# Research into the effects of pigment printing parameters on sensorial comfort to guide garment designers in the apparel industry

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ARZU KILIÇ

**ABSTRACT – REZUMAT**

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*The printing process, which is an aesthetically significant process subprocess in garment design, has the potential to affect the physical properties and sensory comfort of the fabric. Due to its low cost and very fast process period and the fact that it is environmentally conscious, pigment printing is widely used in the textile industry. This study it's aimed to guide the designers in the selection of printing type for piece printing according to the fabric type by considering the print area and print pattern in the apparel industry. For this purpose, the effects of commonly used pigment printing pastes on the physical properties and sensorial comfort in knit fabrics of different constructions were studied. To that end, two different patterns were applied to three knit fabrics with different constructions by using three different pigment printing methods to assess several features of the fabrics, namely, print quality, air permeability, roughness, compressibility and bending. As a result of this study, it was observed that the printing application method and print pattern design have a significant impact on the handle properties of the fabric. Consequently, it was revealed that it is necessary to take into account the printing application method and print pattern design in the process of printed clothing design. Among the print types evaluated in this study, the best print type was determined in terms of sensorial comfort and physical properties. In addition, suggestions were made on the issues to be considered during the print design of print types with worse comfort and physical properties.*

***Keywords:*** *sensorial comfort, printing, air permeability, roughness, compressibility, bending, print design*

**Cercetări privind influența parametrilor de imprimare cu pigmenţi asupra confortului senzorial pentru a ghida designerii de articole de îmbrăcăminte din industria de îmbrăcăminte**

*Procesul de imprimare, care reprezintă un subproces semnificativ din punct de vedere estetic în proiectarea articolelor de îmbrăcăminte, are potențialul de a afecta proprietățile fizice și confortul senzorial ale materialului textil. Datorită costului scăzut, a timpului de proces foarte scurt și a faptului că are o responsabilitate ecologică, imprimarea cu pigment este utilizată pe scară largă în industria textilă. Acest studiu îşi propune să ghideze designerii pentru selectarea tipului de imprimare pentru imprimarea piesei în funcție de tipul de material textil, luând în considerare zona de imprimare și modelul de imprimare în industria de îmbrăcăminte. În acest scop, au fost studiate influența pastelor de imprimare și pigmentare utilizate în mod obișnuit asupra proprietăților fizice și confortului senzorial ale tricoturilor cu diferite structuri. În acest scop, două modele diferite au fost aplicate la trei tricoturi cu structuri diferite, folosind trei metode diferite de imprimare cu pigment pentru a evalua mai multe caracteristici ale materialelor textile, și anume, calitatea imprimării, permeabilitatea la aer, rugozitatea, compresibilitatea și îndoirea. Ca rezultat al acestui studiu, s-a observat că metoda de aplicare a imprimării și designul modelului de imprimare au un impact semnificativ asupra proprietăților de tuşeu ale materialului textil. În consecință, s-a evidenţiat că este necesar să se țină cont de metoda de aplicare a imprimării și de designul modelului de imprimare în procesul de proiectare a îmbrăcămintei imprimate. Dintre tipurile de imprimare evaluate în acest studiu, cel mai corespunzător tip de imprimare a fost determinat din punct de vedere al confortului senzorial și al proprietăților fizice. În plus, au fost enunțate sugestii cu privire la aspectele care trebuie luate în considerare la proiectarea tipurilor de imprimare cu proprietăți fizice şi de confort mai slabe.*

***Cuvinte-cheie****: confort senzorial, imprimare, permeabilitate la aer, rugozitate, compresibilitate, îndoire, design de imprimare*

## INTRODUCTION

In recent years, the consumer's decision to buy a product is determined not only by the clothing's aesthetic and design features but also by the element of comfort. In their daily lives, a consumer expects a high level of comfort from their preferred clothing and requires the clothing to feel comfortable.

Clothing comfort is defined as the state where the physiological, psychological, and physical harmony between the human body and its environment is gratifying. Clothing comfort is studied as two basic components which are psychological comfort and physiological comfort. Physiological comfort includes the subcomponents of thermal physiological comfort, sensorial comfort and body movement comfort [1].

The sensorial comfort of the skin characterizes the sensory input that is caused by attack styles' direct mechanical contact with the skin [2]. Sensorial comfort expresses the manner of sensory perception (sight, hearing, etc.) the surface of a certain textile evokes on the wearer and the level of gratification [3, 4], sensorial comfort is usually defined by the watch the consumer feels when the fabric contacts the skin, such as prickly, itchy, rough or smooth [5]. Sensorial comfort is a clothing field that is related to touch, humidity, pressure and thermal sensations [6]. To ensure a high level of sensorial comfort, the material that contacts the skin needs to have a structure and flexibility that would cause a pleasing sense of touch (softness, slickness), not stick to the skin, and not cause itchiness or allergic reactions. Sensorial clothing comfort is identified through several features such as feel, wettability, skin adhesion strength, surface friction factor and fabric stiffness [7].

Sensorial comfort is a multidimensional concept and impossible to define through a single physical property. Sensorial comfort is related to several fabric features such as roughness, density, flexibility, elasticity, compressibility, surface friction and thermal feature [8]. These fabric properties have been contrasted in several studies resulting in evaluations of the sensorial comfort of the clothing.

Fibre type, yarn structure, fabric structure and finishing processes, the fabric goes through are the parameters that affect sensorial comfort [5, 8–11]. Several studies have been conducted on these parameters and the state of impact of these parameters on sensorial comfort has been studied. Certain parameters focused on these studies are the impact of various fibres, mixture ratios, cross sectional fibres on sensorial comfort [5, 9, 12–15], the effect of fabric structures on sensorial comfort [2, 10, 11, 13–15] and the effect of finishing processes on sensorial comfort [15–19]. Salman et al (2021), observed that the washing process has a positive impact on the softness and resilience score while drapability, wrinkle recovery, and smoothness decrease after washing the fabric [15]. In the study conducted by Özgüney et al (2009), it was indicated that all finishing processes affect the feel of the fabric in terms of increasing roughness, but that pigment printing was the most effective bare finish process. In addition, it was also exhibited that even though the mercerization process performed before dyeing and printing result in improvements and fabric properties, impacts fabric softness negatively [17]. This study was focused on pigment printing due to the use of pigments as the major colouration method, with approximately 50% of the world textile printing market in conventional textile screen-printing [20].

