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ANALYSIS OF SURFACE PROPERTY CHANGES ON THE REVERSE SIDE OF KNITTED FABRICS AFTER PRINTING

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The surface properties of textile materials play a key role in their appearance, tactile perception, and wearing comfort, with the reverse side of knitted fabrics being critical due to their direct connection with the wearer's skin. This paper aimed to investigate the effect of sublimation printing on the surface properties of the reverse side of interlock knitted fabrics intended for activewear. Two types of knitted fabrics were printed using the sublimation printing technique in the CMYK colour model.
Surface properties were evaluated using the KES-FB4 instrument, analysing the surface friction coefficient (MIU), mean deviation of the friction coefficient (MMD), and geometrical roughness (SMD). The results indicated that the knitted fabric structure and yarn fineness significantly affected the resistance of knitted fabrics to changes induced by sublimation printing. Knitted fabric 2KF exhibited higher SMD values and lower MIU values compared to 1KF. Greater stability of surface parameters after printing was observed in knitted fabric 1KF, which is attributed to its higher thickness and more homogeneous structure. For printed samples 1KF, SMD values in the course direction ranged from 2.430 μm to 3.661 μm, while for 2KF samples they ranged from 5.212 μm to 6.965 μm. A strong linear correlation was established between SMD and knitted fabric weight (R^2 = 0.8615), indicating that SMD values increased proportionally with knitted fabric weight. Although sublimation printing was applied to the fabric's face side, the high temperature and pressure also affected the reverse side.

Keywords: Knitted fabrics, surface properties, printing process.

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INTRODUCTION

Knitted fabrics are particularly well-suited for the production of clothing, especially for sportswear, due to their porous structure, high elasticity, and ability to conform to body contours [1]. A wide range of physical and functional properties of knitted fabrics is achieved through the use of different fibres and yarns in their production, as well as through various machine settings [2].

Both the visual and tactile perception of textile materials largely depend on their surface characteristics, making these properties highly relevant for evaluating comfort and the aesthetic value of clothing. In the case of knitted fabrics, these characteristics are even more pronounced because of their structure.

The surface of knitted fabrics is not smooth; it varies in roughness depending on yarn and characteristics (irregularity, hairiness, friction, surface roughness, shape, diameter, density, spinning technology, and fibre composition) and structure of the fabric itself (type, density, thickness) [3–7].

Previous studies have demonstrated that the surface properties of knitted fabrics greatly affect the subjective perception of comfort. For instance, studies comparing the technical face and reverse side of rib knits (1×1 and half-Milano) revealed that the reverse side was perceived as softer and more flexible due to its unbalanced structure, which can be an important factor when selecting materials for garments that come into direct contact with the skin [8].

The importance of the surface roughness (SMD) parameter in assessing surface texture has been confirmed in studies showing that non-contact measurement methods can yield reliable results, closely correlated with the KES-F evaluating system [9].

In recent years, sublimation printing has increasingly been used because of advantages such as environmental sustainability, rich colour, and high color fastness. However, it has been shown that the process can induce changes in the structure and physical properties of knitted fabrics, particularly those made from cotton (Co) and cotton/polyester blends (Co/PES), where alterations in weight, surface roughness, and even compressional properties have been observed. Although changes in polyester (PES) knitted fabrics appear to be less pronounced, they are still present, especially in surface properties such as surface friction (MIU), mean deviation of friction (MMD), and surface roughness (SMD), which directly influence tactile sensation and overall comfort [10, 11].

A particular challenge lies in preserving the stability of surface characteristics on the reverse side of knitted fabrics after the printing process, as this side is in direct contact with the wearer's skin, especially in sportswear. Unfavourable changes in surface attributes – such as increased roughness or reduced softness – can significantly affect subjective comfort and athletes' performance. Therefore, this paper aimed to experimentally assess the impact of sublimation printing on the surface properties of the reverse side of interlock knitted fabrics intended for sportswear, with particular emphasis on parameters that directly affect tactile comfort.

