Estimation of permeability properties of technologically developed jacquard fabrics

Klara Kostajnšek and Matejka Bizjak

University of Ljubljana, Faculty for Natural Sciences and Engineering, Department of Textiles, Graphic Arts and Design, Ljubljana, Slovenia

ORIGINAL SCIENTIFIC PAPER

UDC: 675.017.6: 677.1/.5: 646.21:687.051.5

Hem. Ind. **77(3)** 191-202 (2023)

Abstract

The study investigated how certain design parameters affect the permeability properties of jacquard fabrics. Six woven samples were made on the same cotton warp and with the same loom setting. The fabrics were made from two different types of weft yarns (cotton and Lyocell Clima), in two different pattern sizes (with larger and smaller monochrome areas), and two groups of double twill weaves (self-stitched double cloth, interchanging double cloth). We proved the importance of the size and distribution of the pattern/motif, the type of weave and the type of yarns used in the jacquard fabrics and the influence they have on the permeability properties in close relation to the aesthetic function. All patterns with interchanging double weave have significantly higher air permeability than patterns with self-stitched weave. For thermal conductivity, the influence of the raw material and the size of the pattern/motif is obvious. For fabrics with patterns with larger geometric areas, where the presence of weft threads on the surface is greater, the thermal conductivity is higher. The pattern size, on the other hand, does not affect the ultraviolet protection factor (UPF), unlike the raw material from which it is made.

Keywords: jacquard pattern; self-stitched / interchanging double weave; porosity; air permeability; thermal conductivity.

Available on-line at the Journal web address: *http://www.ache.org.rs/HI/*

1. INTRODUCTION

The use of jacquard fabrics has been popular in the textile and apparel industry for decades. They are used for both clothing and decorative purposes, precisely because of their appearance - diverse weaving patterns and use in various forms, which contribute to the final appearance and functionality of the fabrics. Modern jacquard fabrics can be made of a variety of fibres, from natural cotton or silk to blends with synthetic fibres such as polyester. What they all have in common is the jacquard structure, which means that the pattern is woven and shaped by a combination of different weaves and multicoloured yarns, usually creating complicated shapes in a complex structure, and they are in most cases stronger and thicker than many other fabrics. Some jacquard fabrics are double-sided, meaning that both the front and back side of the fabric are usable (*e.g.*, for decorative curtains), while others are clearly single sided, meaning that only one side of the fabric is usable (*e.g.*, for upholstered furniture).

Jacquard fabrics are not so widely used for clothing purposes, mainly because of the way they are made and their high price. Despite modern weaving technologies, digitization of processes and the use of CAD/CAM systems, the production of jacquard fabrics is still a challenge in itself. The doctrine of fast fashion does not allow the use of expensive jacquard fabrics, so they have been completely displaced by printed fabrics, and with the advantages of digital printing luxury jacquards have completely lost the battle. Only in haute couture, upholstery and interior design, this type of fabric continues to be used. This is also reflected in the small number of studies that have been conducted on the properties and characteristics of jacquard fabrics.

Corresponding author: K. Kostajnšek, University of Ljubljana, Faculty for Natural Sciences and Engineering, Department of Textiles, Graphic Arts and Design

E-mail: klara.kostajnsek@ntf.uni-lj.si

Paper received: 17 October 2022; Paper accepted: 6 March 2023; Paper published: 28 March 2023.

https://doi.org/10.2298/HEMIND221017008K

Recently, the concept of sustainable fashion has come to the fore as sustainable principles have become a necessity in all production technologies, especially in the textile and apparel industry, which are among the biggest polluters. Sustainable production, product quality, product life cycle, recyclability and reusability are more important than price for many consumers. These are new circumstances in which jacquard fabrics have also become important for use in apparel. In addition, jacquard weaving of 3D woven structures for composites is also increasing in the field of technical textiles. Among the other 3D weaving techniques, multilayer weaving is interesting because of the variety and complexity of the possible 3D structures [1].

The literature review shows that most studies have been conducted to evaluate the physical-mechanical properties of jacquard fabrics used for upholstery. A study [2] was conducted on the self-cleaning properties of jacquard upholstery fabrics with different construction parameters. In this research, a nano-TiO_2 coating was applied to 18 double faced woven fabrics produced by the jacquard weaving technique with three different weft densities, two different raw materials for the warp threads, and three different face weave patterns under the same conditions using the sol-gel method. In addition to self-cleaning effectiveness, the effects of fibre type, weft setting and weave pattern on the air permeability of upholstery fabrics were also investigated.

The effects of design parameters of the woven fabrics are also reflected in the surface texture of the woven pattern, so their influence on the properties important to users was studied [3]. The effect of different weft yarn properties (yarn linear density and yarn types such as filament yarn, staple fiber yarn, and textured yarn) on surface abrasion performance of jacquard fabrics was investigated. The experimental results showed that the yarn properties and the degree of yarn crimp affect the abrasion resistance of the jacquard fabrics.

Bending properties of jacquard woven fabrics and the effects of weft density, weft yarn count, weave, and Lycra content in the weft on these properties have also been studied by Sule [4]. Different weft yarns were used on a viscose filament warp yarn for weaving jacquard satin fabrics. The experimental results showed that the bending rigidity of the fabrics in the warp and weft directions increases with increasing weft density and when thicker weft yarn is used. The bending rigidity is also influenced by the weave and, thus, by the number of interlacing points (4/1 satin and 7/1 satin), with fewer interlacing points inducing lower bending rigidity.

Properties of fabric depend on the raw material, the type of yarns and the construction properties of the fabric. The choice of material is important from the point of view that each material has its own properties, which are transferred to the fabric. Functionalization of fabrics allows influencing the physical-mechanical properties by using special yarns to improve for example elasticity [5,6], thermal regulation [7,8], protection against ultraviolet rays (UV) [9-11], *etc*. In addition, from the design point of view, the shape and size of the pattern, its frequency and distribution on the surface are also important, not only as a visual effect, but also in terms of the above-mentioned characteristics [12-14].

Permeability properties are of great importance for certain types of textiles, such as technical textiles (philtres), as well as for clothing and some decorative textiles, as they contribute to the comfort of the user. By comfort, we mean the ability to dissipate excess heat and/or water, regulate airflow, and protect against the effects of UV rays. The permeability of textiles depends on the type of penetrating medium, weather conditions, the geometric structure of the textile and the raw material [15,16].