In the apparel industry, where fast fashion dominates the market, piece printing becomes a frequently preferred method. Although it is a fact that the printing method and printing pattern design should be taken into account in the garment design process, the number of publications on this subject is quite limited. In today's fashion understanding, where the importance of wearing comfort takes precedence over aesthetic concerns, it is clear that the effect of the printing process on comfort is as important as the printing pattern design in customer preferences.

The objective of the study is to evaluate pigment printing in terms of physical properties and sensorial comfort properties to guide garment designers in the apparel industry. In mass production, a designed garment is produced in several colour variations and the printing pattern's dimensions vary regarding the printing area. Therefore, instead of printing on light coloured fabrics, a dark blue dyed fabric was chosen as a substrate. In total, three different water-based pigment printing pastes commonly preferred by the apparel manufacturers were prepared in different colours, and the commonly used knit fabric constructions, single jersey, rib and pique were evaluated in this study. Moreover, it is a fact that pigment printing reduces elasticity and therefore results in lower compressibility values due to the formation of a sticky film on the fabric surface [17]. Therefore, to determine the effect of these printing parameters on sensorial comfort properties, the printed knit fabrics' dimensional properties such as mass per unit area, thickness and compressibility; air permeability, handle properties including surface kinetic friction coefficient, bending properties and the print quality were tested and analyzed by using statistical evaluation.

## MATERIAL AND METHOD

### Material

It is aimed to guide the designers in the selection of printing paste according to the fabric type by considering the print area and print pattern in piece printing. In this context, three different commonly used water-based pigment printing pastes in piece printing were procured (Anadolu Kimya, Turkiye). As the substrates, generally preferred knit fabric constructions, single jersey, rib and pique were purchased (Ekoten Fabrics, Turkiye), which were dyed to dark blue colour with dye stuff. As the aim of the study, the commercial products were procured and the focus was on determining the effect of these commercial products on the physical properties and sensorial comfort properties, therefore the contents of the printing pastes were not researched.

In table 1, the raw materials, the yarn numbers and the knitting structures were presented. As stated in the literature, the base colour of the fabric is influential in the printing process in terms of printing quality. When a darker colour is printed on a lighter base, the visual of the print is not affected and the colour is distinctly visible. However, when a lighter colour is printed on a darker base, the colour of the print becomes obscured and clear printing is not possible [22]. For this reason, especially when printing a lighter coloured pattern on a darker coloured base, the printing is performed two or more times to get the pattern clearer. Besides, to make the colours of dark-coloured patterns printed on dark-coloured bases more clearly visible, a printing paste is used. In addition to these challenges, in the apparel industry, the designers give priority to the garment design over the clothing comfort as well as the producibility of the garment. Therefore, as in the objective of the study, the dark blue base fabric was determined for the results obtained to guide the designers as well as the manufacturers.

Table 1

| THE PHYSICAL PROPERTIES OF FABRICS | | | |
|---|---|---|---|
| **Sample number** | **Raw materials** | **Yarn number (Ne)** | **Knitting structure** |
| **Fabric 1** | 50% Co – 50% PES | 30/1 | Single Jersey |
| **Fabric 2** | 50% Co – 50% PES | 30/1 | 1x1 Rib |
| **Fabric 3** | 50% Co – 50% PES | 30/1 | Pique |

Pigment printing, which dominates the piece printing market in the apparel industry, is the printing type with the lowest cost and is highly preferred in the textile industry because the processing time is quite fast and does not harm the environment [21]. Moreover, it was indicated that all finishing processes affect the feel of the fabric in terms of increasing roughness, but that pigment printing what's the most effective and the most widely used bare finish process [17].
However, a review of the literature revealed that they were not a sufficient number of studies conducted on the effect of pigment printing on fabric handle properties including surface kinetic friction coefficient and bending properties. Therefore, taking into account various fabric structures, printing patterns and various pigment printing types, the effects of the pigment printing process extensively used in the industry on the physical properties and sensorial comfort properties of the fabric were investigated in this study.
In light of this information, the print parameters are displayed in table 2. As mentioned before, since it is difficult to print a lighter colour on a darker base, two layers of white printing paste (PT3) and one layer of black printing paste (PT2) were used. In addition, in emboss printing, it was stated by the manufacturers that the most preferred colour is white, therefore the print colour was chosen as white (PT1).
In the apparel industry, printing patterns are infinite and thousands of new patterns are designed every day. Moreover, the printing patterns' dimensions vary regarding the printing area as well as the body size. Therefore, investigating the effect of print patterns on clothing comfort is of challenge, as almost impossible to simulate all printing patterns. Thus, to achieve an evaluation of the effect of printing on sensorial comfort, two different patterns were determined (figure 1); a striped pattern of 1 cm print + 1 cm space (PP1) and a solid square pattern (PP2). The print area dimension was set at 20*20 cm to simulate larger print patterns and also to capture the measuring areas of the testing instruments. Table 3 presents all acquired samples; two different patterns printed on three knit fabrics of different constructions using three different printing pastes, including the control groups. Sample fabrics were prepared as 30*30 cm dimensions.