MATERIALS AND METHODS

The surface properties of the knitted fabrics — surface friction (MIU), mean deviation of the friction coefficient (MMD), and surface roughness (SMD) were measured using the KES-FB4 AUTO instrument (Figure 1a), part of the Kawabata Evaluation System (Kato Tech Co., Ltd., Kyoto, Japan). This system provides detailed information about the tactile characteristics of textile materials.

During measurement, the textile material was fixed between two clamps and moved across a metal plate over a distance of 20 mm at a constant speed of 0.1 cm·s^{-1}. A preload of 19.62 cN (equivalent to 20 gf·cm^{-1}) was applied. Surface friction was recorded using a U-shaped sensor made of 10 steel wires, each 0.5 mm in diameter. This sensor was designed to mimic a human fingertip. This sensor applied a constant normal force of 49.035 cN to the fabric surface.

Another U-shaped sensor (Figure 1b), consisting of a single wire 0.5 mm in diameter, was used to measure surface roughness by applying a force of 9.807 cN to the textile material.

The MIU parameter represents the ratio of the frictional force to the applied normal force, the MMD indicates variations in friction as the sensor moves over the surface, while the SMD reflects irregularities in the surface structure as deviations from an ideally smooth surface [12]. Three measurements were performed for each sample, and the mean values are reported in this paper.

a) b)

Figure 1. a) KES-FB4 AUTO instrument; b) Sensor for measuring geometric roughness

Structural properties of the tested knitted fabrics are presented in Table 1.

Table 1. Structural properties of the tested unprinted knitted fabrics

Sample	Pattern	Raw material	Yarn linear density Tt (tex)	Density			Thickness h (mm)	Wight m (g·m^{-2})
				Horizontal D_h (cm^{-1})	Vertical D_v (cm^{-1})	Total D_t (cm^{-2})		
1KF-W	Interlock	PES	7.40	16.3	10.5	171.2	0.38	122.4
2KF-W	Interlock	PES	7.04 3.60	16.5	11.8	194.7	0.28	134.9

The printing process was carried out using an EPSON L1800 piezo-electric ink-jet printer, at a resolution of 7760 × 1440 dpi , with Canapa Ventus Master 100 transfer paper of 100 $g \cdot m^{-2}$ and Sublisplash dye sublimation inks Splashjet-Super-Sub-6C. For ink fixation, a Digital High-Pressure Heat Press SHP-15/20/24LP2MS was used. The curing process was conducted at 185°C for 120 seconds.
Knitted fabrics were printed in the CMYK colour model, using four separate dyes: cyan, magenta, yellow, and key, i.e., black. Each printed sample was labelled based on the applied colour (C for cyan, M for magenta, Y for yellow, and K for black, while unprinted knitted fabrics were labelled with the code W (white).
Before testing, all knitted fabric samples were conditioned under standard atmospheric conditions according to ISO 139:2005 [13].
Structural properties were evaluated according to the following standards:

- Density of the knitted fabric: EN 14971 [14]
- Weight of the knitted fabric: ISO 3801 [15]
- Thickness of the knitted fabric: ISO 5084 [16].

RESULTS AND DISCUSSION

In order to gain deeper insight into how sublimation printing affects the surface properties of knitted fabrics intended for sportswear, the parameters MIU, MMD, and SMD were measured on the reverse side of knitted fabrics.
Figure 2 presents the MIU results for the tested knitted fabrics, measured on the reverse side.

Figure 2. MIU results of knitted fabrics, measured on the reverse side

For the unprinted samples, MIU values were slightly higher for sample 1KF-W (wale: 0.157, course: 0.248) compared to sample 2KF-W (wale: 0.150, course: 0.219). These differences indicate higher surface friction in the 1KF sample, which can be attributed to its greater thickness and rougher surface structure.