The internal geometric structure of textiles, empty spaces of different shapes and sizes, *i.e.*, porosity and pore structure, are closely related to the permeability properties of textiles. Porosity is an important physical property of textiles and is defined as the volume of air in the total volume of the body, *i.e.* the ratio between the volume of empty spaces and the total volume of the textile. Porosity itself as a physical parameter of textiles is not sufficient for determination of the textile permeability. For a more accurate prediction, we need parameters that additionally describe the porosity, such as: the size, number, and distribution of pores. These provide detailed information about the internal geometric structure of fabrics and how it relates to the permeability properties of the fabrics. For this purpose, the Jakšić's porosity measurement method and optical methods for determining porosity parameters in woven fabrics were used in several experimental studies [17-21]. The authors' intention is to compare the two methods and obtain more descriptive data about the internal geometric structure of fabrics.

The aim of this work was to investigate how certain design parameters affect the permeability properties of jacquard fabrics and how to influence permeability by different jacquard patterns. The main objective was to determine the importance of the size and distribution of the pattern/motif, the type of weave (self-stitched/interchanging double cloth), and the type of yarns used in the design of jacquard fabrics, and the influence of these parameters on permeability properties in close relation to aesthetic function. For the porosity, size, and distribution of the pores, both the Jakšić and the optical method were used in the work. The influence of basic design parameters of jacquard fabrics on their properties is well known and well studied. However, the influence of design parameters as we ll as the weave structure, which determines the frequency of interlacing and compactness, has been studied to a much lesser extent. The aim of our research is therefore to focus not only on aesthetic function, but also on comfort and UV protection properties as functions of the structure of the jacquard weave.

2. EXPERIMENTAL

2. 1. Material

Six jacquard woven samples were produced on the same cotton warp (Tekstina d.o.o., Slovenia) (8×2 tex; warp sequence 1 black : 1 white) and with the same loom (Minifaber Spa, Italy) setting (40 warps/cm; 40 wefts/cm). The fabrics were made from two different types of weft yarns (Litia Spinnery, Slovenia) (cotton, 24 tex and Lyocell Clima, 25 tex), in two different pattern sizes (Figure 1; left - larger squares and right - smaller squares) and two groups of double twill weaves (Figure 3; self-stitched double cloth, interchanging double cloth). The sample labeling, characteristics of samples and on-loom settings are shown in Table 1.

Table 1. Characteristics of samples and on-loom settings

Sample	Pattern	Material and fineness, tex		Yarn density, cm		Yarn diameter, mm		Weave
		warp	weft	warp	weft	warp	weft	
1	larger	White CO 8×2 tex	CO 24 tex	40	40	0.1947	0.221	Double twill weaves
2	smaller							
3	smaller/ interchanging							
4	larger	Black CO 8×2 tex	Lyocell Clima 25 tex			0.2053	0.199	
5	smaller							
6	smaller/ interchanging							

For the design of fabric production, we used the program Arahne (Arahne d.o.o., Slovenia), which specializes in the development of CAD/CAM software for dobby and jacquard weaving [22]. In the design process, we combined the aesthetic side with the knowledge of how construction parameters and machine settings can affect the pr operties of the jacquard fabric. The size and shape of the pattern and its frequency can greatly affect certain properties of the fabric, both functionality and appearance. The surface texture and colour effect of the pattern on the fabric is determined by the weave, the yarn and its structure, the arrangement of the yarns, the density, and the colour of the yarns. In most cases, the surfaces in different areas of the pattern are not the same, so the size, shape, and frequency of the pattern play an important role.

Ratio of the size and shape of large and small patterns can be clearly seen in Figure 1. The length of the square in the fabric with the large pattern is 12.7 cm, while in that with the small pattern it is 7 cm, which is about 50 % smaller so that the frequency of alternating stripes where the weave changes is about 50 % greater. Patterns with larger areas (compared to smaller ones), exposes more of the yarn from which it is made and affects the surface by influencing the reflection of light, appearance of texture on the fabric surface, *etc.* The weave has also a major influence since it determines the interlacing points and the frequency of weft and warp threads on the surface and in the structure and this is also reflected in certain permeability properties (interchanging double cloth struc ture, self-stitched double cloth structure, weft/warp effect, *etc.*). Each part of the surface in the sample has a specific characteristic, so the differences in size and frequency of the sample area can be considerable.

For this purpose, to study the influence of the size and shapes in the jacquard patterns and the influence of different weave on the permeability properties, we created the first pattern with larger white, black, and grey squares that create a 3D visual effect (Figure 1, left), while the second pattern consists of frequently changing smaller squares (Figure 1, right). Different sizes and shapes in the jacquard patterns mean different frequencies of the different weaves, which affect the frequency of thread interlacing.

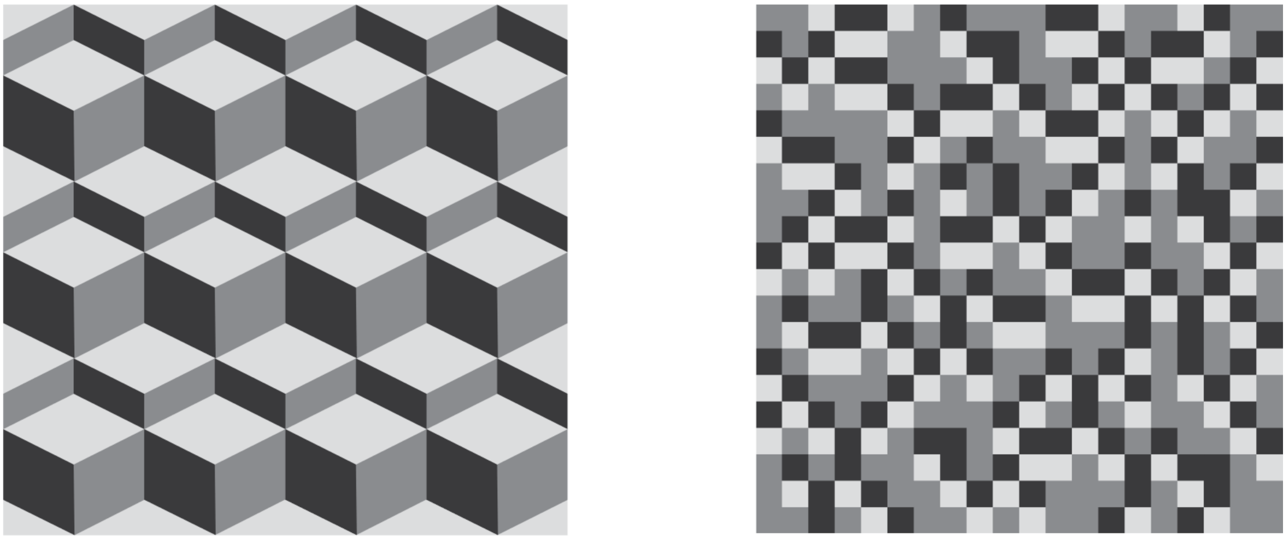

Figure 1. Patterns for fabrics in two different sizes (left - larger, right - smaller)