Print pattern code PP1 Print pattern code PP2

Fig. 1. Samples for PP1 and PP2

Table 2

| PRINT PARAMETERS | | | |
|---|---|---|---|
| **Print type code** | **Printing recipe** | **Printing process** | **Printing machine** |
| PT 1 | • 50 g/kg White Waterbased Pigment Print (Sp 240 by Antex / Anadolu Kimya)<br>• 50 g/kg Emboss Waterbased Pigment Print (Sp 280 by Antex / Anadolu Kimya) | Printing + Fixing (160°C 2–2.5 minutes) | |
| PT 2 | • 48 g/kg Waterbased Pigment Print Base (XP 10 by Antex / Anadolu Kimya)<br>• 48 g/kg Transparent Waterbased Pigment Print (Sp 220 by Antex / Anadolu Kimya)<br>• 4 g/kg Black Waterbased Pigment Print (Fa 3010 by Antex / Anadolu Kimya) | Printing + Fixing (160°C 2–2.5 minutes) | ROQ Oval Evolution P40 XL-18 Head |
| PT 3 | • 90 g/kg White Waterbased Pigment Print (Sp 240 by Antex / Anadolu Kimya)<br>• 10 g/kg Transparent Waterbased Pigment Print (Sp 220 by Antex / Anadolu Kimya) | First layer Printing + Drying (70–80°C/7–8 seconds) + Second layer Printing + Fixing (160°C 2–2.5 minutes) | |

Table 3

| EXPERIMENTAL GROUPS | | | |
|---|---|---|---|
| **Sample number** | **Knitting structure** | **Print type code** | **Print pattern code** |
| 1 | Single Jersey | without print | without print |
| 2 | | PT 1 | PP1 |
| 3 | | | PP2 |
| 4 | | PT 2 | PP1 |
| 5 | | | PP2 |
| 6 | | PT 3 | PP1 |
| 7 | | | PP2 |
| 8 | 1*1 Rib | without print | without print |
| 9 | | PT 1 | PP1 |
| 10 | | | PP2 |
| 11 | | PT 2 | PP1 |
| 12 | | | PP2 |
| 13 | | PT 3 | PP1 |
| 14 | | | PP2 |
| 15 | Pique | without print | without print |
| 16 | | PT 1 | PP1 |
| 17 | | | PP2 |
| 18 | | PT 2 | PP1 |
| 19 | | | PP2 |
| 20 | | PT 3 | PP1 |
| 21 | | | PP2 |

**Method**

Before performing the tests, all samples were conditioned for at least 24 hours in standard atmosphere conditions (constant ambient temperature of 20±2 °C, relative humidity of 65±2%) (TS EN ISO 139).

*Mass per unit area and thickness*

The mass per unit area weight of the samples they're measured in five repetitions according to TS EN 12127 standards. The thickness test for the samples was performed in accordance with TS 7128 EN ISO 5084 standards.

*Paste add-on*

Paste add-on values are one of the important factors that determine the quality of the print. Paste add-on values were calculated using equation 1 [23]:

$$\textit{Paste add-on} = \frac{E_2 - E_1}{A} \quad (1)$$

Where $E_2$ is the after-printing weight of the fabric samples, $E_1$ – the before-printing weight of the fabric samples, and $A$ – the area of samples.

*Colour measurement values*

The $L^*$, $a^*$, $b^*$ values of printed fabrics were measured using a HunterLab UltraScan PRO spectrophotometer. The colour difference values (ΔE) of the samples were calculated by reference to the back side of the unprinted sample and using equation 2 [23, 24].

$$\Delta E = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \quad (2)$$

where $\Delta E$ is the colour difference value, $L^*$ – the brightness value, $a^*$ – red/green colour value, $b^*$ – yellow/blue colour value.

*Air permeability*

Air permeability is an important property, which determines the ability of air to flow through the fabric. Ten repetitions were conducted for each fabric using the Textest FX 3300 air permeability instrument (Textest Instruments AG, Switzerland) at a pressure of 100 Pa in a 5 $cm^2$ measurement area according to TS 391 EN ISO 9237 standards.

*Compressibility*

The response of fabric thickness to the forces applied perpendicular to its surface is known as the fabric compressibility behaviour. The fabric compatibility tests the performed via digital thickness gauge in 5 repetitions for each experimental group. To determine the thickness loss that occurred in the samples, compression values were measured during the dynamic loading/charging process. The compression values of weights were coded from A to G in a way to indicate the total compression value. The pressure values applied by the presser foot without extra weight were as follows; 2 kPa, A: 5 kPa, B: 10 kPa, C: 20 kPa, D: 50 kPa, E: 100 kPa, F: 150 kPa, G: 200 kPa. During the measurement of compressibility, the measurement was started as the presser foot was logged word onto the sample, the weights were carefully added one by one, and the thickness for each weight was recorded.

*Kinetic friction coefficient*

The kinetic friction coefficient is one of the significant indicators in determining fabric handle [25, 26]. For the measurement of the fabric kinetic friction coefficient, the Frictorq (Fabric friction tester) device was used. The Frictorq device uses rotation momentum to determine the kinetic friction coefficient of the fabric [27]. Measurement of five repetitions was performed for each fabric in accordance with ISO 21182 standards. Following the measurement, the kinetic friction coefficient value (µkin) was calculated using rotation power values varying throughout the movement of the device lasting for 20 seconds.

*Circular bending rigidity*

The circular bending rigidity tests for the fabrics were performed according to ASTM D 4032. According to this method, the force resulting from the act of the simple fabric being pushed through a circle with the help of a piston is measured as an indicator of the bending feature of the fabric [17]. In this process, the maximum force required to push the fabric through the hole is an indicator of Fort fabric rigidity (resistance to bending) [28].

*Statical analyses*

SPSS software was used for the statistical analysis of the data acquired in the study. One Way Anova and univariate tests were performed to investigate the individual effects of each parameter and interaction on thickness, kinetic friction coefficient, circular bending rigidity and air permeability. Post hoc analyses were made using the Duncan test to determine which mean values of the groups were significant. All test results were considered at a 0.05 significance level.

