. After the tests, experimental data were analysed graphically and statistically.

Material and methods

In this research, eighteen pile loop knit fabrics and twelve cut-pile loop knit fabrics were produced using 100 % carded ring spun yarns with 19.7, 22.7, 24.6 dtex yarn linear densitys as pile yarn, and 100% polyester filament yarn of 78 and 100 dtex as ground yarn. The pile yarn properties are given in ***Table 1***.

The pile loop knit fabrics were produced by using different sinker heights having 2.2, 2.5, and 2.8 mm in the terry and velour- single jersey- circular knitting machines. All fabrics were knitted by 20 r.p.m. speed. The machine properties were shown in ***Table 2***.

Then the pile loop knit fabrics were dyed, including kiering, dying and washing processes, under the same conditions. Finally the dyed pile loop knit fabrics with a 2.5 and 2.8 sinker were sheared to produce cut-pile loop knit fabrics. However, the pile height of fabric samples with a 2.2 sinker was too short to be sheared, and hence these fabrics were omitted to produce cut-pile loop knit fabric.

Before testing, all the samples were conditioned in accordance with the standard ASTM D1776-08 [10].

Physical properties of courses per centimeter (cpc), wales per centimeter (wpc), pile/ground ratio, surface surface weight, and thickness were measured according to standards TS EN ISO 14971, TS 629, TS EN 12127, and TS 7128 EN ISO 5084, respectively [11 - 14].

For all fabrics, abrasion resistance, bursting strength and air permeability tests were applied. The abrasion resistance tests were made according to the EN ISO 12947-3 standard on a Martindale Tester-2000, and the percentage of mass loss of all samples was determined [15]. Bursting strength tests were made and test results evaluated in kPa, as directed in the EN ISO 13938-2 standard, on a James Heal Truburst Bursting Strength Test Machine [16]. As the last test, air permeability tests were applied, as stated in the EN ISO 9237 standard, on an SDL-Atlas MO21A Air Permeability Tester for a test area of 20 cm^2 and pressure drop of 100 Pa in mm/sec [17].

One way ANOVA was performed in order to understand the statistical importance of the yarn linear density and sinker height on the performance properties, for which the statistical software package SPSS 21.0 was used to interpret the experimental data. All the test results were assessed at significance levels $p \leq 0.05$ and $p \leq 0.01$. In addition to the variance analyses, the correlation of some structural properties and performance property values of the samples was performed to enhance the clarity of the study.

Results and discussion

The structural and performance properties of pile loop and cut-pile loop knit fabrics are given in ***Table 3***. The sinker and pile height were accepted as the same expression since the sinker height determined the pile height in the pile fabrics directly. Thus the pile height term was used mostly in the following sections.

Structural properties

Pile/ground ratio, cpc, and wpc values of the samples produced on the same ma-

Table 3. Structural and performance properties of pile loop and cut-pile loop samples.