For all samples, a 1/5 twill double weave (Fig. 2) was used, a somewhat unclassical weave for all surfaces of the pattern but chosen to simplify the research study.

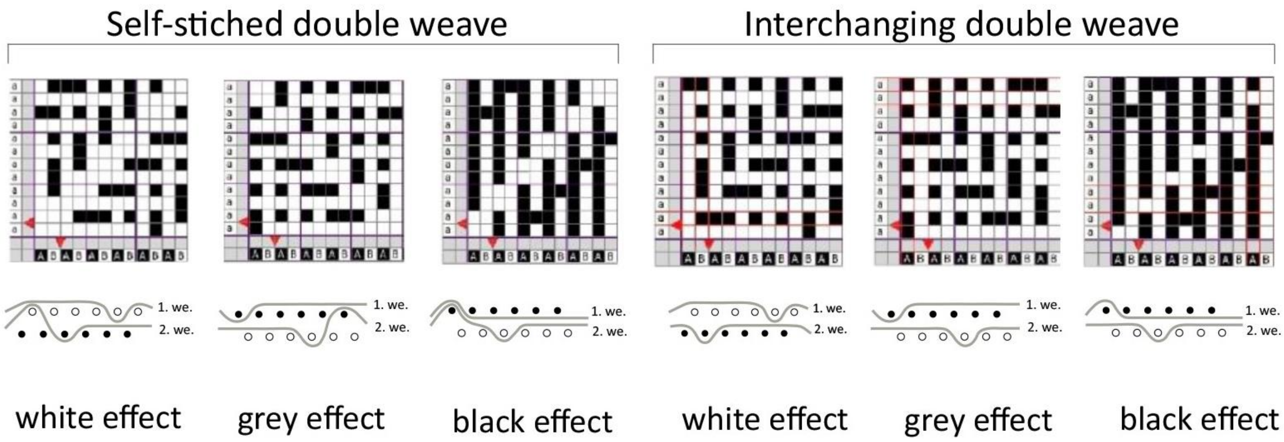

Figure 2. Weaves and weft cross sections for all three colours in jacquard patterns

To achieve the maximum black effect resulting from the colors of the yarn and the white weft threads (due to the warp sequence - 1A (black) 1B (white) and the weft sequence 1a (white), this was the only possibility to choose the stitching points as shown in the cross-section schema of black effect (Fig. 2, Self-stitched double weave). The black colour on the sample (Fig. 3, effect 2) was achieved with the warp weave effect, where the surface is dominated by a black warp. The white colour (Fig. 3, effect 3) was obtained with a weft effect combined with a white warp, with the studied white colour weft dominating the surface. The grey colour (Fig. 3, effect 1) was obtained with a weft effect in combination with a black warp, with the surface also dominated by the white colour weft.

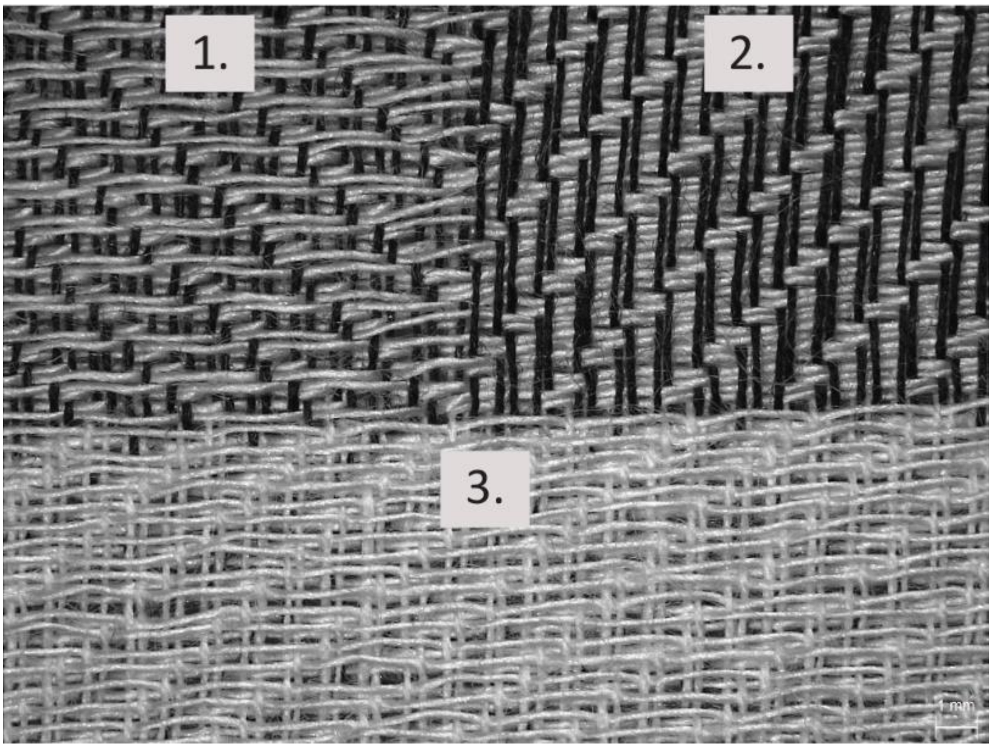

Figure 3. Different colour effects of woven fabric surface: 1. grey, 2. black and 3. white

2. 2. Methods

Physical, permeability and UV properties of the fabrics were investigated according to standard methods: warp and weft density (SIST EN 1049-2) [23], mass per unit area (SIST EN 12127) [24], thickness (SIST EN ISO 5084) [25], air permeability (SIST EN ISO 9237) [26], thermal conductivity (DIN 52 612) [27], UV transmission and reflection were measured and ultraviolet protection factor (UPF) was calculated, according to the standard EN 13758-1:2001 [28], size and distribution of pores were determined by using the Jakšić method [20].