## RESULTS AND DISCUSSION

The mean values of the test results for the group used in the experiment conducted to investigate the effect of printing on sensorial comfort are presented in table 4.

*Mass per unit area*

The mean mass per unit area data for the samples is included in table 4. When the data is considered, the highest values for mass per unit area were observed as expected in samples that were printed by PT3 resulting from the two-layered printing structure. The PT3 printing type is followed by PT1 and PT2 printing types. The statistical analysis of the data indicates that the difference between samples without printing and those with printing in terms of weight is statistically significant ($p$ = 0,000); however, the difference between PT1 and PT2 ($p$ = 0.963), the difference between PT1 and PT3 ($p$ = 0,999) and the difference between PT2 and PT3 ($p$ = 1.000) are not statistically significant.

*Thickness*

There is a significant relationship between fabric thickness and compressibility behaviour and feel, fluidity, comfort and thermal insulation [29, 30]. It was observed that the mean thickness values for fabric samples ranged between 0.429 mm and 1.141 mm (table 4). According to the Oneway Anova test, the effect of the fabrics' knit structure ($p$ = 0.001), printing type ($p$ = 0.000) and printing pattern ($p$ = 0.000) on fabric thickness is statistically significant. For all three knit structures, it was observed that the PT1 printing type had the highest values in terms of thickness and this is considered to stem from the fact that the PT1 printing type is embossed printing. The samples printed according to PT3 and PT2 printing types were also observed to follow these samples. Considering thickness in the statistical analysis conducted, the difference between printing types is statically significant; the difference between PT1 and PT2 at ($p$ = 0.000), the difference between PT1 and PT3 at ($p$ = 0.000) and the difference between PT2 and PT3 at ($p$ = 0.006). On the other hand, there was no significant difference between PP1 and PP2 patterns.

*Paste add-on*

The paste add-on values of samples are given in table 5. When the data were analyzed, the highest values for the paste add-on were seen in the samples printed with PT3, as expected. It is thought that this situation is caused by the double-layer printing in the

Table 4

MEAN VALUES OF THE TEST RESULTS

| Sample number | Knit structure | Print type | Print pattern | Mass per unit-area (g/m$^2$) | Thickness (mm) | Relative compress-ibility (%) | Friction coefficient (μkin) | Circular bending rigidity (N) | Air permeability (l/m$^2$/s) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Single Jersey | without print | without print | 151 | 0.429 | 0.388 | 0.344 | 3.08 | 659.1 |
| 2 | | PT1 | PP1 | 198.9 | 0.770 | 0.321 | 0.383 | 13.65 | 292.1 |
| 3 | | | PP2 | 230.4 | 0.570 | 0.319 | 0.302 | 35.45 | 0 |
| 4 | | PT2 | PP1 | 175.3 | 0.501 | 0.354 | 0.254 | 3.87 | 309.0 |
| 5 | | | PP2 | 199.6 | 0.499 | 0.339 | 0.227 | 7.87 | 171.2 |
| 6 | | PT3 | PP1 | 249.5 | 0.529 | 0.297 | 0.343 | 6.30 | 305.4 |
| 7 | | | PP2 | 314 | 0.504 | 0.256 | 0.395 | 29.00 | 0 |
| 8 | 1*1 Rib | without print | without print | 188.4 | 0.656 | 0.447 | 0.379 | 4.12 | 963.0 |
| 9 | | PT1 | PP1 | 262.5 | 0.964 | 0.329 | 0.530 | 25.02 | 381.4 |
| 10 | | | PP2 | 289.8 | 0.807 | 0.286 | 0.184 | 58.80 | 0 |
| 11 | | PT2 | PP1 | 223.7 | 0.743 | 0.406 | 0.207 | 7.44 | 513.7 |
| 12 | | | PP2 | 243 | 0.731 | 0.336 | 0.144 | 12.10 | 409.5 |
| 13 | | PT3 | PP1 | 324.2 | 0.797 | 0.345 | 0.281 | 11.65 | 448.3 |
| 14 | | | PP2 | 399.6 | 0.744 | 0.300 | 0.335 | 43.66 | 0 |
| 15 | Pique | without print | without print | 210 | 0.736 | 0.438 | 0.354 | 4.88 | 696.1 |
| 16 | | PT1 | PP1 | 269.5 | 1.141 | 0.346 | 0.498 | 34.44 | 314.2 |
| 17 | | | PP2 | 298.8 | 0.844 | 0.299 | 0.444 | 66.24 | 0 |
| 18 | | PT2 | PP1 | 236 | 0.772 | 0.434 | 0.294 | 8.43 | 445.4 |
| 19 | | | PP2 | 256.2 | 0.763 | 0.359 | 0.257 | 13.66 | 394.9 |
| 20 | | PT3 | PP1 | 333.8 | 0.825 | 0.343 | 0.384 | 34.23 | 325.2 |
| 21 | | | PP2 | 406.9 | 0.778 | 0.331 | 0.271 | 48.69 | 0 |

PT3. This printing type is followed by PT1 and PT2 printing types, respectively. It is also seen that PP1 has lower values than PP2 due to its grid structure. When Paste add-on values are examined in terms of knitting structure, it is seen that the highest values are obtained in 1*1 Rib knitting structure in all three printing types, followed by Pique and single jersey fabrics, respectively.

Table 5

| THE PASTE ADD-ON VALUES OF SAMPLES | | | |
|---|---|---|---|
| **Knit structure** | **Print type** | **Paste add-on values** | |
| | | **PP1** | **PP2** |
| Single Jersey | PT1 | 47.9 | 79.4 |
| | PT2 | 24.3 | 48.6 |
| | PT3 | 98.5 | 163 |
| 1*1 Rib | PT1 | 74.1 | 101.4 |
| | PT2 | 35.3 | 54.6 |
| | PT3 | 135.8 | 211.2 |
| Pique | PT1 | 59.5 | 88.8 |
| | PT2 | 26 | 46.2 |
| | PT3 | 123.8 | 196.9 |

*Colour measurement values*

The colour measurement and DE values of the back sides of fabrics are given in table 6. When the literature is examined, it is seen that if the ΔE value is less than “1”, it is assumed that there is no colour difference between the samples [23].