Fabric type	Ground yarn linear density, dtex	Pile yarn linear density, dtex	Sinker height, mm	cpc	wpc	Pile/ground ratio	Surface weight, g/m^2	Thickness, mm	Mass loss, %	Bursting strength, kPa	Air permeability, mm/sec
pile loop	100	19.7	2.2	12.5	9	2.23	214.35	1.58	2.38	185.1	707.3
			2.5	12.5	9	2.53	230.87	1.85	2.33	190.2	667.2
			2.8	14	10	2.62	259.76	1.94	2.06	203.8	759.0
		22.7	2.2	12.5	9	2.23	250.19	1.75	3.41	185.8	495.8
			2.5	13	9	2.47	259.34	1.83	2.10	198.2	539.3
			2.8	15	9.5	2.69	319.22	2.18	1.45	197.3	554.6
		24.6	2.2	12.5	9	2.22	268.48	1.85	2.67	189.6	419.5
			2.5	14	9	2.40	286.57	1.88	2.20	188.9	437.4
			2.8	15.5	9.5	2.68	331.50	2.16	1.57	198.8	465.8
	78	19.7	2.2	12	9	2.21	192.68	1.50	3.02	161.3	737.2
			2.5	13	10	2.48	236.73	1.80	3.10	176.3	689.5
			2.8	14	9.5	2.62	242.99	1.75	2.21	175.0	760.9
		22.7	2.2	13	9	2.24	240.05	1.65	2.81	163.6	523.2
			2.5	12.5	9.5	2.40	240.76	1.75	2.38	169.4	509.1
			2.8	14	9.5	2.59	279.77	2.07	1.91	170.6	540.9
		24.6	2.2	12.5	9	2.23	254.82	1.69	3.14	159.1	559.0
			2.5	12.5	9	2.41	264.33	1.82	3.23	166.0	519.2
			2.8	14.5	10	2.70	320.24	2.01	1.74	173.7	555.9
cut-pile loop	100	19.7	2.5	13	9	-	171.22	1.29	9.50	189.4	757.6
			2.8	15	9.5	-	210.16	1.59	7.22	198.2	885.5
		22.7	2.5	13	9.5	-	203.07	1.41	6.73	191.4	618.9
			2.8	15.5	10	-	236.46	1.65	4.76	196.3	684.4
		24.6	2.5	13	9	-	204.37	1.40	4.67	192.3	528.0
			2.8	15	9	-	250.06	1.73	3.96	199.5	550.8
	78	19.7	2.5	13	9	-	168.92	1.31	15.45	172.3	795.9
			2.8	14	9.5	-	185.82	1.51	9.93	174.1	904.9
		22.7	2.5	12	9.5	-	185.89	1.32	10.16	169.1	620.4
			2.8	14.5	9.5	-	221.58	1.62	5.68	171.8	717.7
		24.6	2.5	12.5	9	-	190.05	1.35	6.89	167.9	561.0
			2.8	14	9.5	-	239.95	1.71	5.73	172.4	552.8

chine were the same or very close to each other since the machine settings were not changed during production. Fabric surface surface weight and thickness values of the samples varied depending on the yarn linear density and pile height. The thickening of yarn and increasing the pile height increased surface weight and thickness values of the samples. All the cut-pile loop samples were, as expected, lighter and thinner than the pile loop samples, which is simply caused by the shearing of the pile loop knit fabrics to produce a cut-pile loop structure. Therefore the surface weight loss of the cut-pile loop samples are approximately 19% to 28%, and the thickness values changed from 14% to 30% in comparison with the pile loop samples. It is seen that an increase in the pile height affects the pile/ground ratio positively.

Abrasion resistance

According to ***Figure 2***, the most important factor is the pile loop format for the abrasion resistance of the fabrics. The mass losses of cut-pile loop samples are considerably higher than those of pile loop samples. Although this situation resulted from the loss of mass and thickness, the increase in mass losses of cut-pile loop samples is much higher than the expected results. As follows, the increase in mass loss is 112% and 398%, whilst that in the loss of surface weight and thickness is 15% to 30%. This may be explained by the fact that fibres of the cut-pile loop separated from the fabric easily compared to those of the uncut-pile