The Jakšić method for determining the porosity of textiles is based on selectively squeezing the liquid in the pores out of the wet textiles by pressure. On the rotameter, at different pressure differences, the volume velocity of the air flow through a given surface of the dry sample is measured. The sample is then immersed in a liquid of known density and surface tension. When it is completely wetted, it is inserted into the measuring head of the rotameter and the pressure difference is determined until an air bubble appears. The differences are read, and the hydraulic diameter of the largest pore is calculated. Then the pressure is increased, and the pressure value is read at preselected volume flows. The measurement is completed when the volume has been squeezed out even from the smallest pores [20].

The optical method uses image analysis and is based on the transmission of visible light through a fabric. Image analysis is commonly used to successfully determine the open structure (or cover factor) of fabrics with sufficient accuracy. The purpose of the above method is to obtain faster and more accurate results by combining the results of image analysis with some results of porosity measurement. For this purpose, we used an open-source image processing program developed in ImageJ platform (open-source software) for analysis of scientific multidimensional images [29-32]. The visually displayed image processing is shown in Figure 4.

The fabrics in self-stitched 1/5 twill double weave are marked as sample 1, 2, 4 and 5, the fabrics in interchanging 1/5 twill double weave are marked as sample 3 and 6 (Fig. 2). The different distribution and frequency of interlacing in the fabric affects the compactness of the fabrics, making it possible to study comfort or protective properties, such as UV protection, as a function of the compactness of the pattern.

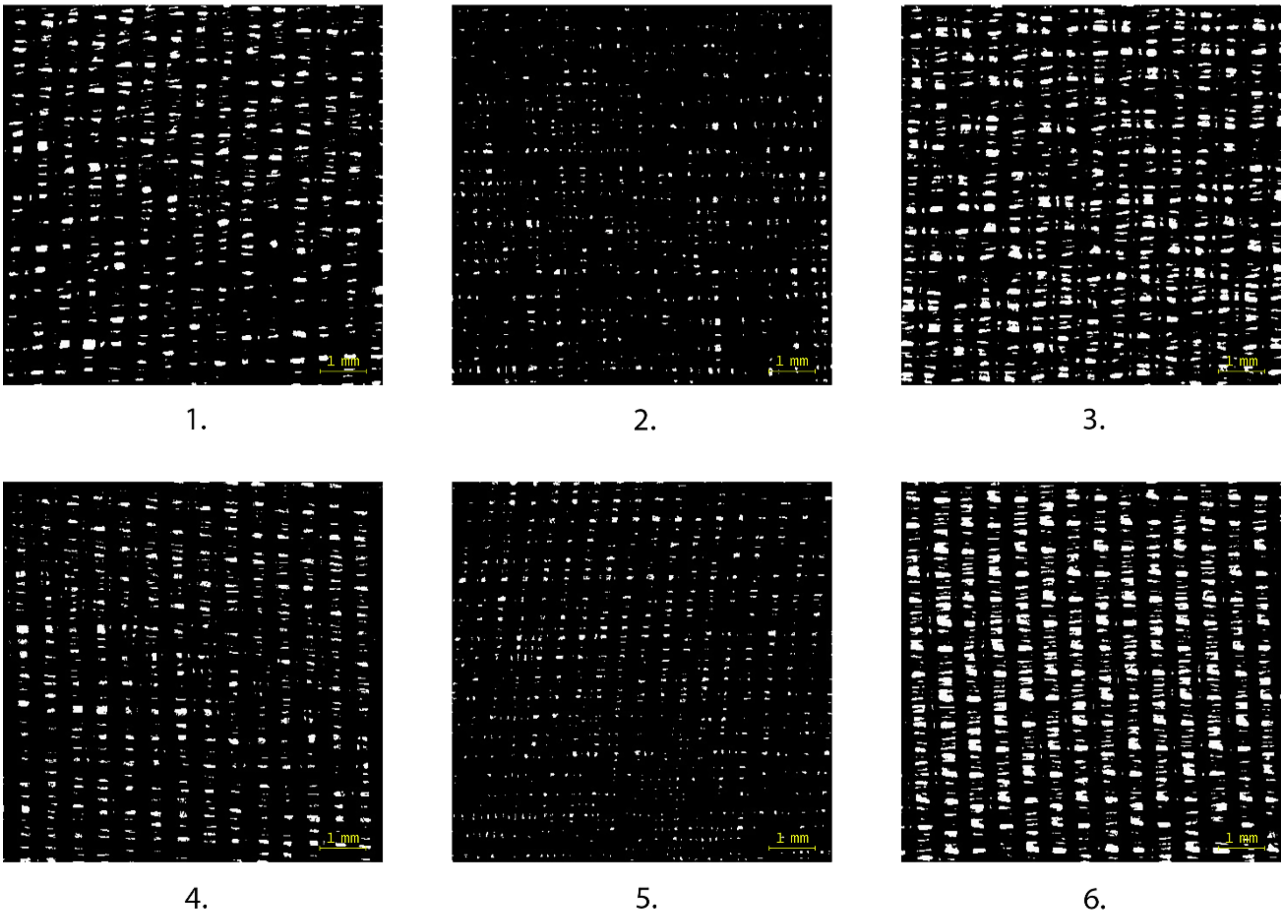

Figure 4. Visual images of all six samples in the light transmission function under stereo microscope (designation of samples from 1 to 6 according to Table 1).

2. 3. Statistical analysis

All statistical analyses were performed using the two-way ANOVA to determine the statistically significant parameters affecting the analysed properties. Two-way ANOVA is used to determine whether two different factors have an effect on a measured variable. Here, we determine whether the factors and the interaction between them affect the dependence variable. The interaction between factors A and B is statistically significant and has a consistent influence when ($F > F_{crit}$ and $p < 0.05$). For the analyses, we investigate the relationship between different materials - yarns (factor A) and different sizes of pattern and weave (factor B) with other physical, permeability and UV protective properties of the samples.