When the data were examined, it was observed that the lowest ΔE values were obtained in the 1*1 Rib knit structure. In the rib knit structure, ΔE values were found to be lower than “1” in PT2 (0.83) and PT3 (0.96) print types, and it can be said that there is no colour difference between the back surface of the fabric and the unprinted fabric in these two print types. It was seen that ΔE values were close to “1” in PT2 (1,12) and PT3 (1.16) print types in the pique knit structure. For single jersey knit structure, the ΔE values obtained in PT1 (3.84) and PT3 (2.89) print types were greater than “1”, which indicates that there is a colour difference between the back surface of the fabric and the unprinted fabric in these two print types. In the single jersey knit structure, the ΔE value is close to “1” in the samples obtained with the PT2 (1.05) print type, unlike the other two print types. This shows that there is no colour difference between the back surface of the fabric and the unprinted fabric in the PT2 print type in a single jersey knit structure. As a result, in all three knitting structures, the lowest ΔE values were reached with the PT2 printing type, and the highest ΔE values were reached with the PT3 printing type (table 6). When are all the samples are considered for three types of a knit structures, the lowest penetration of printing paste into the fabric was found to be in 1*1 Rib fabrics.

Table 6

| COLOUR MEASUREMENT VALUES OF PRINTED FABRICS (BACK SIDE) | | | | | |
|---|---|---|---|---|---|
| **Knit structure** | **Print type** | **Colour values (back side)** | | | |
| | | **L*** | **a*** | **b*** | **DE** |
| Single Jersey | WP | 32.71 | 3.25 | –34.39 | - |
| | PT1 | 36.51 | 3.02 | –34.83 | 3.84 |
| | PT2 | 32.11 | 2.79 | –33.66 | 1.05 |
| | PT3 | 35.35 | 3.33 | –35.8 | 2.99 |
| 1*1 Rib | WP | 33.57 | 1.6 | –33.19 | - |
| | PT1 | 36.29 | 1.52 | –33.97 | 2.83 |
| | PT2 | 32.76 | 1.42 | –33.32 | 0.83 |
| | PT3 | 33.52 | 1.98 | –34.06 | 0.96 |
| Pique | WP | 32.88 | 2.96 | –34.6 | - |
| | PT1 | 33.2 | 3.14 | –36.14 | 1,58 |
| | PT2 | 31.87 | 2.93 | –35.07 | 1.12 |
| | PT3 | 32.69 | 3.32 | –35.69 | 1.16 |

*Air permeability*

The mean values of air permeability for the samples are displayed in table 4 and the graph created by taking the mean values into account is shown in figure 2.

The properties that displayed a statistically significant impact on the air permeability of the fabrics within the experimental group were observed as knit structure ($p$ = 0.006), printing type ($p$ = 0.000) and printing pattern ($p$ = 0.000).

Univariate tests were conducted to determine the effect of print type and print pattern on air permeability

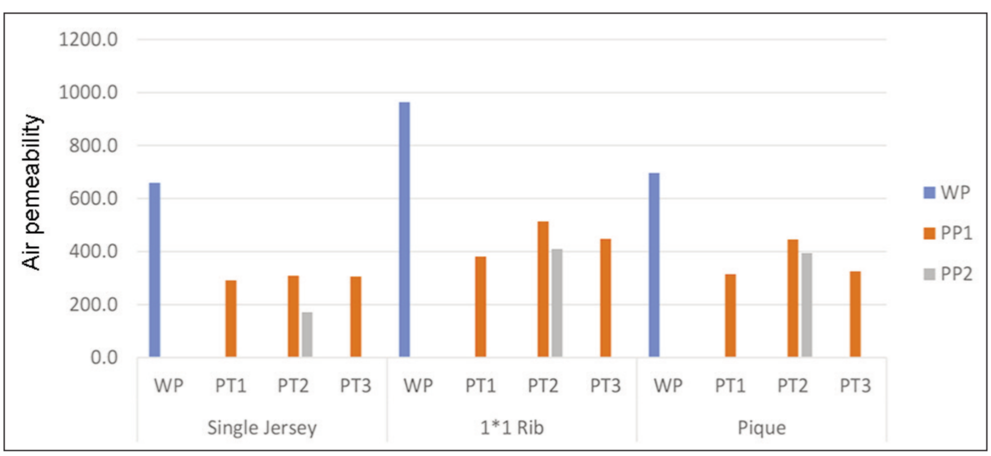


Fig. 2. Air permeability values of samples

according to the types of fabric. The results achieved revealed that the effect of print type ($p$ = 0.000) and knit structure ($p$ = 0.000) on air permeability values were significant (table 7). Moreover, the effect of print type and knit structure interaction on air permeability is statistically significant ($p$ = 0.000). It is believed that, since both print material (observed power: 1.000) and knit structure (observed power: 1.000) have very powerful effects, the interaction between these two variables also becomes significant. When air permeability values are analyzed by taking into account the knit structure, it is seen that the air permeability of the rib knit structure this higher than the other knit structures, similar to what Selli and Turhan [31] found in their study (figure 2).

Air permeability is a test result that is related to the porousness of the fabric [32]. The reason why the highest values are found in rib knit fabrics is thought to be because this type of fabrics has higher porousness because of their different thickness and volume properties.

The interaction between print pattern and knit structure was statistically significant, similar to the interaction of print type and knit structure, due to the dominant effect of the parameters (table 7).