In the 1KF sample series, a decrease in MIU values in the wale direction was observed after the sublimation printing process, except for sample 1KF-K, which showed no change. The decrease in MIU values in the wale direction ranged from 2.55% (1KF-M) to 3.18% (1KF-C), while an increase of 5.1% was observed for sample 1KF-Y, compared to the unprinted sample. In the course direction, a decrease in MIU values was observed for samples 1KF-C and 1KF-M, while increases of 1.61% and 2.02% were observed for samples 1KF-Y and 1KF-K, respectively.

Within the 2KF sample group, MIU values in the wale direction slightly decreased after printing, except for sample 2KF-K, which showed an increase of 4%. In the course direction, all 2KF samples exhibited a decrease in MIU values after printing, ranging from 4.57% (2KF-M) to 7.76% (2KF-C).

In general, the printed 2KF samples showed a decrease in MIU values. As this knitted fabric was produced using two types of yarns of different fineness (including one filament yarn), the applied heat contributed to "ordering" of the surface, reducing roughness. On the other hand, the variations in MIU values observed in the 1KF samples may be attributed to the structural characteristics – being made from one yarn, these knitted fabrics lack internal heterogeneity, which may lead to localized changes.

The obtained MIU values for all printed knitted fabrics ranged from 0.15 to 0.25, which is in the characteristic range of this parameter (0.15 to 0.30) [12]. This indicates that sublimation printing did not adversely affect the surface friction.

The results of MMD for the tested knitted fabrics, measured on the reverse side, are presented in Figure 3.

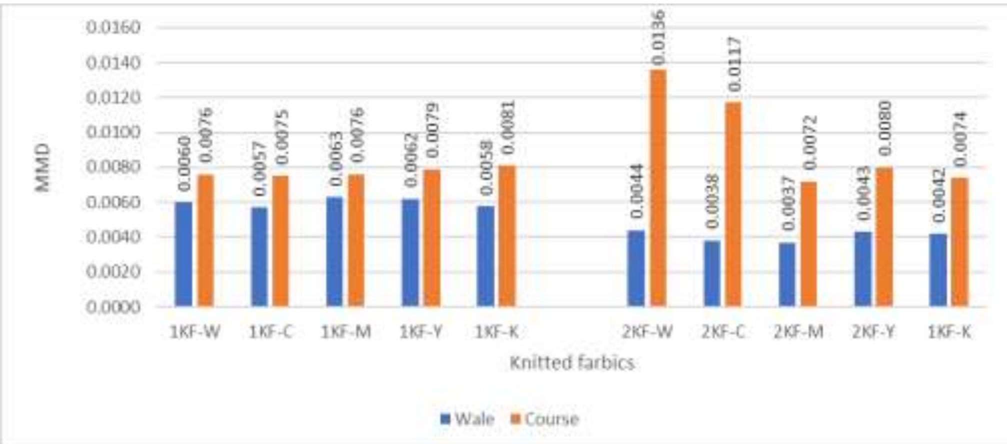

Figure 3. MMD results of knitted fabrics, measured on the reverse side

In comparison to the 1KF samples (1KF-W wale: 0.0060), MMD values were generally lower for the 2KF samples in the wale direction (2KF-W wale: 0.0044). After printing, slight changes in MMD values were observed in 1KF.
A decrease of 6.58% was observed for sample 1KF-K, while an increase of 5% was noted for sample 1KF-M compared to the unprinted sample in the wale direction. In the course direction, minor changes were detected.
For the 2KF knitted fabrics, MMD values in the course direction were significantly higher than in the wale direction, and a substantial decrease in these values was observed after printing in the course direction, ranging from 13.97% (2KF-C) to 47.06% (2KF-M).
The 1KF knitted fabric showed more stable MMD values after the printing process, while more pronounced changes were recorded in the 2KF sample group, especially in the course direction. The higher density and structural complexity of 2KF make it more susceptible to deformation and changes in the microstructure distribution during printing. This leads to reduced friction variation and a more uniform surface (lower MMD).
Figure 4 presents the results of SMD for the tested knitted fabrics, measured on the reverse side.