3. RESULTS AND DISCUSSION

The structural properties of the woven samples are shown in Table 2, with values for thread density, crimp, thickness, and mass per unit area of the fabric samples.

The size and distribution of pores between fibres were determined by using the Jakšić method also known as the flow method. The results of porosity analyses, bubble point (d_1), mean pore diameter (d_m), and mean open area fraction (P) determined by the above method, open area determined by using the image analyses (OA), and theoretically calculated number of pores are shown in Table 3. The pore size distribution is shown in Figure 5 for samples with cotton (a) and with Lyocell-Clima (b) in the weft direction.

Table 3 also includes the results of air permeability (Q) and thermal conductivity (k). The measured values of UV transmission (T) and UV reflection (R) as well as the calculated UV absorption (A) and ultraviolet protection factor (UPF) are listed in Table 4.

Table 2. Physical properties of woven samples

Sample	Density, yarns/cm		Crimp, %		Thickness, mm	Mass per unit area, g m^{-2}
	warp	weft	warp	weft		
1	39.2	43.0	4.6	4.4	0.904	188.6
2	39.4	43.0	4.2	4.2	0.899	190.2
3	39.2	42.2	4.6	4.0	0.979	190.6
4	39.2	42.6	4.6	3.0	0.826	180.4
5	39.0	41.8	3.4	3.6	0.800	176.8
6	40.4	43.4	4.2	3.6	0.844	175.0

Table 3. Porosity parameters of the samples, air permeability and thermal conductivity with corresponding correlation coefficients (corr)

Sample	d_1 / µm	d_m / µm	P / %	OA / %	N_{por} / cm^{-2}	Q / m^3 min^{-1} m^{-2}	K / Wm^{-1} K^{-1}
1	132	40.91	21.48	19.17	1685.6	96.31	0.1124
2	237	48.61	18.65	16.43	1694.2	86.71	0.1054
3	291	64.38	35.23	27.41	1654.2	136.94	0.0841
4	185	46.82	20.01	20.76	1669.9	104.11	0.0918
5	253	43.84	19.73	16.32	1630.2	99.75	0.0876
6	261	64.84	33.33	29.87	1753.4	146.7	0.0843
corr d_1		0.74					-0.78
corr d_{sr}			0.93	0.91		0.91	
corr P				0.95		0.96	
corr OA						0.97	
corr Q							-0.74

Table 4. Measured and calculated values of the UV parameters of the samples

Sample	UPF	T / %	R / %	A / %
1	15.82	7.07	32.76	60.17
2	16.05	6.88	28.95	64.17
3	9.25	11.17	28.48	60.35
4	6.75	16.19	38.41	45.4
5	7.58	14.81	41.22	43.97
6	5.16	19.98	42.97	37.06

The statistical analysis presented in Tables 5 to 7, explains the relationship between different materials (yarns) as well as different sizes of pattern and weave with other physical, permeability and UV protective properties of the samples.

Table 5. Two-way ANOVA results of some physical properties of samples

Source of Variation	Thickness, mm			Mass per unit area, g m^{-2}			Crimp, %		
	F	P-value	F_{crit}	F	P-value	F_{crit}	F	P-value	F_{crit}
Material	176.32	1.21×10^{-18}	4.019	1609.12	1.65×10^{-23}	4.260	13.71	0.00111	4.2597
Pattern	22.638	7.24×10^{-8}	3.168	10.186	0.00063	3.403	0.286	0.75400	3.4028
Interaction	4.474	0.0159	3.168	50.372	2.57×10^{-9}	3.403	2.00	0.15727	3.4028

Table 6. Two-way ANOVA results of porosity parameters, air permeability and thermal conductivity of samples

Source of variation	d_1 / µm			d_{sr} / µm			P / %		
	F	P-value	F_{crit}	F	P-value	F_{crit}	F	P-value	F_{crit}
Material	323.814	4.77×10^{-10}	4.747	0.5463	0.47405	4.747	1.161	0.3025	4.7472
Pattern	9321.51	7.08×10^{-20}	3.885	331.676	3.15×10^{-11}	3.885	181.288	1.08×10^{-09}	3.8853
Interaction	1086.30	2.75×10^{-14}	3.885	18.3108	0.00023	3.885	1.706	0.2228	3.8853
	OA / %			Air permeability, m min^{-1}			Thermal conductivity, W m^{-1} K^{-1}		
	F	P-value	F_{crit}	F	P-value	F_{crit}	F	P-value	F_{crit}
Material	6.112	0.0294	4.747	14.711	0.00033	4.020	128225.5	1.51×10^{-25}	4.747
Pattern	187.28	8.95×10^{-10}	3.885	130.119	2.23×10^{-21}	3.168	7118.62	3.57×10^{-19}	3.885
Interaction	1.984	0.1802	3,.885	0.33038	0.7201	3.168	407.35	9.35×10^{-12}	3.885

Table 7. Two-way ANOVA results of UV parameters

Source of Variation	UPF			T / %			R / %		
	F	P-value	F_{crit}	F	P-value	F_{crit}	F	P-value	F_{crit}
Material	455.505	6.52×10^{-11}	4.7472	702.030	5.12×10^{-12}	4.7472	803.807	2.3×10^{-12}	4.7472
Pattern	74.376	1.73×10^{-07}	3.8853	81.045	1.07×10^{-07}	3.8853	1.05757	0.3776	3.8853
Interaction	21.624	0.00010	3.8853	1.2028	0.3341	3.8853	48.6029	1.76×10^{-06}	3.8853

	A / %		
	F	P-value	F_{crit}
Material	2599.46	2.13×10^{-15}	4.7472
Pattern	72.1478	2.05×10^{-07}	3.8853
Interaction	42.678	3.51×10^{-06}	3.8853

The warp density of the woven samples (Table 2) is quite similar to the on-loom warp density (40 ends/cm). An increase in densities is observed in the weft. Crimp is higher in warp direction in samples with cotton in weft direction. Woven samples with thinner wefts reach the highest density in the weft and vice versa. This is also reflected in the density and thickness. The samples with cotton in the weft direction are the thickest and have greater mass, while the samples with Lyocell-Clima are 10 % thinner and have 6 % less mass per unit area. The samples with interchanging double weave (samples 3 and 6) have the largest thickness indicating the voluminosity of the samples.