Table 7

THE UNIVARIATE ANALYSIS RESULTS: AIR PERMEABILITY

| Source | Air permeability | | |
|---|---|---|---|
| | **F** | **Sig.** | **Observed power** |
| Print type | 150.696 | 0.000 | 1.000 |
| Knit structure | 21.254 | 0.000 | 1.000 |
| Print type * Knit structure | 4.202 | 0.001 | 0.977 |
| Print pattern | 33.071 | 0.000 | 1.000 |
| Knit structure | 393.520 | 0.000 | 1.000 |
| Print pattern * Knit structure | 5.737 | 0.000 | 0.980 |

According to the univariate test results where print pattern and knit structure were taken as parameters and their effect on air permeability was investigated, it is observed that the impact of print pattern and knit structure on air permeability is statistically significant. Analysis of air permeability values supports that the air permeability without printed fabrics is much higher than printed fabrics and that the printing process significantly decreases air permeability. It is considered that this results from the fact that the print material covers the pores of the fabric in a way to prevent air permeability. PT1 and PT3 samples printed with PP2 patterns were observed to permeate no air in all three knit structures. On the other hand, samples printed with the PP1 pattern were considered to have air permeability through the pattern's spaced parts, but not through the printed parts. Regarding the PT2 print type, air permeability values were able to be measured for both patterns and this was the print type with the highest level of air permeability among all three print types.

According to the Duncan test done to compare air permeability with regard to print types, three different subsets were formed. According to the achieved results, the samples printed with the PT1 print type had the lowest air permeability values for all three knit structures, but the PT1 and PT3 print types displayed no statistically meaningful difference ($p$ = 0.934) and were placed in the same subset (table 8). When the results are analyzed, it can be observed that the air permeability value presents a steep decline in all three print types compared to nonprint fabrics, and the difference between nonprinted and printed fabrics is significant ($p$ = 0.000).

Table 8

MULTIPLE COMPARISONS OF AIR PERMEABILITY VALUES

| Print type | N | Air permeability | | |
|---|---|---|---|---|
| | | **Subset** | | |
| | | **1** | **2** | **3** |
| PT1 | 60 | 164.62 | | |
| PT3 | 60 | 179.82 | | |
| PT2 | 60 | | 373.95 | |
| without print | 30 | | | 772.73 |
| Sig. | | 0.597 | 1.000 | 1.000 |

*Kinetic friction coefficient*

The mean values of the kinetic friction coefficient for the samples are displayed in table 4 and the graph created by taking the mean values into account is shown in figure 3.

The analysis of the data belonging to the sample's kinetic friction coefficient reveals that the PT2 print type has the lowest values (0.144–0.294) for all three knit structures (table 4). The lower the kinetic friction coefficient is, the smoother the product is [33]. Therefore, it is deduced that smoother products were

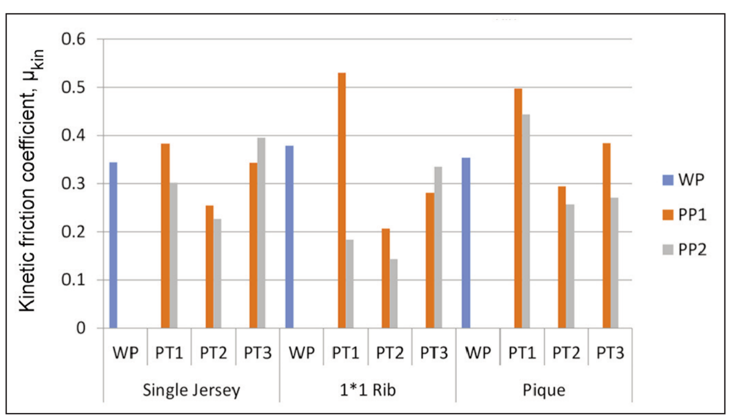


Fig. 3. Kinetic friction coefficient values of samples

Table 9

| THE UNIVARIATE ANALYSIS RESULTS: KINETIC FRICTION COEFFICIENT | | | |
|---|---|---|---|
| **Source** | **Kinetic friction coefficient** | | |
| | **F** | **Sig.** | **Observed power** |
| Print type | 21.188 | 0.000 | 1.000 |
| Knit structure | 3.412 | 0.037 | 0.629 |
| Print type * Knit structure | 2.628 | 0.021 | 0.836 |
| Print pattern | 6.475 | 0.002 | 0.897 |
| Knit structure | 1.381 | 0.256 | 0.291 |
| Print pattern * Knit structure | 1.561 | 0.191 | 0.466 |

achieved through the PT2 print type compared to the other printing types involved in the study. The statistical analysis of print types shows that in terms of kinetic friction coefficient, the difference between PT1 and PT2 ($p = 0.000$), the difference between PT1 and PT3 ($p = 0.047$) and the difference between PT2 and PT3 ($p = 0.000$) were statistically significant.

The analysis of print patterns reveal starts the difference between the print patterns used in the study is statistically significant ($p = 0.004$). It was observed that due to its striped structure, PP1 caused the roughness value to increase and that, especially the embossed print structure off the PT1 print type enhanced this increase (figure 3). Moreover, it is believed that the lower value of PP2 led to the perception that the roughness of the solid pattern was lower.

According to the results of the Oneway Anova test conducted, it was observed that the effects of the knit structure ($p = 0.045$), the print type ($p = 0.003$) and the print pattern ($p = 0.045$) on the kinetic friction coefficient are statistically significant.

The statistical data regarding the effect of print type and print pattern on kinetic friction coefficient according to types of fabric are presented in table 9.

Upon analysis of the print type and knit structure on kinetic friction coefficient values, it was detected that the difference between print types ($p = 0.000$) and knit structure ($p = 0.037$), and as a result, the difference between their interactions ($p = 0.021$) were statistically significant (table 9). According to the results of the univariate test conducted to determine the parameters of print pattern and knit structure on kinetic friction coefficient values, it was observed that while the effect of print pattern on kinetic friction coefficient values is statistically significant, the difference between knit structure and therefore, the interaction between the two variables ($p = 0.191$) was not statistically significant (table 9).