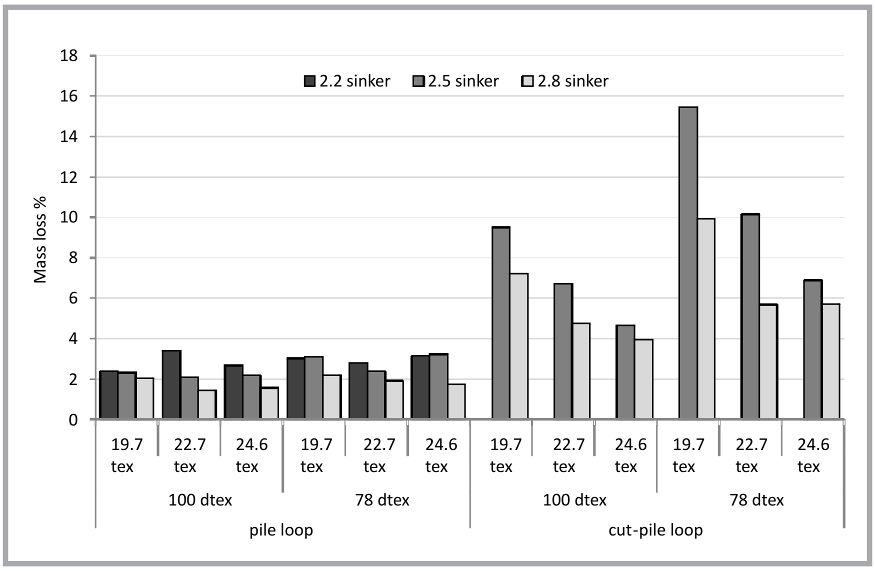

Figure 2. *Abrasion resistance of the samples.*

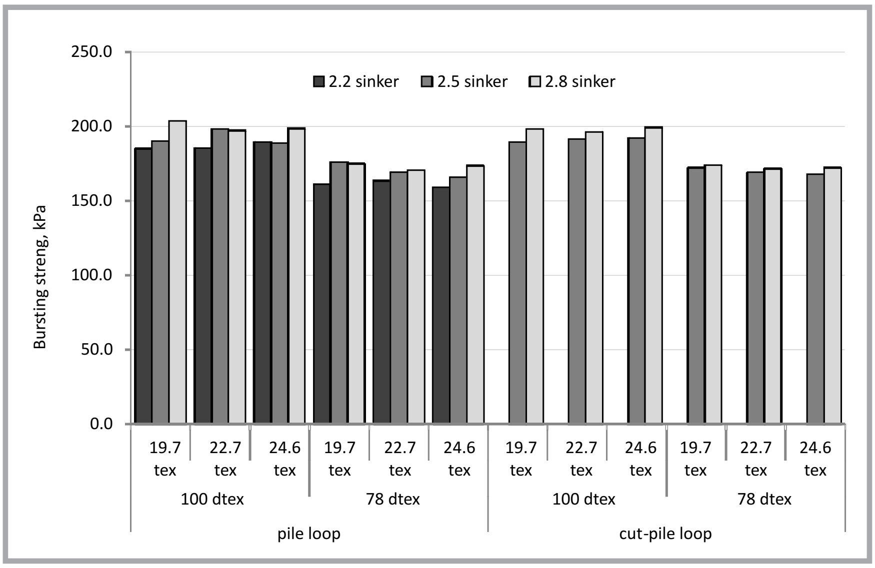

Figure 3. *Bursting strength of the samples.*

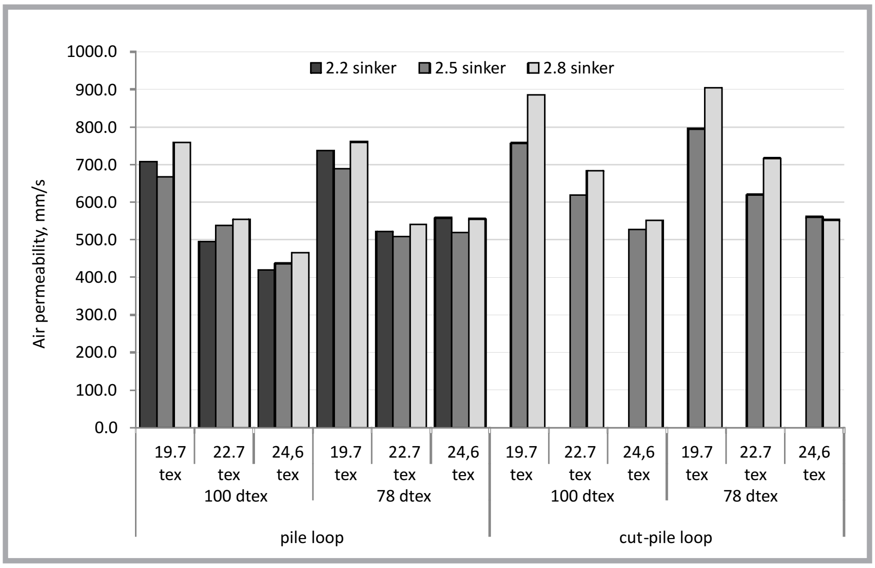

Figure 4. *Air permeability of the samples.*

loop, since the deformation of yarn twist, which adheres fibres, and the coherence of fibres in the cut-pile loop decreased very much as yarn. As a reasonable assumption, the variation in mass loss of the cut-pile loop samples is observed too much for the contrary, pile loop samples.