All samples with interchanging double weave have significantly higher air permeability than samples with self-stitched double weave, although they have the greatest thickness and density. In addition, smaller diameter of the Lyocell-Clima thread results in the highest air permeability. In fabrics with interchanging double weave, the threads are loose in the fabric, and the many interstices allow greater air permeability; the looseness of the weave is crucial for the air permeability between the threads. In fabrics with self-stitched double weave, the threads lie compactly next to each other, so there are fewer spaces between the threads, resulting in poorer air permeability. The influence of the weave structure is very clear. We further strengthen the results by determining the porosity parameters. The samples with the interchanging double weave, samples 3 and 6 with the highest value of air permeability have the largest d_1, d_m, P and OA, and sample 6 has larger number of pores per surface area, which further confirms/explains the results. T is also highest for samples 3 and 6. Such a difference does not exist between samples 1, 2, 4 and 5. High correlation between d_m, P and OA with air permeability (corr. from 0.91 to 0.97) confirms the influence of porosity parameters on air permeability. Here we can confirm the comparability of the open area results measured by the Jakšić method (P) and the results obtained by image analysis (AO).

Considering the raw material, all samples with Lyocell-Clima in the weft direction have higher air permeability, values of d_1, d_m, number of pores, OA and T, which we attribute to the consequence of the smaller diameter of the yarn compared to the cotton weft.

Figures 5 show pore size distributions for samples with cotton and with Lyocell- Clima in weft direction.

The trend of the curves in the diagram is similar for both materials. Samples with interchanging double weave (samples 3 and 6) differ from the others.

Samples 3 and 6 are similar, about 36 % of all pores are 25 -22 µm in diameter, 32 % are about 14 µm, 7-10 % of all pores are 46 µm in diameter and larger. In samples 1, 4 and 5, about 57-64 % of all pores have a diameter of 15-21 µm, 8 % of all pores have a diameter of 46 µm and larger. In sample 2, 70 % of pores have a diameter of 17 µm, 1 3 % are about 43 µm in size, and 6 % of all pores have a diameter of 58 µm and larger.

We wanted to confirm that the air permeability of samples with higher fractions of smaller pores is lower than that of samples with lower fractions of larger pores.

The highest UV protection factor (UPF) exhibited the sample 2 with cotton in weft direction, smaller pattern, and self-stitch double weave, and the sample 1 with cotton weft and larger square pattern, and only these two samples meet the classification of good protection (UPF = 16). None of the other fabrics provide good UV protection. The best protection is provided by fabrics made of cotton yarn with the largest diameter that affects the covering area. It is obvious that the size of the pattern does not affect the UPF, unlike the material from which it is made.

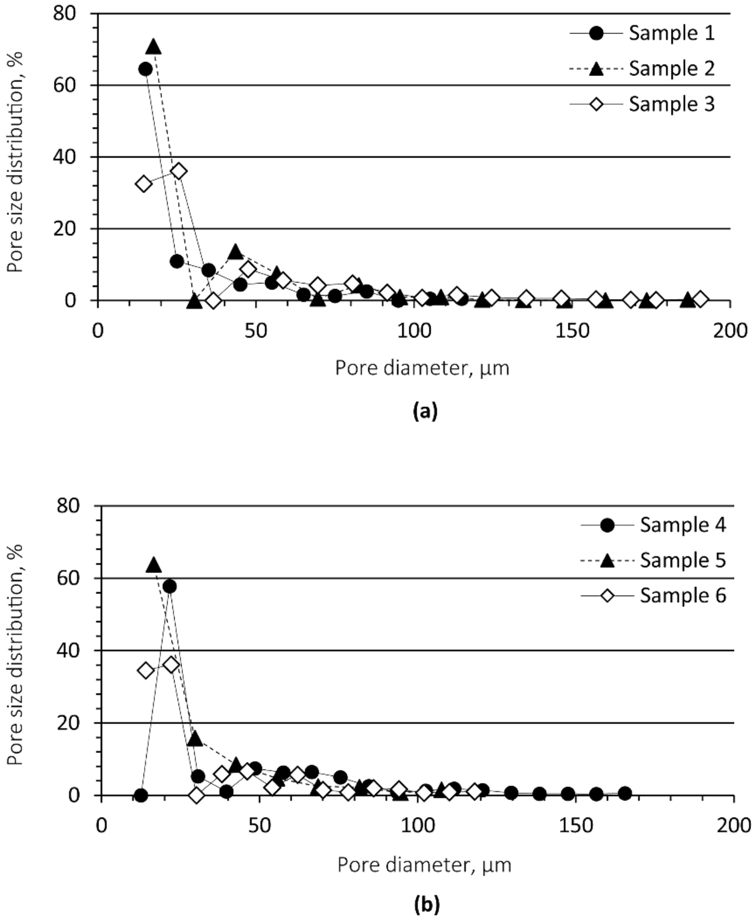

Figure 5. Pore size distribution curve of the samples with cotton (a) and Lyocell-Clima (b) in weft direction

A higher *T* was demonstrated for fabrics with an interchanging double weave, which is less compact and has a larger open area than fabrics with a self-stitched double weave. This is evident by inspecting Figure 4 and the results of the *OA* data in Table 3. Despite the difference in density, the *T* value is related to the yarn diameter, with the lowest values obtained for samples with cotton in the weft direction (yarn with the largest diameter). The highest *R* value is recorded for the sample with a larger pattern (43 %), and the lowest for samples with the smaller pattern and self-stitched double weave (35 %). The pattern size influences appearance of the white weft on the surface - therefore the reflection is greater as the pattern is enlarged. Absorption is highest for samples with cotton in weft direction (62 %) compared to Lyocell-Clima samples (42 %).

3. 1. Statistical processing

Different yarns affected thickness, mass, and crimp, which is expected and confirmed by the two-way analysis ANOVA. The interaction between factors *A* (different material) and *B* (different pattern) is statistically significant as $F > F_{crit}$ and $p < 0.05$. The magnitude of the *F*-statistic is obviously higher for factor *A* than for factor *B* so we can say with greater statistical confidence that the difference in materials has a greater effect on thickness, mass, and crimp in the weft direction (Table 5).

Samples with an unstitched structure have the highest air permeability and the best thermal insulation, as we found.