*Relative compressibility*

As the starting thickness values of the samples are different from each other, to compare their compressibility accurately, their relative compressibility values were taken into account and calculated according to the following formula [34, 35]:

$$\text{Relative compressibility (\%)} = (h_2 - h_1) / h_2 * 100 \quad (3)$$

Where $h_2$ is the thickness of fabric under low weight (A: 5 kPa) and $h_1$ – the thickness of fabric under higher weight (G: 200 kPa).

The relative compressibility values calculated according to the gathered data are shown in table 4 and graph in figure 4. Upon analysis of the relative compressibility values of the samples, WP was observed to be higher, and thus, it was concluded that the printing process has an effect that decreases the relative compressibility of the material.

The values belonging to printed samples have revealed that the values for the samples prepared with the PT2 print type were higher than the other two print types. In addition, the analysis done in terms of print patterns has indicated higher values for the PP1 print pattern. According to these results, it is possible to conclude that in terms of the ability to absorb more energy during the compression process, the PT2 print type is more efficient than the other print types that add a PP1 print pattern than PP2.

*Circular bending rigidity*

The mean values of circular bending rigidity for the samples are displayed in table 4 and the graph created by taking the mean values into account is shown in figure 5.

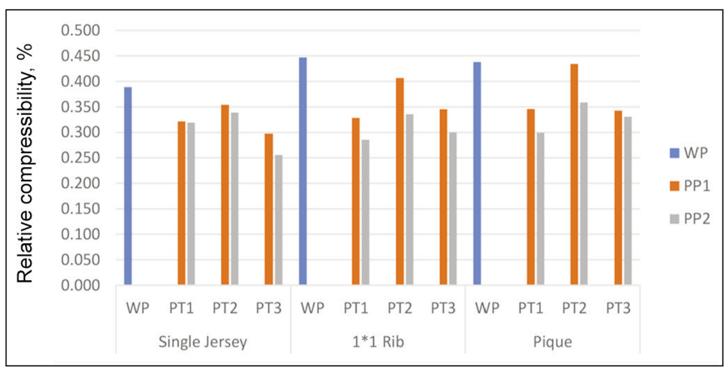


Fig. 4. Relative Compressibility values of samples

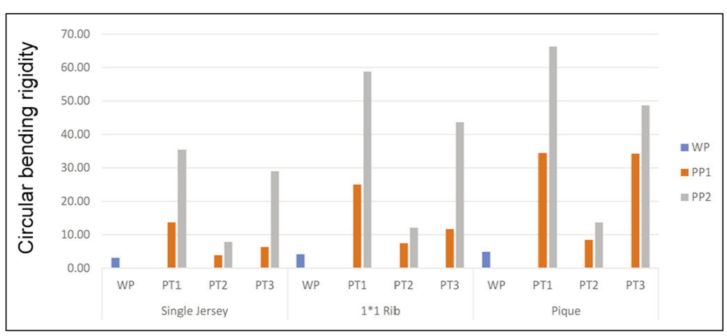


Fig. 5. Circular bending rigidity values of samples

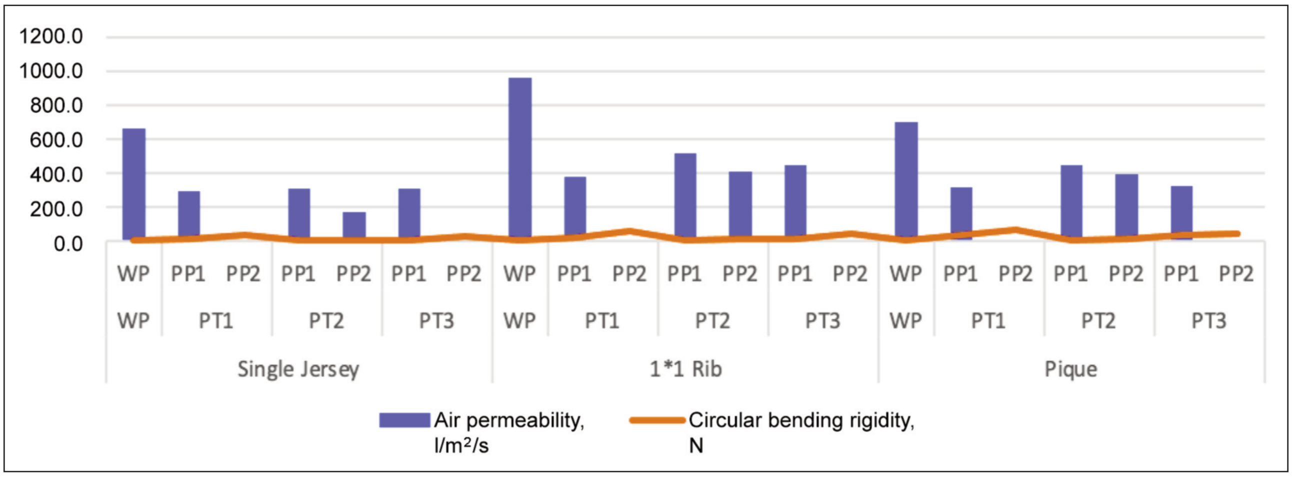


Fig. 6. Air permeability versus circular bending rigidity

The bending behaviour of fabric it's highly significant for fabric producers, garment designers and in apparel production [28]. The analysis of test results shows that the highest values were observed for PT1 print type for all three knit structures and the lowest values were found for PT2. As the bending rigidity of a fabric increases, so does the stiffness of the material [34]. When the fabric is stiffer, the handle of the fabric worsens [36]. Therefore, it can be observed that the materials printed which PT2 were softer than the others. It is believed that the embossed print structure causes the material to become stiffer. In terms of a knit structure, the lowest values were presented for single jersey fabrics and therefore, the stiffness of these materials was lower than the other knit structures, and the highest values were observed in pique fabrics. Consequently, it can be stated that the samples printed on pique fabrics are stiffer than the other samples. Statistical consideration of the gathered data, and regarding Oneway Anova test results, revealed that the effect of a knit structure, print type ($p = 0.000$) and print pattern ($p = 0.000$) on circular bending rigidity were statistically significant.