The pile height has less effect on the abrasion resistance of the samples compared to the loop format. A higher pile height causes an increase in fabric surface weight and thickness. As is known, the abrasion resistance of heavier and thicker fabrics is higher than that of lighter and thinner fabrics. Thus an increase in the pile height decreases mass losses in all samples. When analysing the mass losses in detail, mass loss values of the pile loop samples with a 2.2 sinker are between 2.38% and 3.41%, while those with a 2.5 sinker have 2.1% to 3.23% mass losses. Additionally the mass loss values are almost same or very close for samples with a 2.2 and 2.5 sinker. Samples with a 2.8 sinker have the lowest mass loss in all the pile loop and cut-pile loop knit fabrics. For these samples, the mass losses vary from 1.45% to 2.21%. The difference between a 2.5 and 2.8 sinker is higher in the cut-pile loop samples than that of pile loop samples for mass losses. When ***Table 1*** is examined, the reason for this is that the differences for surface weight and thickness in the cut-pile loop samples are higher than those of the pile loop samples. Nevertheless these findings cannot explain that the abrasion resistance of the pile loop samples is very close. This situation may result from the test cycles not being enough to abrade the pile loop samples. Thus the pile loop samples were abraded superficially, and thus mass losses occurred less than expected.

The abrasion resistance of samples with a different pile yarn linear density is very close in pile loop fabrics. The difference between them is close to 1%, which was too low a value. The mass loss of pile loop samples with 100 dtex ground yarn is slightly lower than that of pile loop samples with 78 dtex ground yarn. The same findings are not observed for the cut-pile loop fabrics. The thinner ground and pile yarns increase mass losses significantly. This finding is supported by the fact that the sample with the thinnest yarns of 78 dtex ground yarn and 19.8 pile yarn has the highest mass loss (15.45%). Differences between the mass losses of the cut-pile loop samples change from 1% to 6%.

In addition, the effect of the fabric surface weight and thickness is high on the abrasion resistance of the samples. It is clear that the fabric surface weight and thickness is due to the yarn linear density and pile height. Thicker yarns and higher pile heights lead to an increment in the surface weight and thickness of fabrics. Thus an increase in fabric surface weight and thickness decreases the mass loss of samples.

Bursting strength

The most effective factor is ground yarn for the bursting strength for both the pile loop and cut-pile loop samples, shown in ***Figure 3***. The reason for this is that ground stitches are smaller than uncut-pile ones in the pile loop samples, and hence ground stitches of lower stitch length are initially burst. However, uncut-pile stitches of higher stitch length resist bursting with enough extension, but are burst later. The bursting process only occurs in *t* ground stitches since pile stitches are already cut in the cut-pile loop samples. In comparison, the bursting strength values vary between 185.1 kPa and 203.8 kPa in the samples with 100 dtex ground yarn, while they vary between 159.1 kPa and 175 kPa in the samples with 78 dtex ground yarn for all fabrics. Accordingly the contribution of the ground yarn linear density to the bursting strength is approximately 80%, showing that the bursting strength of samples changes depending on the ground yarn linear density, and that

Table 4. *One way ANOVA test results.*

Factors	Mass loss				Bursting strength				Air permeability			
	Pile loop		Cut-pile loop		Pile loop		Cut-pile loop		Pile loop		Cut-pile loop	
	F	Sig.	F	Sig.	F	Sig.	F	Sig.	F	Sig.	F	Sig.
Pile yarn linear density	0.313	0.732	19.415	0.000	0.605	0.547	0.123	0.885	502.051	0.000	363.880	0.000
Ground yarn linear density	6.449	0.013	10.345	0.002	490.759	0.000	519.838	0.000	5.866	0.016	0.826	0.365
Pile height	31.877	0.000	11.657	0.001	11.145	0.000	5.110	0.026	2.721	0.069	9.315	0.003
Fabric surface weight	-	-	-	-	22.910	0.000	10.878	0.000	90.896	0.000	69.386	0.000
Fabric thickness	1.940	0.036	5.479	0.001	6.303	0.000	2.857	0.000	3.495	0.000	11.400	0.000

thicker ground yarn obviously increases the bursting strength.