In the analyses using two-way analysis ANOVA, the interaction between factors *A* and *B* is statistically significant ($F > F_{crit}$ and $p < 0.05$) for the air permeability. The magnitude of the *F*-statistics is higher for factor *B* than for factor *A*. Thus, we can confirm with greater statistical confidence that the difference in patterns and weave has a greater effect on the air permeability (Table 6).

In the analysis of thermal conductivity, the influence of the raw material and the size of the pattern/motif is obvious. In fabrics with patterns with larger geometric areas, where the representation of individual weft threads on the surface is larger, the thermal conductivity is higher than in fabrics with patterns with smaller geometric areas. Fabrics with cotton yarn in the weft direction have the highest thermal conductivity. Better thermal insulators are fabrics with Lyocell-Clima in the weft. High/strong negative correlations (corr. -74) between the thermal conductivity and air permeability and between the thermal conductivity and d_1 (corr. -78) were demonstrated. The application of the two-way analysis ANOVA shows that different materials and consequently the pattern size influence the thermal conductivity. The difference in materials has a greater influence on the thermal conductivity, but interactions between the material and the pattern can be also observed (Table 6).

In the statistical analyses of UV parameters, the interaction between factors *A* and *B* is statistically significant ($F > F_{crit}$ and $p < 0.05$). The magnitude of the *F* statistic is higher for factor A than for factor *B*. We can confirm with greater statistical confidence that the difference in materials has a greater effect on all UV parameters than different patterns (Table 7).

4. CONCLUSION

We have found that the permeability properties of the fabric are influenced not only by the basic design parameters, but also by the size and shape of the jacquard pattern. The design of the pattern influences the frequency of thread interlacing, the frequency of thread transition from the back to the front side of the fabric and vice versa, and the frequency of floating of individual threads.

We can conclude that the thickness of the fabrics is not always an indicator of the permeability properties of the fabric, generalising that thicker fabrics are less breathable. The study shows that the compactness of the weave and the yarn diameter are also important. Thus, it was demonstrated that all samples with interchanging double weave have significantly higher air permeability than samples with self-stitched double weave, even though they have the greatest thickness and density. In addition, a smaller diameter of the Lyocell Clima thread results in the highest air permeability.

When considering the thermal conductivity of fabrics, along with the size of the pattern/motif, the influence of the raw material is obvious. For larger geometric patterns, where the percentage of weft yarns on the surface is larger, the thermal conductivity is higher than for fabrics with patterns with smaller geometric areas. Fabrics with cotton yarns in the weft have lower thermal insulation than fabrics with Lyocell-Clima in the weft, which is obviously due to the functional yarn used. However, the statistical analysis confirmed that the raw material has a greater influence on the thermal conductivity than the pattern size.

The jacquard fabrics used in this study are not designed to provide adequate UV protection and, if used for protective purposes, would require additional finishing for UV protection. Nevertheless, we were able to investigate the effects of the type of the threads used, the compactness of the weave reflected in the position and thread, on UV protection properties of the samples. The best protection is provided by the fabric made of cotton yarn with the largest diameter, which affects the covering area. It is obvious that the size of the pattern does not affect the UPF, unlike the raw material from which it is made, which was confirmed by the statistical analysis.

When designing jacquard fabrics for a specific purpose where permeability properties are important, great attention should be paid to pattern size, weave and the use of functional yarns.

REFERENCES

[1] Decrette M, Mourad S, Osselin JF, Drean JY. Jacquard UNIVAL 100 parameters study for high-density weaving optimization. *J Ind Text*. 2016; 45(6): 1603-1618. https://doi.org/10.1177/1528083714567241

[2] Yavuzkasap AYakta D, Çaglar Cinperi N, Özdemir H. Investigating the effect of self-cleaning treatment on the air permeability, stain removal and water repellency properties of functionalized double jacquard woven upholstery fabrics. *Ind Textila.* 2019; 70 (6): 512-518. http://doi.org/10.35530/IT.070.06.1483 .

[3] Akgün M, Ulu İ, Erkek E. The effect of properties and positioning of yarns used in jacquard woven fabric pattern on abrasion resistance. *Tekst*. 2021; 28 (123): 180-190. https://doi.org/10.7216/1300759920212812303 .