It is observed that the difference between without printed samples and PT2 print type is statistically insignificant ($p = 0.511$). When the difference between print types is investigated, it is observed that the difference between PT1 and PT2 ($p = 0.000$), the difference between PT1 and PT3 ($p = 0.004$) and the difference between PT2 and PT3 ($p = 0.000$) were statically significant.

Moreover, the difference between print patterns is statistically significant ($p = 0.000$). For each print type, the PP1 print pattern presented lower values than PP2. It is believed that the fact that the PP2 print pattern is applied to the whole surface increases circular bending rigidity and therefore, causes the material to become stiff.

To determine the effects of print type and print pattern on circular bending rigidity according to knit structure, univariate tests were conducted (table 10).

Analysis of print type and knit structure on circular bending rigidity shows that the difference between print types ($p = 0.000$) and the difference between knit structures ($p = 0.000$) are statistically significant, and it is believed that the effects of the print material (observed power: 0.997) and the knit structure (observed power: 1.000) are very strong, resulting in the fact that the interaction of these two variables also become significant ($p = 0.018$) (table 10).

Table 10

THE UNIVARIATE ANALYSIS RESULTS: CIRCULAR BENDING RIGIDITY

| Source | Circular bending rigidity | | |
|---|---|---|---|
| | F | Sig. | Observed power |
| Print type | 13.054 | 0.000 | 0.997 |
| Knit structure | 54.061 | 0.000 | 1.000 |
| Print type * Knit structure | 2.720 | 0.018 | 0.850 |
| Print pattern | 5.709 | 0.005 | 0.855 |
| Knit structure | 36.174 | 0.000 | 1.000 |
| Print pattern * Knit structure | 1.056 | 0.382 | 0.322 |

According to the univariate test results where the effects of the parameters of print pattern and knit structure on circular bending rigidity were investigated, it was observed that while the effects of the print pattern ($p = 0.005$) and knit structure ($p = 0.000$) on circular bending rigidity were statistically significant, the interaction between the two variables ($p = 0.382$) was not (table 10).

As filaments in fabrics with more fluidity will move more freely, air permeability is more easily allowed [37]. In support of the literature, samples with low circular bending rigidity values, and thus, higher fluidity, displayed higher air permeability values (figure 6).

## CONCLUSION

In recent years, customer demands in the fashion and apparel sectors have increased, just as in all other sectors, and the comfort of the produced garment is present as a significant factor in the purchasing decision. It is important to avoid subprocesses like printing, which is one of the aesthetic and design properties of a garment and does not impose a negative effect on the physical and comfort properties of the garment. Printing is an especially important subprocess in the adornment of knit garments. This study focused on pigment printing, which is highly preferred in the textile industry since it is the lowest cost print type, the processing time is quite fast and it is environmentally friendly [21].

Based on this research the following conclusions can be drawn out:

- Regarding the test results of PT1, which was applied as a single layer, it had the highest thickness in all three knitting structures and the air permeability values were lower than the PT2 and PT3. Therefore, it is recommended not to be used in patterns that cover a large surface, particularly in the chest and back areas of the garment where sweating is intense, especially in summer clothes. In addition, it is recommended not to use this printing type, especially in 1*1 rib fabric structure, since the surface friction coefficients of the samples prepared with PT1 were higher than other printing types, thus a rougher surface was obtained. Moreover, it was observed that the bending rigidity of the samples prepared using PT1 printing paste was higher than the others. This reveals that the samples obtained with this printing paste are stiffer than the others. Consequently, it is recommended that this printing paste, which is used to achieve special effects, should be used in small-sized patterns.
- The analyses made regarding the conducted tests revealed that the print type coded as PT2 presented the best results in terms of kinetic friction coefficient, compressibility and circular bending rigidity, which impact the physical properties, air permeability and sensorial comfort of the fabric. In addition, especially in 1*1 rib and pique fabrics, this type of printing causes the lowest penetration to the back side of the fabric.
- For PT3, concerning results obtained, it was observed that the highest values for the mass per unit showed by these samples due to the double-layer printing structure, as expected. It was understood that the air permeability values of the samples obtained with this printing type were similar to those obtained with PT1 and that airflow did not occur, especially in large-area patterns. It has been observed that this printing type had higher values compared to the unprinted samples in terms of handle properties such as smoothness and stiffness. For this reason, it is recommended to choose small-sized print patterns for garments in which this print type will be used and to choose a light colour base in the designs that are desired to be smooth and soft, since they are applied in double layers to cover the dark coloured bases.
- Likewise, it was observed that the PP1 print pattern, which did not cover the whole surface due to its striped structure, displayed better values in terms of air permeability, compressibility and circular bending rigidity.

Considering the results, it is recommended that the print type and print pattern to be used in the clothing design step should be chosen to not cause problems in terms of sensorial comfort. PT2 print type could be prioritized for areas that may face a higher level of compression due to its space of use such as the back piece of the garment and when PT1 and PT3 print types are to be used, the print area should not be too large and not to cover the surface completely with printing paste in the patterns created, and to design patterns so that the ground fabric can be seen. It is believed that the conducted study wheel assists fashion designers and apparel producers in terms of print design.

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**Author:**

ARZU KILIÇ

Ege University, Fashion and Design Faculty, Department of Fashion Design, Bornova, İzmir, Türkiye

**Corresponding author:**

ARZU KILIÇ
e-mail: arzu.senkilic@ege.edu.tr