The pile height is found as the second effective factor with respect to the bursting strength of the samples. An increase in the pile height improves the bursting strength of all samples. However, the contribution is not as high as for the ground yarn linear density. Moreover the bursting strength values are very close to each other in the same sinker group.

The samples having the same the ground yarn but different pile format have very close bursting strength values. ***Table 3*** and ***Figure 3*** also exhibit that the fabric type is clearly not effective with respect to the bursting strength of samples.

The findings given above are supported by the fact that the sample with 100 dtex ground yarn and a 2.8 sinker has the highest bursting strength, while that with 78 dtex ground yarn and a 2.2 sinker has the lowest bursting strength.

Structural properties such as surface weight and thickness are also not effective regarding the bursting strength of samples according to the test results.

Air permeability

The air permeability of the samples was tested for the front and back face of the fabrics. The test results show that the difference between the air permeability values of the samples is very low. Hence the average air permeability values of both faces were accepted as the test results. According to ***Figure 4***, the effective factors are the pile format, pile yarn linear density, ground yarn linear density and pile height for the air permeability of the samples. The pile yarn linear density between them has the highest effect on air permeability. The pile loop samples and cut-pile loop samples of finer pile yarn exhibit higher air permeability, resulted in thicker pile yarns inducing an enlargement of the surface area of samples, and hence the pores that allow airflow through the fabric decrease. In addition, the thicker pile yarns increase the surface weight and thickness of the fabrics, causing an increase in resistance to airflow through the fabric. As a result, thicker pile yarn decreases the air permeability of the samples.

It was usually observed that the samples with 100 dtex ground yarn have slightly lower air permeability than that of samples with 78 dtex ground yarn. Thus it can be said that thicker ground yarn decreases the air permeability of the samples, but it is not as effective as as the pile yarn linear density regarding air permeability.

Compared to the pile yarn linear density, the pile height has a lower effect on the air permeability of samples. This effect is clearly higher for the cut-pile loop samples. In general, it is seen that an increase in the pile height increases the air permeability of samples.

The other finding indicates that the air permeability of the cut-pile loop samples is higher than that of the pile loop samples. This evaluation can be explained by the fact that pile loops have lower stability than the others. The pile loops with lower stability deviate from their original position during airflow. The distorted pile loops fall into the zone of the inter spaces between the base loops. As the inter spaces are the major contributors of airflow due to uninterrupted airflow through them, hindrance occurs due to fall off, and the distorted pile loops obviously affect the air permeability value [4]. Cut-pile loops are more stable than pile ones since cut-pile loops do not fall into the zone of inter spaces, and stand upright. Thus inter spaces are not covered and they allow airflow through the fabric. This situation is clearly seen from ***Figure 5***.

The fabric surface weight and fabric thickness is also effective regarding the air permeability of samples, since heavier and thicker fabrics prevent airflow through the fabric, hence such fabrics decrease air permeability.

Statistical analyses

One way ANOVA and Pearson correlation tests results are given in the following tables.

ANOVA test results revealed that the ground yarn linear density, pile height and thickness have a significant effect on the mass loss in the pile loop samples. The effect of all factors is significant for the mass loss, except the surface weight for cut-pile loop fabrics. The ground yarn linear density, pile height, surface weight and thickness, except the pile yarn linear density, have a significant effect on the bursting strength for both the pile loop fabrics and cut-pile loop fabrics. Especially F values clearly show that the effect of the ground yarn linear density is too much for the bursting strength, shown in ***Table 4***. On the other hand, there is a significant effect of all factors and air permeability, except pile height,

Table 5. *Pearson correlation test results; * Correlation is significant at the 0.05 level (2-tailed), ** Correlation is significant at the 0.01 level (2-tailed).*

Sources	Mass loss		Bursting strength		Air permeability	
	Pile loop	Cut-pile loop	Pile loop	Cut-pile loop	Pile loop	Cut-pile loop
Pile yarn linear density	-0.054	-0.653**	-0.082	-0.024	-0.892**	-0.928**
Ground yarn linear density	-0.289*	-0.414**	0.859**	0.904**	-0.179*	-0.083
Pile height	-0.678**	-0.435**	0.335**	0.205*	0.118	0.270**
Fabric surface weight	-0.587**	-0.764**	0.368**	0.382**	-0.550**	-0.416**
Fabric thickness	-0.666**	-0.628**	0.482**	0.319**	-0.356**	-0.087

on the pile loop fabrics. As for the cut-pile loop fabrics, the effect of the ground yarn linear density is not significant on the air permeability only. According to F values, it is clear that the pile yarn linear density is the most effective factor for the air permeability of all fabrics.