Figure 4. SMD results of knitted fabrics, measured on the reverse side

SMD values for the 1KF fabrics increased in the wale direction after printing, ranging from 1.40% to 2.56% compared to the unprinted sample, with the exception of sample 1KF-M, where a slight increase in SMD values was recorded. In the course direction, an increase was observed for all 1KF samples, with the largest being 21.10% (sample 1KF-M), while sample 1KF-C was the exception, showing a decrease of 1.42%.
In the 2KF samples, minor changes of SMD values in the wale direction were recorded, with the highest increase of 12.21% for sample 2KF-K. Additionally, in the course direction, SMD values decreased after printing in all samples except for 2KF-M, which showed an increase of 4.19%.

Although the 2KF fabric is thinner, its higher density and more complex structure contributeto a greater perception of roughness. The applied heat and pressure during the printing process contributed to alterations in the structures of knitted fabrics. Regarding changes in the structure on the reverse side of knitted fabrics 2KF, it is possible that the yarns were "impressed" under the influence of the press, which reduced the roughness in the course direction. In the 1KF sample group, with a less dense and thicker structure, only minor changes were observed in comparison to the unprinted sample.

In addition, based on the analysis of the results shown in Figures 2, 3, and 4, it can be concluded that the printing process had a smaller effect on the change of the surface properties of 1KF knitted fabrics.

Figures 5 and 6 show the linear dependence of MIU on the surface mass and thickness of printed knitted fabrics, respectively.