[4] Süle G. The Effects of Jacquard Woven Fabric Constructional Parameters and Elastane Yarn on Bending Rigidity. *J Eng Fibers Fabr*. 2015; 10 (2): 164-170. https://doi.org/10.1177/155892501501000219 .
[5] Kostajnšek K, Dimitrovski K, Kadoğlu H, Çelik P, Başal Bayraktar G, Bedez Üte T, Duran D, Ertekin M, Demšar A, Bizjak M. Functionalization of Woven Fabrics with PBT Yarns. *Polymers*. 2021; 13 (2), 260: 1-19. https://doi.org/10.3390/polym13020260
[6] Rijavec T, Bukošek V. Novel fibres for the 21st Century. *Tekstilec*. 2009; 47: 13-25. http://www.tekstilec.si/wp-content/uploads/2009/11/Novel-Fibres-for-the-21st-Century.pdf
[7] Iqbal K, Sun D. Development of thermal stable multifilament yarn containing micro-encapsulated phase change materials. *Fibers Polym*. 2015; 16 (5): 1156-1162. https://doi.org/10.1007/s12221-015-1156-9 .
[8] Ng WS, Hu H. Woven Fabrics Made of Auxetic Plied Yarns. *Polymers*. 2018; 10 (2): 226. https://doi.org/10.3390/polym10020226 .
[9] Kostajnšek K, Urbas R, Dimitrovski K. A New Simplified Model for Predicting the UV-Protective Properties of Monofilament PET Fabrics. *Autex Res J.* 2019; 19 (3): 263-270. https://doi.org/10.1515/aut-2018-0041 .
[10] Kocić AA, Bizjak M, Popović D, Poparić, GB, Stanković, SB. UV protection afforded by textile fabrics made of natural and regenerated cellulose fibres. *J Clean Prod*. 2019; 228: 1229-1237. https://doi.org/10.1016/j.jclepro.2019.04.355 .
[11] Ghane M, Ghorbani E. Investigation into the UV-Protection of Woven Fabrics Composed of Metallic Weft Yarns. *Autex Res J.* 2016; 16 (3): 154-159. https://doi.org/10.1515/aut-2015-0021 .
[12] Ng MCF, Zhou J. A Study on Figured Double-face Jacquard Fabric with Full-color Effect. *Text Res J.* 2009; 79 (10): 930-936. https://doi.org/10.1177/0040517508095603 .
[13] Bilisik K, Demir F. Dimensional and mechanical characterization of newly developed denim fabrics based on experimentally determined property-structural pattern relations for upholstery applications. *Fibers Polym*. 2010; 11: 521-530. https://doi.org/10.1007/s12221-010-0521-y .
[14] Bizjak Bojič M, Dimitrovski K. The Role of Technological Parameters at Woven Fabrics Construction. *Int J Polym Mater*. 2000; 47(4): 603-612. https://doi.org/10.1080/00914030008031315 .
[15] Kostajnšek K, Dimitrovski K. Multilayer cotton fabric porosity and its influence on permeability properties. *Tekstilec.* 2018; 61 (4): 254-264.https://doi.org/10.14502/Tekstilec2018.61.254-264 .
[16] Zampetakis A, Katsaros G. Optimization of wear comfort parameters for summer cloths *Ind. Textila*. 2008; 59(5): 213-220. https://www.researchgate.net/publication/294419954_Optimizing_the_wear_comfort_parameters_for_summer_clothes .
[17] Dimitrovski K. Določanje odprte površine za pretok v tekstilijah. *Tekstilec*. 1997; 40 (1-2): 5-10. (in Slovenian)
[18] Dimitrovski K. Metode za določanje poroznosti v tekstilijah. *Tekstilec*.1995; 38 (5):121-123. (in Slovenian)
[19] Kostajnšek K., Zupin Ž, Hladnik A, Dimitrovski K. Optical assessment of porosity parameters in transparent woven fabrics. *Polymers*. 2021; 13(3): 408. https://doi.org/10.3390/polym13030408 .
[20] Jakšić D, Jakšić N. Assessment of Porosity of flat textile fabric. *Text Res J.* 2007; 77 (2): 105-110. https://doi.org/10.1177/0040517506065892 .
[21] Dobnik Dubrovski P. Volume porosity of woven. *Text Res J*. 2000; 70: 915-919. https://doi.org/10.1177/004051750007001011
[22] Arahne CAD/CAM for weaving. https://www.arahne.si/sl/. Accessed April 7, 2022.
[23] SIST EN 1049-2: Textiles - Woven fabrics - Construction - Methods of analysis - Part 2: Determination of number of threads per unit length (ISO 7211-2:1984 modified). 1999
[24] SIST EN 12127: Textiles - Fabrics - Determination of mass per unit area using small samples. 1999
[25] SIST EN ISO 5084: Textiles - Determination of thickness of textiles and textile products. 1999
[26] SIST EN ISO 9237: Textiles - Determination of permeability of fabrics to air. 1999
[27] DIN 52 612: Testing of Thermal Insulating Materials; Determination of Thermal Conductivity by the Guarded Hot Plate Apparatus; Test Procedure and Evaluation. 1979
[28] EN 13758-1:2001: Textiles - Solar UV protective properties - Part 1: Method of test for apparel fabrics. 2006
[29] Tàpias M, Ralló M, Escofet J, Algaba I, Riva A. Objective measure of woven fabric's cover factor by Image processing. *Text Res J*. 2010; 80: 35-44. https://doi.org/10.1177/0040517509104471 .
[30] Ragab A, Fouda A, El-Deeb H, Abou-Taleb H. Determination of Pore Size. Porosity and Pore Size Distribution of Woven Structures by Image Analysis Techniques. *J Textile Sci Eng.* 2017; 7: 1-9. https://doi.org/10.4172/2165-8064.1000314 .
[31] Kostajnšek K, Dimitrovski K, Hladnik A. Use of image analysis for the determination of open area fraction in woven fabrics. In: *Proceedings of 13th Autex Conference.* Dresden, Germany, 2013, pp. 1-5.
[32] Kostajnšek K, Zupin Ž, Hladnik A, Dimitrovski K. Optical Assessment of Porosity Parameters in Transparent Woven Fabrics. *Polymers*. 2021; 13(3): 408. https://doi.org/10.3390/polym13030408.

Ocena svojstava propustljivosti žakar tkanina dobijenih tehnološkim postupkom

Klara Kostajnšek i Matejka Bizjak

Univerzitet u Ljubljani, Prirodnotehnički fakultet, Katedra za tekstil, grafiku i dizajn, Ljubljana Slovenija

(Naučni rad)

Izvod

U okviru ovog istraživanja ispitivan je uticaj određenih parametara dizajna na svojstva propustljivosti žakar tkanina. Proizvedeno je šest tkanina od iste pamučne pređe za osnovu i sa istim tehnološkim parametrima razboja. Tkanine su izrađene od dve različite vrste pređa za potku (pamuk i Lyuocell Clima), u dve različite veličine dezena (sa većim i manjim monohromatskim površinama) i dve grupe dvostrukih keper prepletaja (dvoslojne tkanine spojene sopstvenim žicama, dvoslojne tkanine sa mestimičnom zamenom pozicije gornje i donje tkanine). Dokazan je značaj veličine i raspodele motiva, vrste prepletaja i vrste pređa korišćenih za izradu ispitivanih žakar tkanina. Takođe je ustanovljeno da je uticaj ovih parametara na svojstva propustljivosti u bliskoj vezi sa estetskim karakteristikama tkanina. Sve dvoslojne tkanine u prepletaju gde dolazi do mestimične zamene pozicije gornje i donje tkanine imaju značajno veću propustljivost vazduha u poređenju sa dvoslojnim tkaninama koje su spojene sopstvenim žicama. Očigledan je uticaj sirovinskog sastava i veličine motiva na toplotnu provodljivost žakar tkanina. Tkanine sa većim površinama motiva, gde je izraženije prisustvo potke, odlikuju se većom toplotnom provodljivošću. Sa druge strane, pokazalo se da, za razliku od sirovinskog sastava, veličina motiva ne utiče na ultraljubičasti zaštitni faktor (engl. ultraviolet protection factor, UPF) žakar tkanina.

Ključne reči: žakar motiv; spajanje sopstvenim žicama / spajanje zamenom pozicije gornje i donje tkanine; poroznost; propustljivost vazduha; toplotna provodljivost