According to ***Table 5*** (see page 95), the correlations between the ground yarn linear density, pile height, surface weight, thickness and mass loss are strong and negative for both the pile loop fabrics and cut-pile loop fabrics, meaning that an increase in the ground yarn thickness, pile height, surface weight and thickness of the fabrics raises the resistance to abrasion. There is no correlation between the pile yarn linear density and mass loss in the pile loop fabrics, but the correlation is strongly negative for cut-pile loop fabrics. Accordingly thicker pile yarn increases the abrasion resistance. Strong and positive correlations are seen between all sources and the bursting strength, except the pile yarn linear density for all fabrics from the figure. This means that thicker ground yarn, higher pile height, and heavier and thicker fabrics increase the bursting strength. For the pile loop fabrics, correlations between the pile yarn linear density, ground yarn linear density, surface weight, thickness and air permeability are negatively strong. Thus thinner pile and ground yarns as well as lighter and thinner fabrics increase the air permeability. As for cut-pile loop fabrics, the strong correlation is negative between the pile yarn linear density, surface weight and air permeability, but it is positive between the pile height and air permeability. This means that while thicker pile yarns and heavier fabrics decrease the air permeability, a higher pile height increases it.

Conclusions

It was established that the pile yarn linear density, ground yarn linear density, pile height, surface weight, and thickness are effective factors for the performance properties of pile loop and cut-pile loop knit fabrics.

The main conclusions from the experimental and statistical study are as follows;

- The fabric surface weight and thickness increase proportionally with an increase in the pile height and pile and ground yarn thickness in pile loop and cut-pile loop knit fabrics.
- The pile format, pile height, pile yarn linear density, ground yarn linear density and thickness are effective parameters for abrasion resistance. The most effective factor is the pile format on abrasion resistance of the fabrics. The mass losses of cut-pile loop knit fabrics were distinctly higher than those of pile loop knit fabrics. Thicker ground and pile yarns, higher pile height, as well as heavier and thicker fabrics increase the resistance to abrasion for both pile loop fabrics and cut-pile loop fabrics. While the pile height is more effective the the abrasion resistance in pile loop fabrics, the pile yarn linear density is more beneficial concerning abrasion resistance in cut-pile loop fabrics in comparison to the other factors.
- The most important factor for the bursting strength is clearly the ground yarn linear density for both pile loop and cut-pile loop knit fabrics. The bursting strength of pile loop and the cut-pile loop knit fabrics increases with the thickening of ground yarn. Additionally a higher pile height as well as heavier and thicker fabrics increase the bursting strength of all the fabrics. On the other hand, the pile format is ineffective regarding the bursting strength, since there is not much difference between pile loop knit fabrics and cut-pile loop knit fabrics.
- The effective factors for the air permeability of pile loop and the cut-pile loop knit fabrics are the pile yarn linear density, pile format, pile height, surface weight and thickness. However, the pile yarn linear density is found to be the most effective factor for both types of fabrics. According to this, thicker pile yarn decreases the air permeability of the fabrics. Furthermore the pile format also has more effect on the air permeability since that of cut-pile loop knit fabrics is higher than that of pile loop knit fabrics. A higher pile height increases the air permeability, whereas the surface weight and thickness decrease the air permeability of these fabrics.

Acknowledgement

I am thankful to Serpil Koyuncu. Abdülkadir Koyuncu. Cemal Gül. Ayhan Durmaz from AKO ÖRME for the production of the knit fabrics. I am also grateful to Hakan Konukoğlu of SANKO Textile for providing the pile yarns. I would also like to express gratitude to H. Kübra Kaynak for assisting the carrying out of several experiments and supporting of many subjects. Lastly I would like to give thanks to Canan Kılıç for assisting in the performing of several tests.

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Received 07.05.2014 Reviewed 02.07.2015