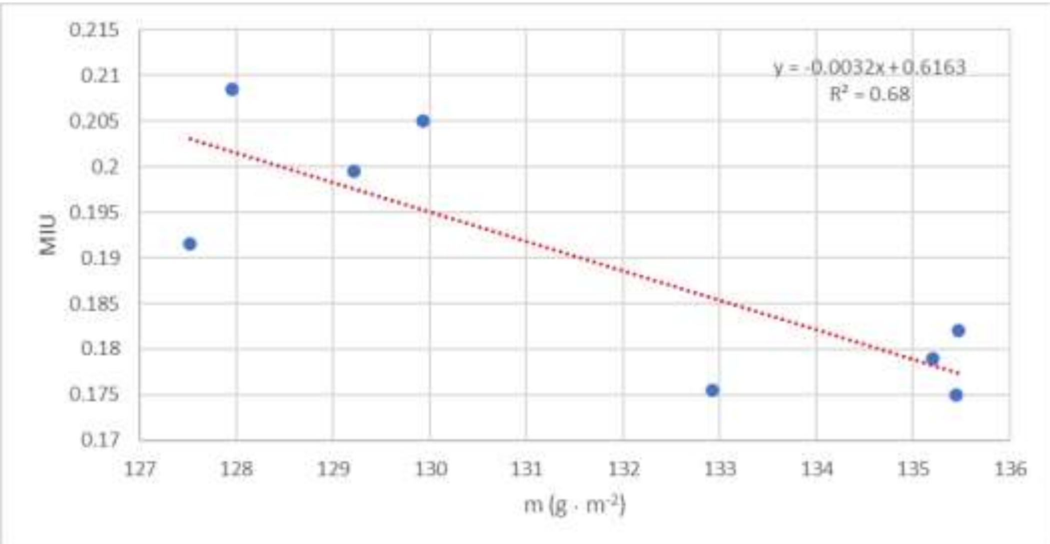

Figure 5. Dependence of MIU on the printed knitted fabric weight

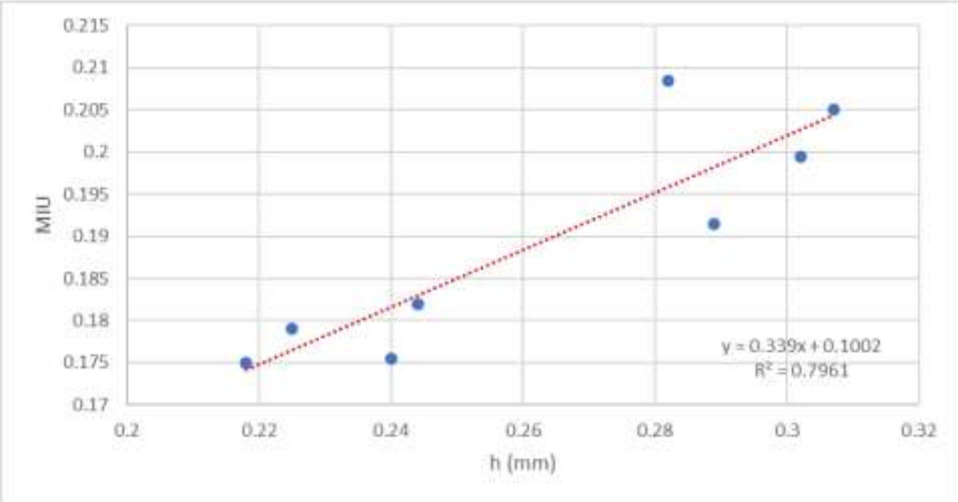

Figure 6. Dependence of MIU on the thickness of printed knitted fabrics

A strong linear correlation was observed between MIU and the weight of printed knitted fabrics, as confirmed by a high Pearson correlation coefficient ($R = 0.9275$; $R^2 = 0.8600$). In contrast, the linear correlation between MIU and the thickness of knitted fabrics was slightly lower ($R = 0.8911$; $R^2 = 0.7961$).

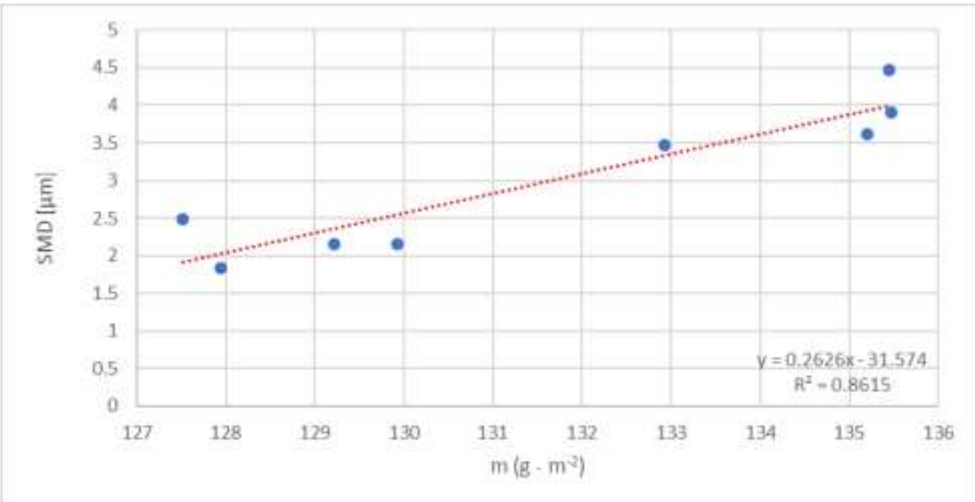

Figure 7. Dependence of SMD on the printed knitted fabric's weight

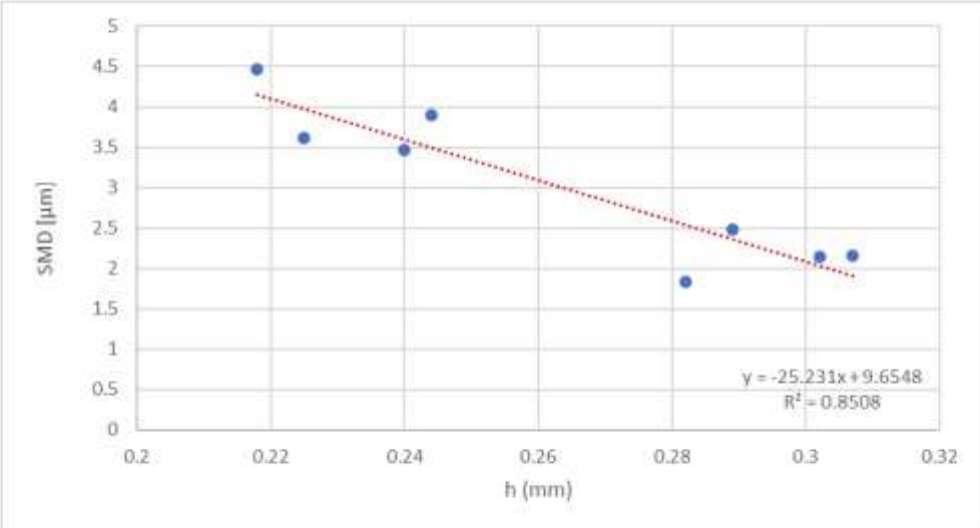

Figure 8. Dependence of SMD on the printed knitted fabric's thickness

Based on the results presented in Figure 7, a strong linear correlation was found between the SMD and the weight of printed knitted fabrics, with a Pearson correlation coefficient of R = 0.9282 (R^2 = 0.8615). Similarly, the correlation between SMD and (printed) knitted fabric thickness was also high, with R = 0.9224 (R^2 = 0.8508), as shown in Figure 8.

The results showing the dependence of the MMD parameter on the thickness and weight of printed knitted fabrics are not presented due to the weak linear dependence.

CONCLUSION

This paper examined the influence of sublimation printing on the surface properties of the reverse side of knitted fabrics made from PES yarns of different fineness. Two knitted fabric types were tested: 1KF, produced from a single yarn, and 2KF, made from a combination of two yarns.

The experimental results confirmed that sublimation printing affected the surface characteristics of knitted fabrics on the reverse side, despite being applied to the face side. The degree of change is closely related to the thickness and weight of the fabrics. The 2KF knitted fabric, which has a thinner and denser structure, exhibited sensitivity to the printing process, as indicated by decreased MIU (in both directions) and increased SMD values in the course direction. The 1KF knitted fabrics, on the other hand, showed more resistance to structural alterations following printing due to their higher thickness and uniform structure (made from a single yarn).

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Izvod

ANALIZA PROMENA POVRŠINSKIH SVOJSTAVA NA NALIČJU PLETENINA NAKON ŠTAMPANJA

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Površinska svojstva tekstilnih materijala imaju ključnu ulogu u njihovom vizuelnom izgledu, taktilnom osećaju i udobnosti pri nošenju, pri čemu je naličje pletenih tekstilnih materijala od posebnog značaja zbog neposrednog kontakta sa kožom korisnika.
Ovaj rad ima za cilj da ispita uticaj sublimacione štampe na površinska svojstva naličja interlok pletenina namenjenih za sportsku odeću. Dve vrste pletenina štampane su tehnikom sublimacije u CMYK kolor modelu.
Površinska svojstva ocenjivana su pomoću KES-FB4 uređaja, analizom koeficijenta površinskog trenja (MIU), prosečnom vrednošću apsolutnog odstupanja koeficijenta trenja (MMD) i geometrijske hrapavosti (SMD). Rezultati su pokazali da struktura pletenine i finoća pređe značajno utiču na otpornost materijala na promene izazvane procesom sublimacione štampe. Pletenina označena kao 2KF imala je višu vrednost SMD i nižu vrednost MIU u poređenju sa pleteninom 1KF. Veća stabilnost površinskih parametara nakon štampe uočena je kod pletenine 1KF, što se pripisuje njenoj većoj debljini i homogenijoj strukturi. Kod štampanih uzoraka 1KF, vrednosti SMD u pravcu osnove kretale su se od 2.430 μm do 3.661 μm, dok su kod 2KF uzoraka iznosile od 5.212 μm do 6.965 μm. Ustanovljena je snažna linearna korelacija između SMD vrednosti i površinske mase pletenine (R^2 = 0.8615), što ukazuje da se vrednosti SMD

proporcionalno povećavaju sa površinskom masom materijala. Iako je sublimaciona štampa primenjena na lice materijala, visoka temperatura i pritisak delovali su i na naličje.

Ključne reči: Pletenine, površinska svojstva, proces štamapanja.